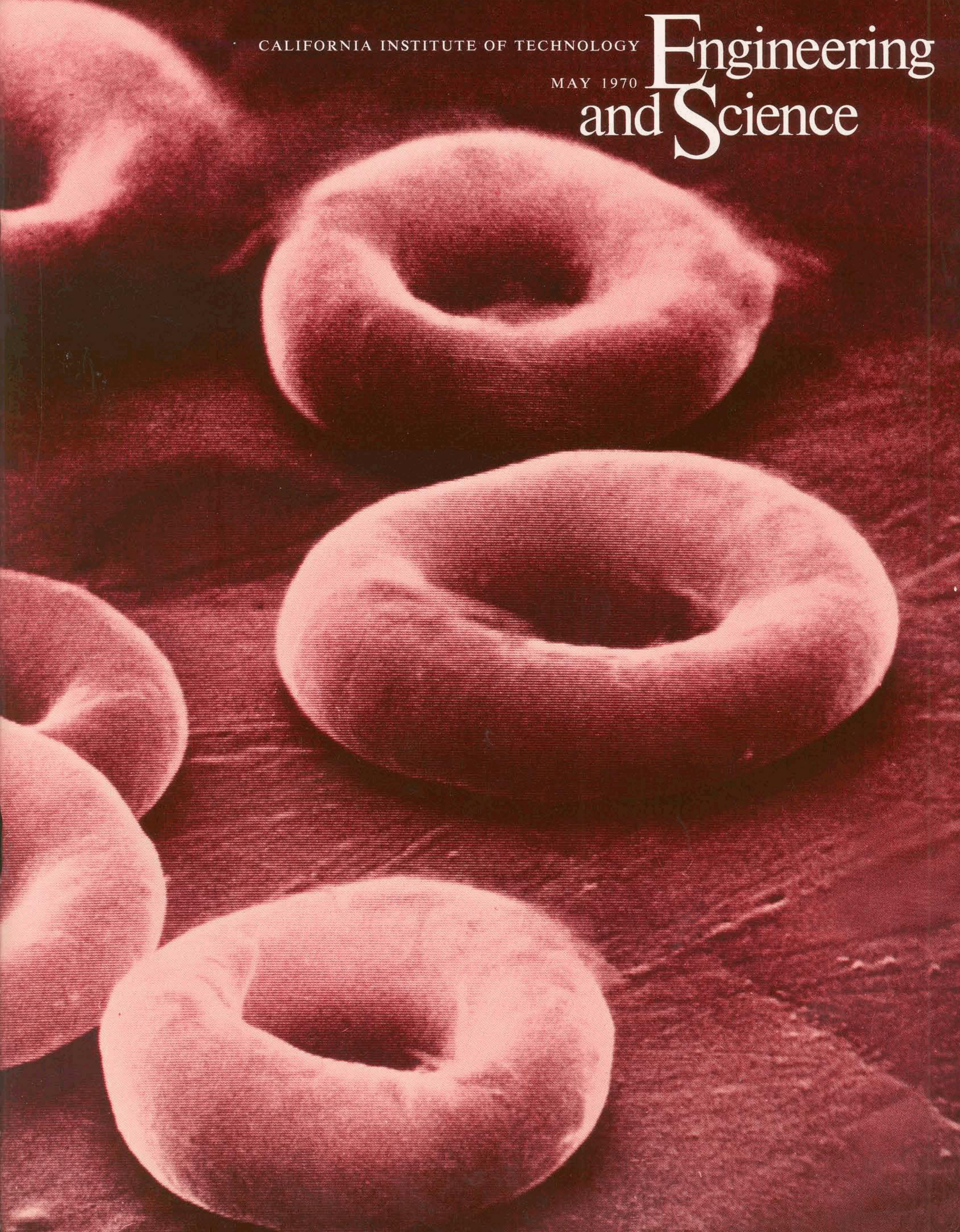
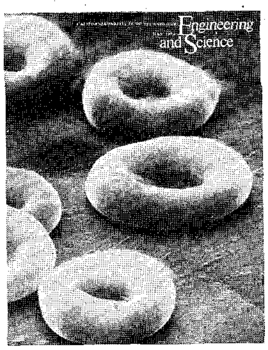
CALIFORNIA INSTITUTE OF TECHNOLOGY

MAY 1970

Engineering and Science





On Our Cover

The striking electron micrograph of human red blood cells was made not by biologists but by engineers. Richard Baker, a research associate in engineering science, working at Caltech in collaboration with Harold Wayland, professor of engineering science, and with engineer John Devaney at JPL, has been studying the mechanical structure of the cells. More pictures of his work are on pages 10 and 11.

2001

Arthur Clarke, author of *2001—A Space Odyssey*, is a prolific writer, one of whose articles ("Next—The Planets" in *Playboy*) won a coveted $1,000 Westinghouse Science Writing Award for 1969. His provocative "The Future Isn't What It Used to Be" on pages 4-9 is adapted from a Caltech lecture on April 12, sponsored by the Faculty Committee on Programs.

Grand Tour

Astronomer Ray Newburn, after getting his BS in 1954 and MS in 1955 from Caltech, decided to take off from school for a few years to bolster his finances. He took a job at JPL, and was one of the few astronomers there when Sputnik introduced the space age in 1957. Ever since he has been too busy to get back to school. His article on "The Grand Tour of the Outer Planets" on pages 12-19 is adapted from a Monday Evening Lecture in Beckman Auditorium.

Pleasure

James Olds, professor of behavioral biology, adapted the article on pages 22-31 which discusses his classic studies of "Pleasure Centers in the Brain" from a Beckman Monday Evening Lecture.

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Engineering and Science

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Or, for that matter, is Los Angeles? Or Chicago? Or Philadelphia? Or Dallas?

Or any other city groping its way to an uninhabitable anachronism.

A curious situation has developed in America. Eighty per cent of the people in this country live on less than ten per cent of the land area.

There used to be a good reason for this.

At the time of the industrial revolution, we congregated in cities because that's where the sources of energy were. Coal. Water. Electricity.

And our communications network was so limited that we had to be in close proximity to each other for business and social purposes.

No more.

There are no longer any good reasons to continue this hopelessly outmoded life style.

With the advent of the whole spectrum of new communications available to us (wide-band communications, laser beams), we will have the opportunity to live in significantly less dense population centers.

This is no idle prophecy.

The concept is quite realistic and well within the bounds of engineering capabilities which we already have.

Not only do we have the tools to provide the means for new styles in human settlements, but also to rebuild, in a sociological sense, the crowded inner core of our major cities.

The combination of international satellites and cable will provide the means of bringing individuals all the information they need or want without interference or control.

And without the need to be in any specific place.

(Think for a moment about the Apollo 11 moon landing in July, 1969. 500 million people around the world saw, via television, *precisely the same thing at the same time*. Being in New York or Los Angeles held no advantage over being in Keokuk or Harrisburg.)

Historically, we've been preoccupied with moving people and objects. Thus, our intricate network of highways and railroads and airlines — all of which have become enormously inefficient (not inherently, but in application).

The future will see us moving *information*, not, by necessity, people and things.

Your home will be the absolute center of your life.

You will work from home, shop from home, "visit" with family and friends from home, receive in your home any intellectual or cultural achievement known to man.

Fantastic, yes. Fantasy, no.

It is quite within reason to expect these changes by the 1980's.

If we want them.

If we want to change. If we want a better life for ourselves.

Technology has advanced to such an extent, that man is now, literally, capable of changing his world.

Yet, today, a certain gap has developed between the potential of technology and its use by mankind.

There is an obvious contradiction in a method which can land a man on the moon, yet tolerates, perhaps even accepts as inevitable, poverty and ignorance here on earth.

There is a contradiction in a method which affords the best of everything for some, and next to nothing for others.

So we must, in a sense, catch up with the technological potential and apply it for the benefit of all mankind.

All we need sacrifice are the antiquated work practices and our anachronistic traditions.

At RCA, through research and product development, we are committed to closing the technology gap and cancelling the contradictions.

This is the age of the engineer. Nobody understands this better than RCA.

If you're an engineer, scientist or systems programmer, and want to be part of RCA's vision of the future, we invite inquiries.

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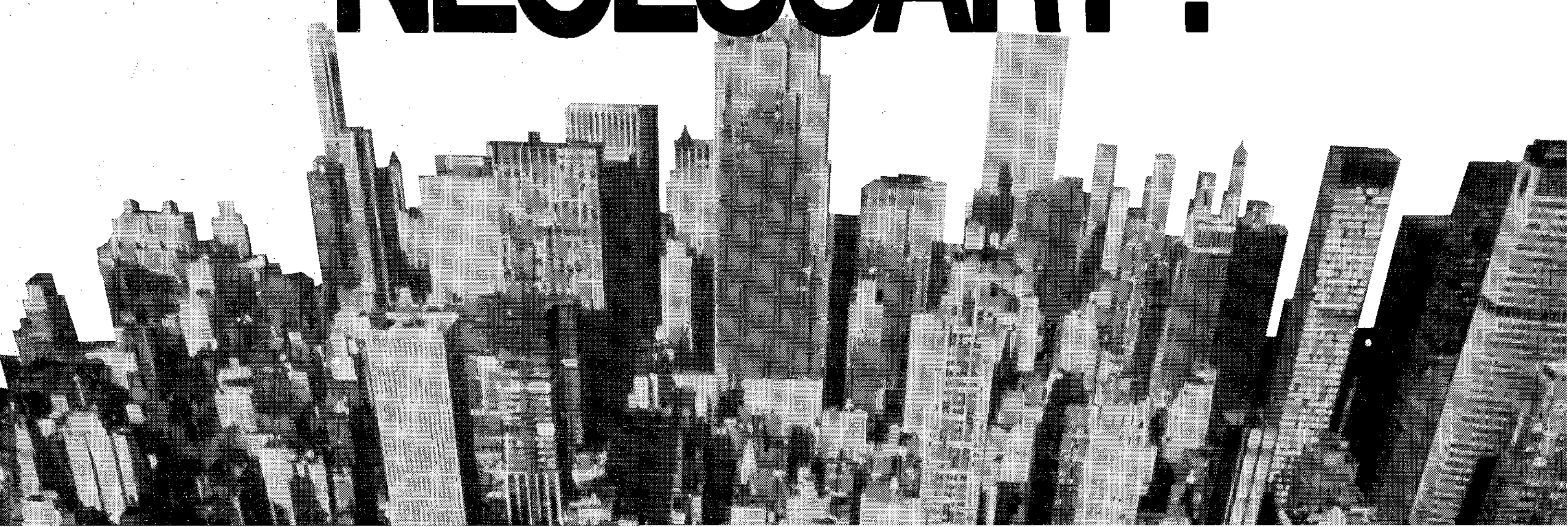
IS NEW YORK REALLY NECESSARY?




THE FUTURE ISN'T WHAT IT USED TO BE
MIGNONS ARE
OUT OF STOCK

Even though the future isn't what it used to be—nor is it what it's going to be—science fiction author Arthur C. Clarke gamely speculates on life in the year 2001.

Until a century ago nobody was very interested in the future for the simple reason that, apart from natural catastrophes and wars, the future was going to be the same as the past. A man knew that the pattern of his life would be the same as his great grandfather's, as far back as anyone could remember.

Well, now we know differently. We know the future is going to be profoundly different from the present, just as the present is profoundly different from the past. So let me outline some possible technological futures here—without pretending to predict which will come to be. However, even a technological forecast is extremely difficult, because inventions are going to be made soon—or may already have been made—that can have an impact on society far greater than the most far-sighted, optimistic, or pessimistic prophet could ever imagine.

I have two other reservations to hedge my bets—two technical developments which make any discussion of the future meaningless. They're both going to happen, but nobody knows when. The first is contact with intelligent extraterrestrials. This may happen tomorrow. It may not happen for a thousand years. It will happen one day. The second is development of ultra-intelligent machines. This will probably happen by the year 2001. When either of these things happens, all bets are off.

The pace of technology is doubling every ten years; 2001 is really as far off as the 1890's. Now the 1890's are an interesting period, because around then the great domestic revolution was taking place which transformed our everyday way of life more than anything that had happened in all the past—and perhaps in some ways more than anything that has happened since. The elements of that revolution are piped water, indoor plumbing, gas cooking and heating, electric light, and the telephone. The only comparable technological advance in the 1,000 years before was the introduction of glass windows.

What might be some *equally* great future changes in the home?

Within a couple of decades we'll be able to buy a kind of home automat in which the month's meals will be delivered in a package weighing perhaps a hundred pounds for the average family. Food will arrive dehydrated, as the astronauts have it, and it will be reconstituted and cooked automatically when we dial the right number on the selector panel. Or else a sign will flash, saying, "Sorry, filet mignon is out of stock."

But even if it is in stock, it will never have been near a cow, because we've got to face the fact that natural meat production is inefficient. It takes about ten pounds of vegetable matter to make one pound of meat. That means that for every man who eats meat ten men have got to starve—a situation that is already occurring in much of the world.

Cows, sheep, and pigs are mobile processing factories with an efficiency of less than 10 percent. We can't continue to waste good agricultural land on them. Well, I happen to be a carnivore who hates vegetables, so I regard this situation with considerable dismay. Maybe we can continue natural meat production on marginal land that's of no use for anything else, but this will mean domesticating new animals—such as antelopes, tapirs, or hippos—to exploit it.

And, of course, there is the sea. On the sea we are still what we were everywhere on the land until 10,000 years ago—primitive hunters. We've got to develop the equivalent of agriculture on the sea. I've written one novel about whale ranching, which is rather an exciting and spectacular possibility. After all, whales are intelligent animals; they can be controlled and herded, I'm sure, more easily than one can herd cattle. A 50-ton cow producing half a ton of milk a day is certainly an interesting economic proposition.

But even so, in the long run, our main food production will come from inorganic, nonliving materials, or materials which are no longer living such as coal, oil, and limestone. There is already some interesting work going on in the intermediate field of microbiological engineering. This is the development of strains of bacteria that can process inedible materials—such as sawdust and wastes of various kinds—into food which we or our animals can eat. If this sounds singularly revolting, let me remind you that cheeses, wines, and spirits are all the products of microbiological engineering.

This sort of technique has been applied to petroleum products, and the first fairly large-scale pilot plants have been built to produce large quantities of high-grade protein from petroleum. It has been calculated that three percent of the world's oil production can provide all the protein the human race needs.

Another thing that is going to come inevitably is the autonomous, self-contained community—perhaps as small as a single household—which can produce all its own food, indefinitely. This is going to be a by-product of space research, because for long-duration journeys and bases on the moon and planets, we have got to develop a closed-cycle ecology in which all wastes are reprocessed and converted back to food.

Buckminster Fuller has pictured this autonomous home as having no roots; it needs no water pipes and no drains and—we hope—no power lines. (Sooner or later we're going to have to find a way of either storing or generating electricity easily without forests of wires.) This autonomous

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Let me give a couple of examples of unanticipated inventions, which may seem rather comic, but which do teach a valuable lesson.

About a hundred years ago, when news from the United States reached England that a Mr. Edison had invented an electric light, the British called a parliamentary commission at which expert witnesses assured the gas companies that nothing further would be heard of this impractical invention. One of the witnesses was the chief engineer of the post office. Somebody said to him, "What about this latest device these ingenious Yankees have invented, the telephone? Do you think this has any applications in England?" Whereupon the chief engineer of the post office, no less, replied, "No, sir. The Americans have need of the telephone, but we do not. We have plenty of messenger boys."

Now, this is what I call a "failure of imagination." He obviously failed to see in the telephone anything more than a substitute for messenger boys. He coudn't even imagine that the time was going to come when it would transform the patterns of business, of social life, in fact of almost all human affairs.

Another example I'm fond of is a little nearer our own time. When the first horseless carriages started junketing around in clouds of smoke, it was pointed out that even when the bugs had been got out of them and they could travel as far as 50 miles without breaking down, they would be of limited application for an absolutely fundamental reason: There were no roads outside the cities. Who could have dreamed that within a lifetime most of the United States would be road?

One other, perhaps apocryphal, story about the way in which one can underestimate the social impact of an invention is that of the scientific committee called to evaluate the newly invented printing press—whether they should put any money into it—and they turned it down, pointing out to Mr. Gutenberg that there was obviously no call for such a device because, after all, hardly anybody could read.

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home could be completely mobile; a large house could be picked up by one of today's large helicopters and taken anywhere.

A mobile, planet-wide culture of the type I envisage demands cheap, instantaneous, and universal communications. The telephone revolutionized life in the past, but that was nothing compared to the communications revolution that is coming as a result of solid-state devices and the communications satellite, which abolished the last obstacles of distance. The first commercial comsat, Earlybird, which is now five years old, carries 240 separate television channels. Intersat 4, which is due for launching next year, will carry more than 6,000. By the end of the century there will be enough communications capability in orbit for the whole human race to pair off and talk to each other. And we'll need this kind of capacity, because our computers are even more talkative than we are.

What are the consequences of the communications revolution? Within ten years the home will have a kind of communications console with a television screen, television camera, computer keyboard, microphone, and probably hard-copy readout. Through this anyone will be able to exchange visual and written information with anyone else.

The newspaper as we know it will be extinct. Just dial a channel, and there will be the front page of our local paper —if there is a local paper. We'll see all the headlines, decide which ones interest us, and have them blown up one at a time so we can read the news, editorials, sports, and so forth. But this is only the beginning, because not only our local news service, but every news service—the *Sydney Morning Herald*, the *London Times*, *Pravda*, *La Prensa*—will be equally accessible at the touch of a button.

Ultimately this device will be plugged in to a global electronic library, and scholarship will be revolutionized. Another generation, which will take this for granted, will be unable to imagine how we were able to function without this information grid.

In the last hundred years civilization has spread several different types of grids. The first were the water and gas grids, then the electricity grid, then the telephone grid. The most recent, and perhaps the most significant of all, is the television grid. These television cable systems will be connected to the communications satellite system, and all mankind will be involved in an electronic nervous system. Any book that's ever been printed, any information, will be available as fast as we can dial the 20- or 30-digit numbers to retrieve it.

Telephone service as we know it now will be replaced; there will be no such thing as a long-distance call, because there are no long distances in the world of communications satellites. This means that all phone calls will be billed at a flat rate, if indeed they're billed at all. I suspect that we will just hire this service by the month or the year.

The really great revolution caused by communications satellites will come when the direct broadcast satellites are launched. Today's satellites are very low powered; they can only be picked up by huge ground stations with antennas as big as football fields, which then send a signal into the local television network. But most of the world has got no local television network. The capability will soon exist of launching satellites that will be so powerful that they can be picked up by the ordinary, domestic receiver, with perhaps $100 worth of extra antenna equipment that can be aimed up at the satellite in the sky. This is going to be of immense importance to the developing countries, which have inadequate or practically zero communications.

The Indian government has signed a contract with NASA to launch such a satellite in about 1973. The satellite will be powerful enough so that the signals can be picked up in all the villages of India. Now, the Indian government has social problems which we can scarcely imagine. They have half a million villages and half a billion people scattered over a whole continent, and about 90 percent of those people are illiterate. The Indian government thinks the only way they may be able to solve their twin problems of population growth and improved educational techniques will be through the use of educational TV programs broadcast directly to the villages.

On the educational level there have been some interesting studies of direct-broadcast satellites. For example, it has been estimated that we can provide 12 channels of color television to every school in a country like Brazil or Mexico. (Latin American countries are particularly promising because there are only one or two languages to deal with.) The cost works out at about $1.00 per pupil per year. No other method of getting information is remotely comparable in cheapness. These communications satellites may drag the whole world out of the Stone Age.

As far as the political impact is concerned, remember that the modern United States was created by two inventions a hundred years ago. Before they existed, there could not be a United States. Afterwards, it was impossible not to have a United States. Those inventions were, of course, the railroad and the electric telegraph.

We are now seeing the same situation on a global scale, but up one turn of the spiral; instead of the railroad and the telegraph it's the jet plane and the communications satellite. I think the parallel is exact, and I think the final consequences will be the same. I only hope that the intermediate period is not as bloody.

On the linguistic level too the direct broadcast satellite is going to have a profound impact. Obviously, if any one country were to establish a monopoly of direct broadcast satellites, the language of that country could become the language of all mankind. I can think of nothing of greater political and cultural importance.

Bucky Fuller, whom one always seems to be quoting, says that this is the first generation to be reared by three parents. All future generations are going to be reared by three parents, and I know which is going to be the most influential in some families—that little box in the corner. Future generations will learn their vocabularies from it; in many countries they're going to learn their main language from it.

One of the problems of the global communications system is going to be the time zone. The world of the future will be like living in a small town where at any one time a third of the people are asleep, but we won't know which third. There seem to be two possible practical alternatives. One is to abolish sleep; it's never been proved to be necessary. It may be a bad habit we picked up a billion or so years ago. Many animals don't sleep; deep-sea creatures don't sleep. We may be able to find chemical or electronic means at least to compress our sleep into an hour or so a day.

If that doesn't work, we may have to abolish time zones, and say that everywhere on earth it's the same time of day. But if we were to do it in this brutal, simple, straightforward way, some people would be unlucky—they'd have to get up at sunset, work all through the night, and go to bed during the daytime. So besides synchronizing our watches and forgetting about time zones, we'd also switch from solar time, which is 24 hours, to sidereal time, which is four minutes shorter. In the course of a year the sidereal clock goes right around the daylight cycle. If I get up at six o'clock now and the sun is just rising, six months from now when I get up at six o'clock, the sun will just be setting. So everybody all around the world has equal time in the sun.

Finally, perhaps the greatest impact of communications satellites will be on the structure of our lives. Many people will be able to do most of their work without leaving home —unless their wives insist. (This is how we're going to solve the traffic problem.) I can see the time when almost any skill can be made independent of distance. Face-to-face contact will be necessary really only for social occasions. This means, amongst other trivia, that the city is doomed.

The city was necessary because it was the only way that men could get together to exchange ideas and do business. The communications explosion will render this obsolete. The city is probably dying already for other causes, but when men everywhere can meet at the touch of a button far more cheaply and conveniently than they can find a cab in a Manhattan rainstorm, they're going to choose the easier way of life.

Now, small cities and large towns will be necessary for many reasons for industrial processes. There will also be university towns, even in the age of teaching machines and televised lectures. But the vast congregations that have blighted so much of this planet for the last two centuries will slowly fade away. Very slowly, I'm afraid, because bricks and walls have got such enormous inertia and represent such gigantic capital investments.

I've little doubt that there will be even larger cities in the year 2001 than there are today, but they'll be like the dinosaurs in their last stage of giantism. A century later they'll be only bones—unless, well, there's always a possibility that the population explosion cannot be controlled. In that case the whole world could become one seething city.

Although everybody who understands the problem now accepts the need for population control, there's been very little thought given to the ultimate level. But once we take charge of reproduction and control the population growth, we can aim for any absolute level of population.

What level should we aim at? Well, the world could support a much larger population than it does today and at a good standard of living, apart from the psychological overcrowding. But should it do so? In a world of instantaneous communication, where all men are neighbors, what's the point of a population of more than a few million? The answer to this depends on the individual's

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Here we have a fascinating flashback to the point in time where all this trouble started—the building of the tower of Babel. I like to recall a passage from Genesis XI because it's so appropriate to this whole subject and to space exploration generally: "And the Lord said, 'Behold they are one people and they have all one language, and this is only the beginning of what they will do. And nothing that they propose to do now will be impossible for them.' "

We are seeing the beginning of the establishment of several global authorities. One of them—the International Telecommunications Union—has been in existence for a hundred years, yet most people have never heard of it. But even countries like mainland China belong to it. Now we're seeing an extension of it with the formation of InTelSat, an organization of about 70 countries in the communications satellite network. ComSat is the American member. Soon we'll see the organization of a world meteorological system based on weather satellites. And we've already got the World Health Organization and UNESCO. What I think and hope will happen is that some of these bodies, probably InTelSat, will get more and more powerful, more and more international, with more and more people working for them—and suddenly, to their great surprise, they'll find they're running the world. Before anyone realizes it.

philosophical and religious outlook. Astronomer Fred Hoyle once remarked to me that the optimum population of the world should be about 100,000 because that's the maximum number of people you can possibly get to know in a lifetime. You may say this is a rather self-centered point of view, but it's an interesting one, and it's worth remembering too. Plato thought the ideal city should contain about 5,000 free men. However, Plato's city also contained several times that number of slaves.

His "democracy" couldn't have managed without them, nor can the world of the future, especially if, as I hope, its population is ultimately stabilized at a small fraction of today's figure. Most of them, of course, will be robots at all levels of sophistication from simple-minded things like today's washing machines up to much more sophisticated, intelligent robots—the home computer to run the household, baby-sit the children, teach the children, answer phone calls, do income tax returns. The central brain will be somewhere in the house like today's air-conditioning or furnace system, and a lot of little slave robots will run around, doing odd jobs and cleaning up.

However, why should we go to the trouble of building complex electronic robots when nature has already done 99 percent of the job for us? We have been using animals for a long time as extensions of our personalities and our bodies. A sheep dog at work is a revelation; the working elephant, ditto; more recently, the seeing-eye dog for the blind. They are quite remarkable examples of what can be done with existing animals and really primitive training techniques. If we tried, in a few decades we could develop an animal—perhaps based on the chimpanzee—with a tenfold improvement in intelligence, motivation, vocabulary, and—above all—disposition. When it comes on the labor market, the servant shortage will be over. The housewife of 2001 need no longer be envious of her great grandmother of 1901—until the animals start to form their own unions.

You may well object that the net result of all these developments will be to eliminate 99 percent of human activity and to leave our descendants faced with a future of boredom, where the main problem in life will be deciding which of the several thousand television channels to tune to. This is perfectly true if we look at humanity as it's constituted today. H. G. Wells once said that future history will be a race between education and catastrophe. I doubt if even Wells realized the educational standards that must ultimately be reached to cope with the problem of universal leisure. While, ironically, politicians are always talking about full employment, we're heading for the exact reverse—full unemployment.

Just as there is no function today for manual laborers, there will be none tomorrow for those of only clerical or executive skills. The day after tomorrow society will have no place for anyone who is as ignorant as the average, mid-twentieth-century college graduate, who will be as lost and helpless then as a Pilgrim father would be if he were dumped suddenly in Times Square during the rush hour.

The greatest single industry of the future is education. The second greatest industry will be entertainment. And the two, despite the beliefs of some educators, are not necessarily incompatible. For every man education will have to be a process that continues all his life. We've got to abandon the idea that schooling is something restricted to youth. How can it be in a world where half the things a man knows at 20 are no longer true at 40, and half the things he knows at 40 hadn't been discovered when he was 20? The main social problem of the future is going to be that of raising the school-leaving age to approximately 120.

In the race against catastrophe of which Wells warned us, the last lap has already begun. If we lose it, the world of 2001 will be much like ours with its problems and evils and vices enlarged—perhaps beyond endurance. But if we win, 2001 could mark the great divide between barbarism and civilization. It is inspiring to realize that with some luck and much hard work, many of us have a chance of living to see the final end of the Dark Ages.

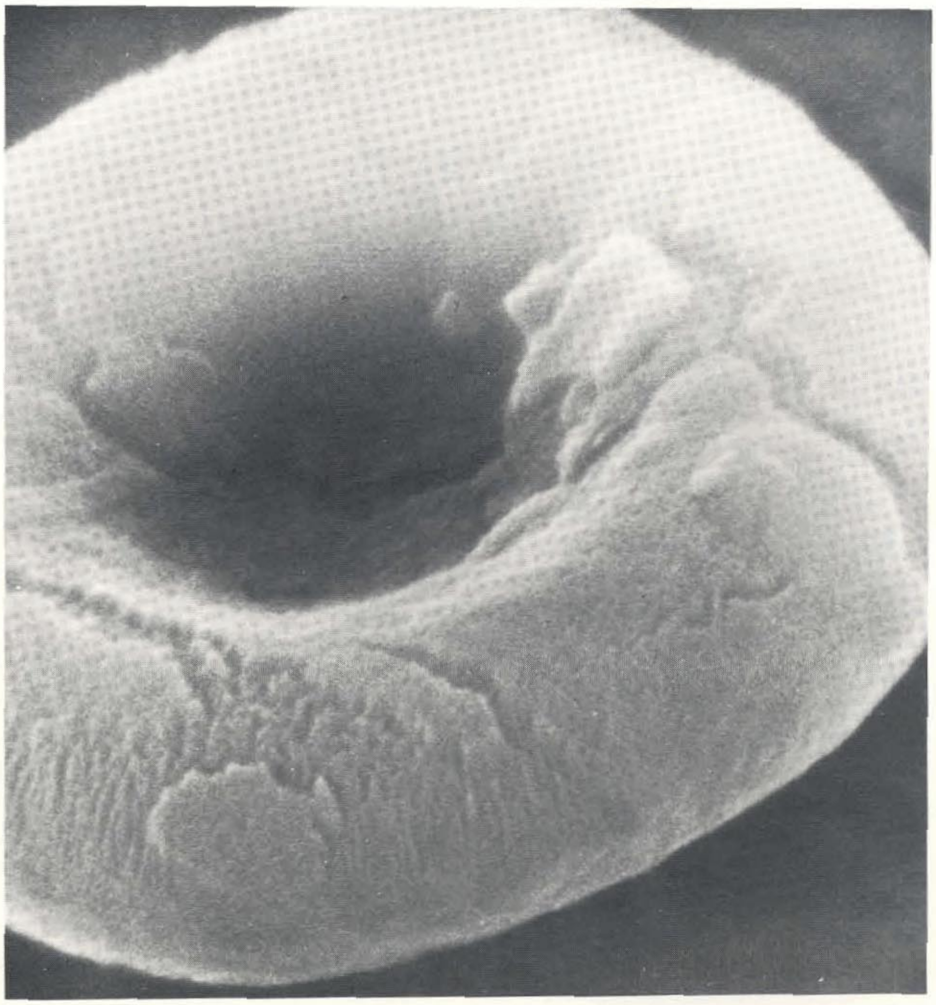
An Engineer Looks at Red Cells

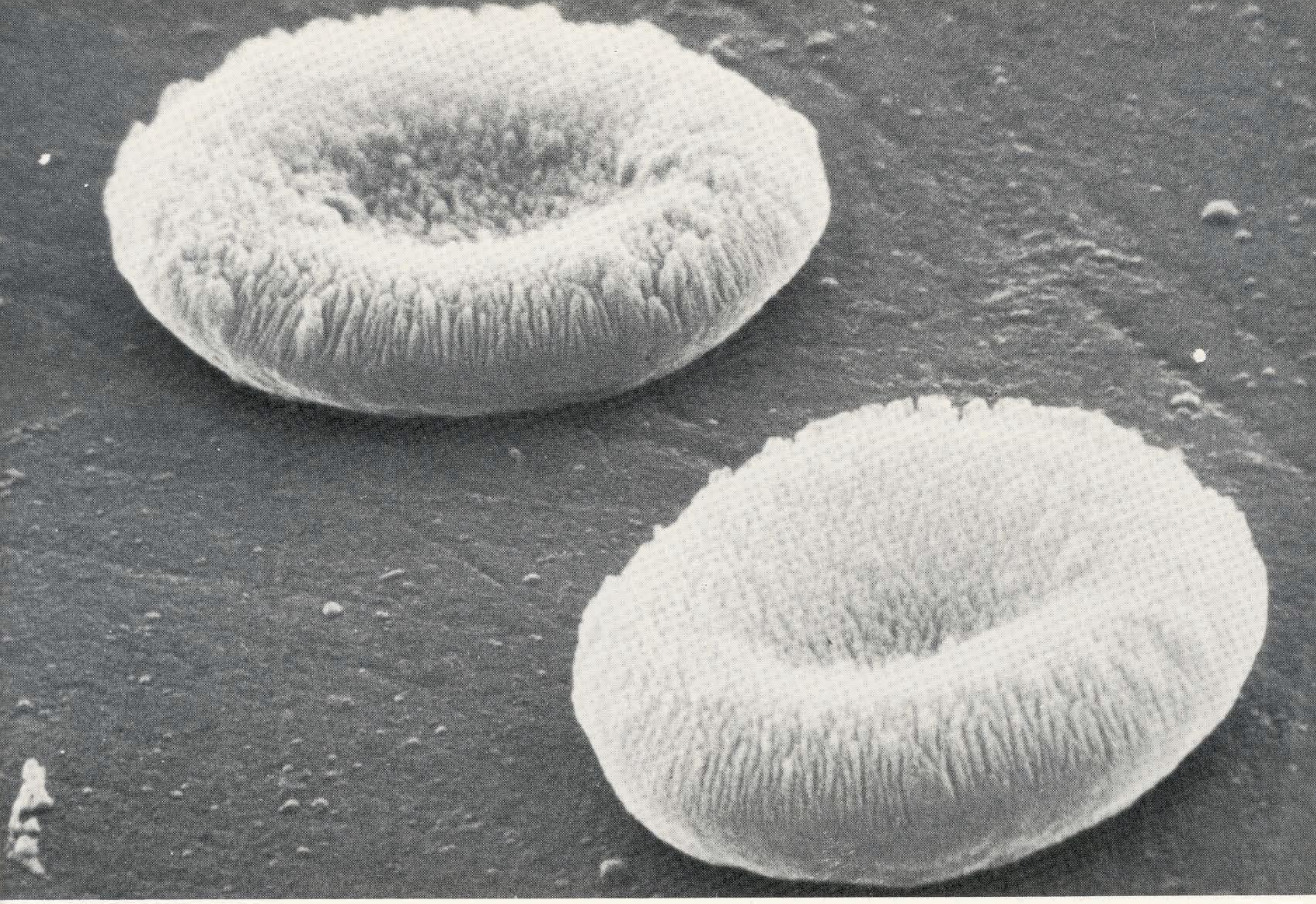
The scanning electron microscope has provided a unique way to look at the external surface of biological materials. The technique gives a large depth of field —resulting in a vivid impression of three dimensions—allows large specimen area, and permits a wide magnification range. There are some disadvantages of the method, including limited resolution (100-200 Angstroms, compared with 5-10 Angstroms using transmission electron microscopy), the need to fix the specimen both physically and chemically, and the need for a conductive coating on the material being studied.

Because, with biological specimens, it is a thin metal coating whose "picture" is being taken, methods have to be used to enhance the surface contrast. Although either physical or chemical etching of atoms might be used for this purpose, physical removal of atoms from the target by ion bombardment was the technique used for producing the effects shown in these photographs of red blood cells. The pictures were made by Richard F. Baker, professor of microbiology at the USC School of Medicine and a research associate in engineering science at Caltech.

Baker's work, done with an electron microscope located at the Jet Propulsion Laboratory and operated by engineer John Devaney, has shown that a low-frequency glow discharge is useful for ion etching of biological specimens and that the patterns seen in the etched red cells do not represent preexisting structure within the cell, but are reflections of heterogeneity in or near the plane of the membrane of the cell. He suggests that if a pattern of etch-resistant sites exists in the membrane, the ion beam would produce a mosaic of holes and high points as it begins to etch. Even after the high points had been eventually eroded, the palisade pattern already established would continue as the beam worked on the homogeneous cell interior.

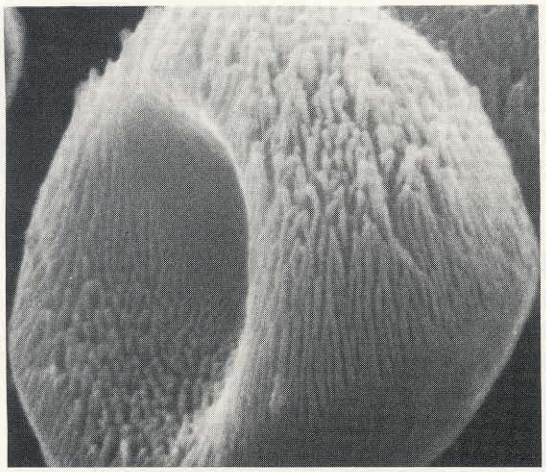
1. Red blood cells, as shown on this month's cover, are coated with a 100-Angstrom thick gold film preparatory to etching with an ion beam. Here, about 15 seconds of etching with the beam has removed portions of the cell's membrane and is beginning to show traces of a fenestrated pattern.



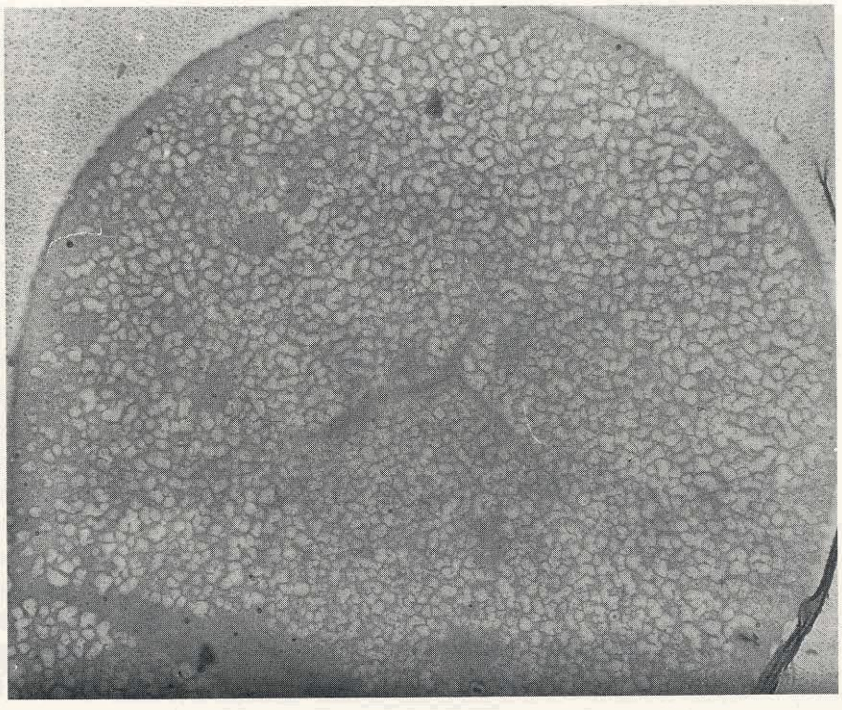


2. After 2¼ minutes of etch, the membrane has been almost completely removed except for the lower part of the cells, which have been shielded from ion impact. The cell at the top has a few fragments of membrane still attached. An array of parallel channels is seen around the rim of both cells.

4. Sixty seconds of etching on an isolated red cell membrane produces a mosaic of holes. The larger holes are formed from the merger of smaller holes.



3. While most cells lie flat on the aluminum surface on which they are placed, high concentrations lead to crowding, and an occasional cell may be seen standing on edge supported by close neighbors. When this occurs, it is seen that the palisade pattern on the rim does not rotate through 90 degrees with the cell, but remains parallel to the incident ion beam. This is direct evidence that the filaments did not preexist in the cell, but were created by action of the ion beam.



The Grand Tour of the Outer Planets

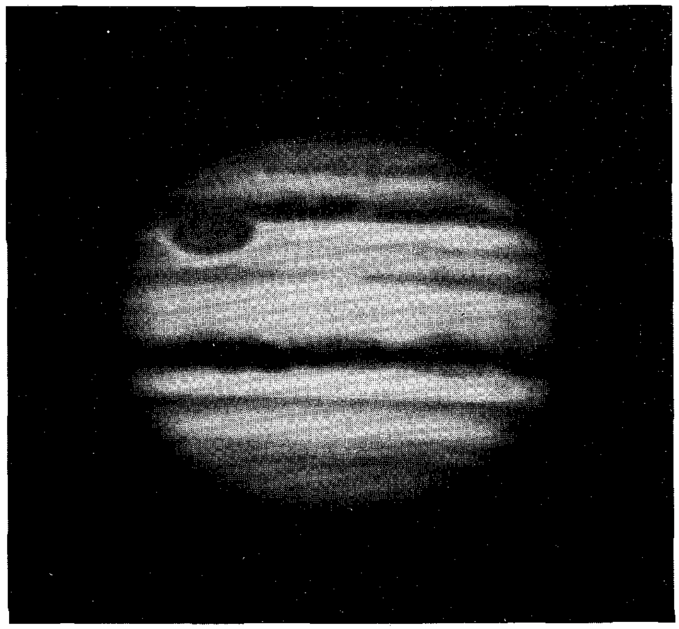
The planets will be uniquely aligned in 1976. The last time was when Thomas Jefferson was President. The next time will be in 2148.

All space missions flown to date have been from the earth to a single other body—the moon, Mars, or Venus. About nine years ago Caltech's Jet Propulsion Laboratory began studying space missions that might use the gravitational field of one planet to go to another planet, or out of the plane of the earth's orbit around the sun, or perhaps even to escape from the solar system. The first such mission is scheduled for 1973, when JPL will fly a spacecraft to Venus and then, using the gravitational field of that planet to change the speed and the direction of the spacecraft, on to the planet Mercury.

Back in 1965, Gary Flandro, a Caltech graduate student doing some work at JPL, was given the job of looking at various possible missions to the outer planets. He discovered that during the years 1976 to 1978 it would be possible to use Jupiter to go on to Saturn, use the field of Saturn to go on to Uranus, and use the field of Uranus to go on to Neptune. He dubbed this mission "The Grand Tour."

If we were to launch a Grand Tour from earth toward Jupiter in 1977, the spacecraft would arrive at Jupiter in 1979. Arriving there it would receive an increase in velocity of almost 11 kilometers per second and be deflected in its course by about 97 degrees to go on to Saturn, where it would arrive in 1980, then on to Uranus in 1984, then to Neptune in 1986.

But this all-in-one mission is hazardous because it requires passing very near to Saturn; Saturn's beautiful set of rings, composed of a multitude of small particles, could easily destroy the spacecraft. It would be more



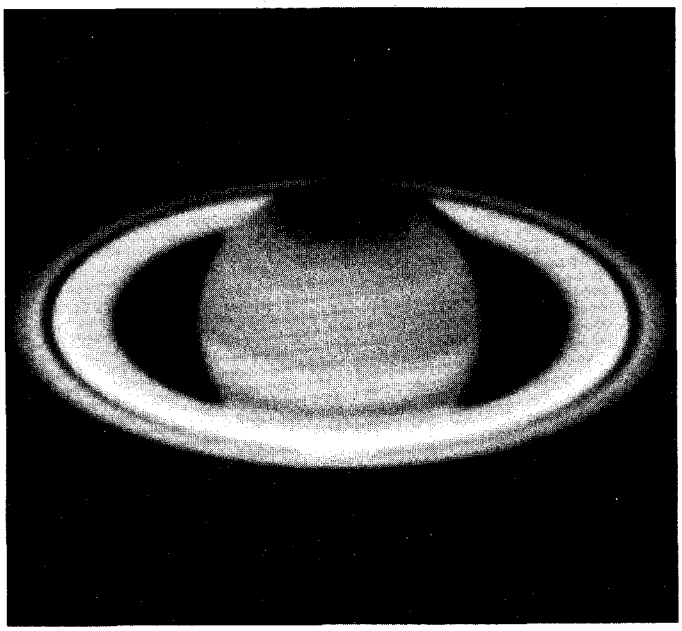
Jupiter: Are conditions under the clouds like those of a primitive earth?

prudent to send two spacecraft. The first one would go from earth in 1977 to Jupiter in 1979, to Saturn in 1980, and on out to Pluto in 1986. The second mission, launched in 1979, would go to Jupiter in 1981, Uranus in 1985, and Neptune in 1988. An interesting thing about the Saturn part of the mission is that although the velocity change is very small, the deflection angle, 25 degrees, is almost entirely up and out of the plane of the earth's orbit. Pluto is in a highly inclined orbit, and at the time of arrival in 1986, Pluto will be more than 1¼ billion kilometers above the main plane that most of the solar system lies in. Pluto also has an orbit of large eccentricity, and it can, when it is nearest the sun, come nearer the sun than Neptune ever gets. This is actually the situation at the arrival time in 1986.

This unique opportunity of flying from Jupiter to Uranus to Neptune depends on the relative positions of Uranus and Neptune. The last time this configuration of the planets existed, Thomas Jefferson was President of the United States; the next time will be in 2148.

Now, just the stunt of making a "four-cushion shot" is no reason to fly an expensive planetary mission. There are important scientific reasons for undertaking the Grand Tour.

by Ray Newburn



Saturn: How could the rings have survived for 5 billion years?

First, we want to know as much as possible about the origin and evolution of the solar system. Terrestrial planets like the earth have lost most of their lightest elements, and the earth has been differentiated so that what we see in the crust is, we think, very different from what is in the interior of the earth. But Jupiter, and perhaps Saturn, should contain almost all of the matter that originally went into their makeup when the planets were formed. In the case of Jupiter we deal with a planet about as near in composition to the material of the primordial nebula as we are likely to find in the solar system. Furthermore, that material may be well mixed so that a sample of the upper part of it may be representative of what the whole thing is made of.

Furthermore, to truly understand what the planets may have been like eons ago we need to know certain basic things about their structure today, and that structure can only be derived if we have certain basic facts such as size, density, composition, and energy balance. These facts can be found accurately (especially for Uranus, Neptune, and Pluto) only by visiting each of these planets.

A second major goal is to search for life on another planet, both to give more perspective to our own existence and to better understand the origin and evolution of life here on earth. We don't expect to find little green men running around on Jupiter and Saturn, but conditions on Jupiter and Saturn today are very like those conditions which most scientists think existed on the primitive earth several billion years ago when life may first have originated. Jupiter has a reducing atmosphere (one with no free oxygen in it) of hydrogen, methane, and ammonia. Although the temperatures we measure above the clouds are frigid, we know from radio observations that temperatures below the clouds are like those on earth today. And although we have never detected water spectroscopically on Jupiter (because it freezes out in the upper part of the atmosphere), there is every reason to think that most of the cosmic abundance of oxygen that we don't see may be trapped, together with hydrogen, in the form of water.

So the conditions below Jupiter's clouds today may be very like those that probably existed on the primitive earth; they are the exact conditions under which scientists in terrestrial laboratories have been able to produce amino acids—one of the fundamental building blocks of living matter. Of course, it may be that on Jupiter the atmosphere will be convective, mixing to such a depth that the heat far below may destroy these compounds. But even if that's true, there are regions—such as that of the great red spot—which may be stagnant and so may be a good place to look for the complex organic compounds that are precursors to life as we know it. And if Jupiter has no such good place, we can look on Saturn, which is very like Jupiter.

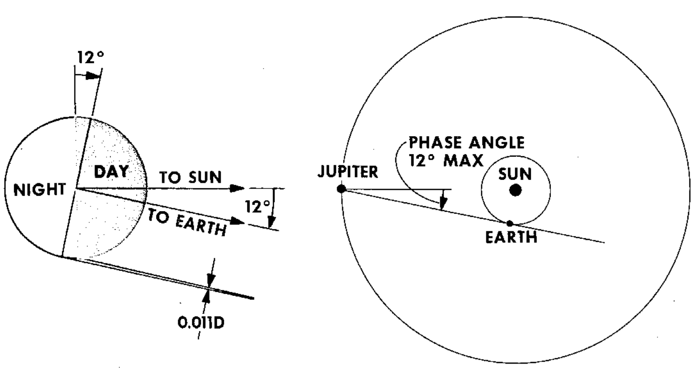
We know so little about Uranus and Neptune that we can't really say much about conditions there, but they too should be of some interest to the biologists.

A third major goal in the space program is to understand our own planet and its environment better. Much of the study of the weather and environmental pollution requires an understanding of atmospheric circulation and thermal balance. We can't very well simulate a whole planetary atmosphere and its large-scale effects in the

PLANETARY COMPARISONS

	MEAN SOLAR DISTANCE AU	EQUATORIAL DIAMETER EARTH = 1	MASS EARTH = 1	DENSITY g/cm^3	ROTATION PERIOD SIDEREAL	ATMOSPHERE MAJOR COMPONENTS
MERCURY	0.387	0.382	0.056	5.50	58.6d	None detected
VENUS	0.732	0.948	0.815	5.27	243.0d	$CO_2 > 90\%$
EARTH	1.496×10^8 km	6,378.16 km	5.97×10^{24} kg	5.52	23^h56^m	N_2, O_2
MARS	1.524	0.532	0 107	3.94	24^h37^m	$CO_2 \sim 90\%$
JUPITER	5.203	11.19	317.9	1.33	9^h55^m*	H_2, He
SATURN	9.523	9.47	95.1	0.69	10^h14^m†	H_2, He
URANUS	19.164	3.69 ?	14.5	~1.68	~10.8h	H_2, He
NEPTUNE	29.987	3.92	17.3	~1.59	~15.8h	H_2, He
PLUTO	39.37	~0.5	0.18 ?	~7.7 ?	6^d09^h	None detected

*SYSTEM III
†VISIBLE SPOTS AT EQUATOR



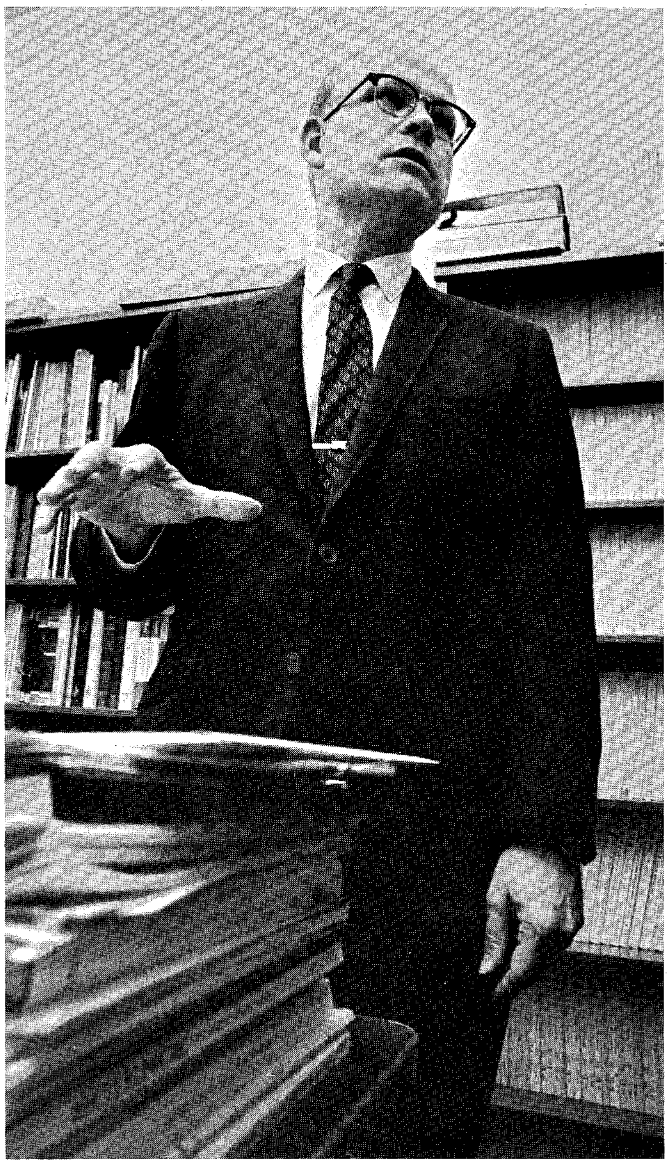
In looking at Jupiter from the earth, we can never see more than a sliver of its night side—far too little to permit understanding of the planet's energy balance.

laboratory, so we really need other examples against which we can compare the predictions of our theories.

Now this may sound like a red herring to suggest that we can learn more about the earth by study of the outer planets, but that's not the case. Here on earth, for example, there is a mysterious ocean current (called the Cromwell current or the equatorial undercurrent) which flows about 400 kilometers wide and 300 meters thick in a westerly direction at the earth's equator in the Atlantic and Pacific Oceans. Oceanographers say that the question of what drives this Cromwell current is one of the most interesting unsolved problems in dynamic oceanography. Similarly, in the stratosphere above the equatorial region there are winds called the Berson Westerlies. They too are unexplained. On Jupiter and Saturn there are equatorial atmospheric jets that seem to be an exact analog of the peculiar currents in the earth's ocean and atmosphere. So there are close analogies between some of the dynamic things going on in outer planet atmospheres and things occurring on our own earth.

The evolution of the solar system is a continuous process, although there have almost certainly been periods during which change was more rapid than at present. To understand the past, an accurate knowledge of the present is mandatory. Only by knowing "what is" can we use physical principles to imply "what was." The problem of the present structure of the planets is a complex one, requiring knowledge of composition, energy balance, and basic physical parameters, among other things. Yet, some of these parameters are known very poorly.

There are fundamental limitations, caused by the vast distances involved, on trying to do astronomy from the earth. For example, the equatorial diameter of Neptune is 3.92 that of the earth—about 50,000 kilometers. But in almost any astronomy textbook the value that's given is at least 10 percent less than that. In 1968 Neptune moved in front of a faint star, and by timing the passage of Neptune in front of it, astronomers made a more accurate measurement of the radius than had ever been made from earth before. Now, a 10-percent error in the size of a planet means a 30-percent error in the density of that planet. So while most textbooks give the mean density as about 2.3, we now think it is about 1.6. How can we possibly understand the planet when we don't even know the density of the material making it up? If the value of



JPL astronomer Ray Newburn

How can we possibly understand a planet when we don't even know the density of the material making it up?

Neptune's radius was so far in error, that of Uranus may be equally poor.

Measurements made by a spacecraft can resolve such ambiguities. If we track a spacecraft as it passes behind each planet and time the disappearance and reappearance of the radio signal, we can get a measure of the planets' sizes. Obviously, in a planet with an atmosphere there are complications—such as refraction of the signal—but these can be accounted for. We may be able to find out something about the rotation periods of the farther planets if there happen to be markings on them and we take pictures over a period of time. We can also measure the flattening of planets, such as that obviously exhibited by Uranus; we have only the very crudest idea of how flat Uranus and Neptune really are. Neither mass nor radius are known with any accuracy for Pluto. The density of that peculiar body is uncertain by at least 50 percent.

Another limitation of trying to do astronomy from earth is that the angle between the earth and sun as seen from Jupiter (the phase angle) is small, and in fact can never be more than 12 degrees. The angle is even smaller for planets more distant from the sun. Consequently, we can never see more than a sliver of the night side of *any* of the outer planets from earth. No telescope on earth or in orbit around the earth can overcome that geometric fact. Only a spacecraft flying outward can do so.

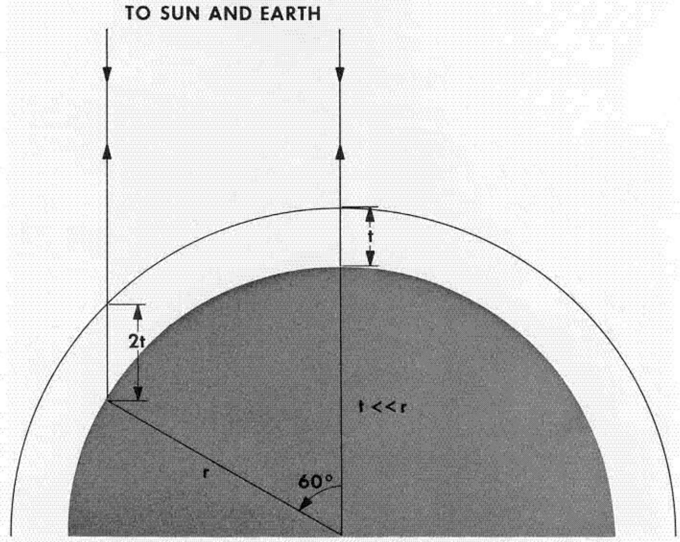
The inaccessible large-phase angles hold the key to quantitative understanding of the planetary energy balance. We know how much power the earth receives from the sun (the solar constant); the power from the sun that reaches other planets is reduced by the square of their relative distances. Part of that power is reflected, although the exact amount is uncertain because the part reflected at large angles cannot be seen from earth, and the remainder is absorbed.

If these outer planets are in equilibrium with the sun, we can equate the energy absorbed to the energy emitted and find out what the average temperature of the planet should be. But because we don't know how much energy is reflected or emitted from the parts of the planet we can't see, there is some uncertainty in the temperatures. When we measure temperatures on Jupiter or Saturn, they are higher than the temperatures we might expect no matter what we assume about their reflecting properties. Somehow, if we believe these figures, Jupiter is radiating 2.7 times more energy than it is receiving from the sun, and Saturn appears to be radiating about 3.5 times as much energy as it receives.

If this is true, then the classic descriptions of Jupiter and Saturn—a core of very cold, solid metallic hydrogen and helium; a surrounding region of nonmetallic solid hydrogen and helium; and an atmosphere of low conductivity—seem unlikely to be correct. A second possible picture of Jupiter, a modified classic picture, is the same except that the core is fluid. It still maintains some lattice structure, it is still metallic hydrogen and helium, but now the core material can move and can

The rotation period of Jupiter's great red spot has changed more or less continually during the last 100 years.

transport energy by convection. Instead of being cold, its temperature might be 10,000 degrees Kelvin. The excess energy observed could be the result of gravity causing the planet to collapse as little as one millimeter in a year, converting gravitational potential energy to thermal energy. Furthermore, the fluid conducting core, as it moves, might generate the magnetic field on Jupiter very much as it is thought that the earth generates its magnetic field.



If Jupiter's atmosphere were relatively simple, then a measurement of the abundance of constituents would vary according to the thickness of atmosphere being looked at, with the smallest amount at the center of the disk. But, in fact, all the measurements seem to be about the same.

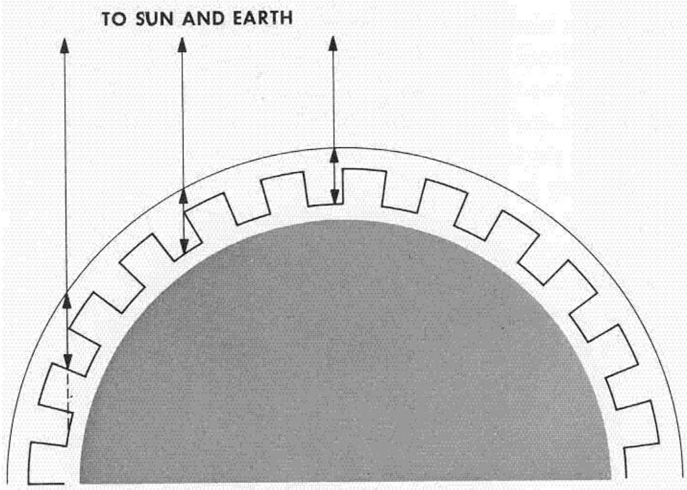
Two other interesting hypotheses about the structure of Jupiter are worth noting. The first is an idea of Raymond Hide, the deputy chief of the Meteorology Office in Great Britain. He suggests that perhaps the denser atmosphere below the clouds has sufficient conductivity to become a self-exciting dynamo and to generate the magnetic field. He further suggests that there could be energy storage within toroidal magnetic fields in that region and that these fields might store energy and later release it in a long-period cyclic process, thereby accounting for the present excess of power radiated. In this model the temperature of the interior could be low or high, although for other reasons Hide would prefer to have it hot enough for some fluid motion. Yet another hypothesis is that the planet is fluid throughout, having no solid surface, as calculations done by W. B. Hubbard at Caltech showed was possible.

Obviously, unless we know which of these or other models approaches the real Jupiter, we'll never have any idea of how the planet originated. If we can make radiometer measurements and find out if the energy imbalance is real and where the energy seems to be appearing, that will be one step. Another step would be to take a magnetometer to Jupiter and to measure its magnetic field. The origin of the field may be revealed by measurements of its detailed structure very near the planet. The same problem exists for Saturn, although to date it is not known whether Saturn even has a magnetic field; as for Uranus and Neptune, we don't know much about their thermal balance or anything about possible magnetic fields. It is unlikely, at least with any present instruments, that we will be able to determine these facts from the earth.

There is another quantity that is important if we are going to have a reasonable picture of these outer planets —and that is their composition. If we don't know it, then we don't know important structural parameters like specific heat, viscosity, opacity, conductivity. It may seem that the exact composition of these planets could be determined spectroscopically from earth, but so far this has not been possible.

The simplest model of a planet is that of a surface or cloud layer which reflects diffusely (like a perfect Lambert sphere) over which is a transparent atmosphere. The strength of the spectral lines (the record of how much light at a specific wavelength is absorbed by atoms or molecules in the atmosphere) is directly related to the number of atoms present in a planetary atmosphere. The thicker the atmosphere, the stronger the lines. For this simple model, a "look" toward the edge of the planet's disk sees a thicker atmosphere than one right at the center; for an ideal Jupiter we should see a spectral line near the edge that is twice as strong as the one near the middle. But, in fact, they are virtually the same. The model just doesn't work.

About 15 years ago Squires suggested that great cumulus clouds—like towering thunderheads on earth, though not made of water—might occur on Jupiter, complicating the atmospheric geometry. This is ingenious



One suggestion advanced to explain the anomalous measurements of Jupiter's atmosphere was that the base of the atmosphere was not the planet's spherical surface but the very uneven top surfaces of great cumulus clouds. But if that were the case, ammonia would freeze out of the atmosphere at the top of the clouds, leading to different relative abundances of ammonia and methane for different measurements. But the relative abundances of methane and ammonia are essentially the same in all measurements.

geometrically, but it does not solve the problem on Jupiter. For example, Jupiter has both methane and ammonia in its atmosphere. But ammonia freezes at temperatures that are present in the upper atmosphere of Jupiter, so up at the top of those clouds there shouldn't be any ammonia. Therefore, the relative abundances of methane and ammonia shouldn't seem to be the same at the center of the Jovian disk, where the bottoms between the towers are visible, and at the edge of the disk where only tower tops can be seen. But the apparent abundances are about the same, so that approach won't work either.

What we see when we look at Jupiter's atmosphere is probably the result of an inhomogeneous atmosphere, an atmosphere containing both molecules which absorb light and aerosols which scatter it, further complicated by the relative abundance of absorbers and scatterers changing with altitude. This creates a problem of great difficulty, both theoretically and observationally. We do know that Jupiter, because of its low density, is composed mostly of hydrogen and helium. Furthermore, in 1953, Jupiter occulted a star, and a crude measurement of the molecular weight of the atmosphere was obtained at Mt. Wilson—3.3. This led people to suggest that there was about the same amount of helium (molecular weight of 4) and molecular hydrogen (weight of 2). But it was a difficult measurement to make, complicated by noise because the star was faint and scattered light from Jupiter relatively large.

The observations were very important because they ruled out heavy gases as major atmospheric components, but they could support, equally well, pure molecular hydrogen or pure helium. Other (spectroscopic) observations since that time have convinced planetary astronomers that there is probably five to ten times as much hydrogen as helium; in fact, observations today are compatible with no helium at all. To better understand this situation we require extremely high-resolution spectral observations as well as a theory for inhomogeneous atmospheres. It is unlikely that the observations of Jupiter can be made with satisfactory accuracy from earth, and similiar observations of Saturn, Uranus, and Neptune seem impossible from earth with existing equipment.

We can actually create our own occultation, using the radio signals transmitted from spacecraft, however, and these signals do not have the noise problem of optical observations. Knowing something about the atmosphere already, we can find the relative abundance of hydrogen and helium in a fairly unambiguous fashion, especially if supporting temperature measurements are also made.

Another fascinating problem we face on the outer planets is that of differential atmospheric rotation. The equatorial region of Jupiter rotates at a higher rate than the rest of the planet. This System I region, which includes 10 degrees on either side of the equator, rotates in 9 hours and 50 minutes. System II, the high latitude regions, rotates in 9 hours and 55 minutes, so there is an equatorial jet on Jupiter moving about 225 miles an hour faster than the rest of the visible cloud surface of the planet. There is also a so-called System III determined by radio observation which is rather near to that of System II, but not identical. The System III period is most probably that of the bulk of material making up the body of Jupiter. Detailed imagery and thermal maps may help us to understand these complex dynamics.

One of the fascinating dynamical problems of Jupiter concerns the great red spot. Its rotation period apparently has changed more or less continually during the last 100 years. All of the early theories were that it floated in the atmosphere of Jupiter. We know now that the atmosphere of Jupiter is mostly hydrogen and, since there is nothing lighter than hydrogen, it can hardly be a floating island. Perhaps the best current explanation (due to Raymond

Iapetus, the ninth satellite of Saturn, varies in brightness by two magnitudes—a factor of six. How can that be?

Hide) is that it is a so-called Taylor column—a stagnant region formed as the thick, rapidly rotating atmosphere encounters and interacts with some topographic irregularity like a mountain range or large hole.

If the great red spot is such a column, how can it be rotating with a variable rate? Perhaps the period of rotation of Jupiter itself has changed, as matter is redistributed within the fluid interior of the planet. Or perhaps the planet is fluid throughout, and the irregularity is not a fixed mountain range but just the upper end of a great convection cell in the interior of the planet, or a magnetic loop within the dense, lower atmosphere. There are all kinds of theories, but very few answers. Close-up photographs might provide some.

Saturn also appears to have an equatorial jet like Jupiter. Near the equator the period of rotation appears to be about ½ hour less than the rotation in the higher latitude region. But the biggest dynamical problem of Saturn is its beautiful rings. They are known to be composed of a myriad of individual particles, because at times stars have been seen right through a ring and because the outer parts of the ring rotate more slowly than the inner parts. If those particles are not all in perfect circular orbits, then there must be collisions, which would tend to destroy the rings. Similarly, if there is any inclination among the various orbits, again there must tend to be collisions among the particles. Yet, gravitational perturbations by Jupiter and by Saturn's own satellites must tend to introduce such imperfections. It's difficult to understand how these rings could have survived such collisions for five billion years, yet it's equally difficult to understand how they might have been created more recently. We don't really understand the rings today. We don't know how big the particles are, and we don't know what the composition of the rings is, although there is some spectroscopic evidence that ice is present. We don't know how thick the rings are, though they can't be more than a few kilometers thick.

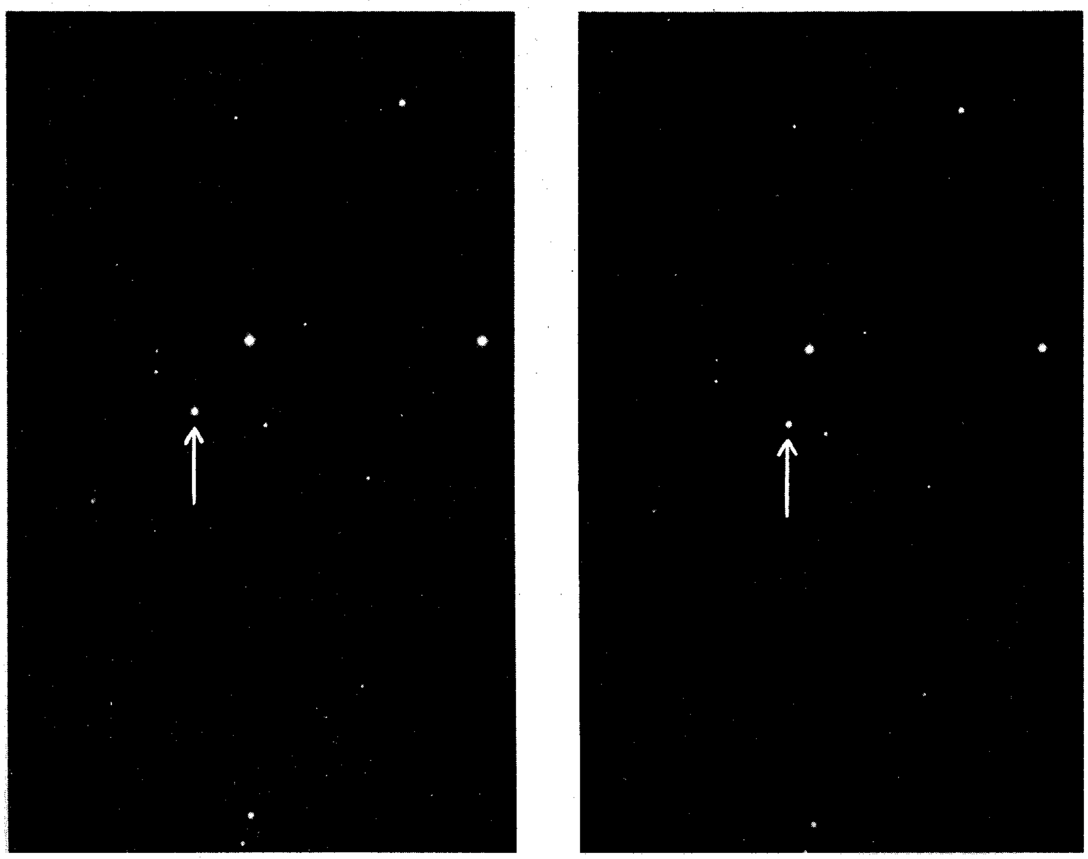
One of the difficulties in studying the rings is that the maximum viewing angle (sun-ring-earth) that can ever be achieved from earth is 6 degrees. If we can have a spacecraft observe the rings at different angles, studying brightness and polarization, we may learn something more about the particle size and distribution. Simple imagery should help to set an upper limit on the ring thickness.

Uranus presents another unique situation. While most planets have their axes of rotation near the pole of the orbit of the planet (on earth the equator is inclined only 23½ degrees to our planet's orbit around the sun), Uranus is tipped completely over so that the axis of rotation of Uranus is almost in the plane of its orbit. How this orientation came about is one of the great mysteries of the solar system's formation. There should be some interesting atmospheric effects occurring on a planet which is heated at one pole, with the other pole in darkness for a quarter of the planet's 84-year period of revolution about the sun. A study of its behavior may teach us a great deal about atmospheric dynamics.

We can't say much about Neptune and Pluto; we just don't have enough data to know what the problems are there. It may be that Pluto is an escaped satellite of Neptune, a possibility first pointed out by Professor Raymond Lyttleton of Cambridge about 35 years ago. In fact, everything we know about Pluto indicates that it's almost identical to Triton, one of the two known satellites of Neptune.

The satellites of the outer planets are also worth more study. Jupiter's Ganymede is probably larger than the planet Mercury, so it is certainly not an insignificant body. And four of the 29 outer planet satellites—Callisto and Ganymede of Jupiter, Titan of Saturn, and Triton of Neptune—are bigger than our moon. Titan even has an atmosphere of methane.

One of the stranger satellites is Jupiter's Io. When it is observed coming out from behind Jupiter's shadow, it appears to be a bit brighter for about ten minutes than it was when going into eclipse; then it decays to the brightness it had before. *If these observations are correct,* the simplest explanation is that Io, too, has a bit of an atmosphere—perhaps methane or nitrogen. It might be that as Io falls into the shadow of Jupiter and gets colder, the atmosphere snows out on the surface, making the surface brighter. When Io reappears, it's brighter; but as it warms up in the sun, the atmosphere vaporizes again and Io goes back to normal.



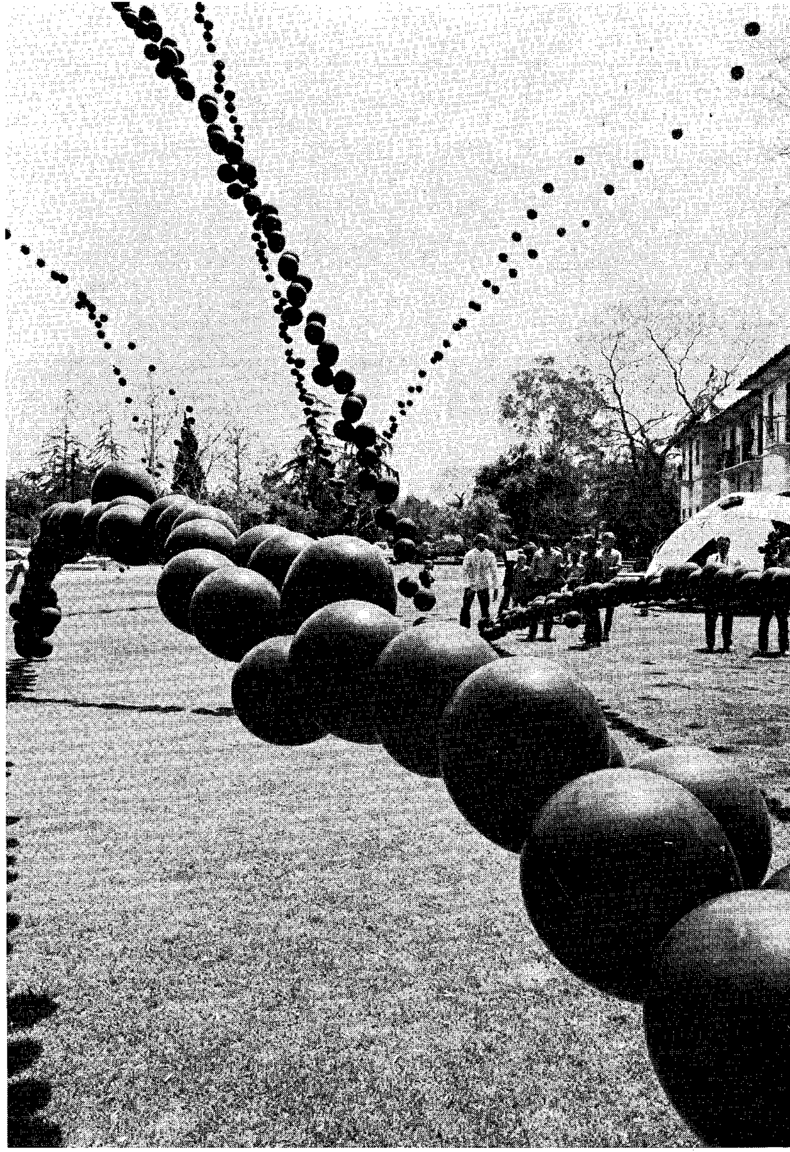
Pluto: Is it an escaped moon of Neptune?

Io is peculiar in other ways too. It is distinctly orange, much redder than the other Jovian satellites, and the color changes as Io moves around in its orbit. Io also has very peculiar back-scattering properties—when we look at it, the energy falling on it comes almost straight back at us. Its retro-reflection properties are greater than those of any other natural body in the solar system. It would be extremely useful to get a series of pictures of this satellite at different angles and through different color filters.

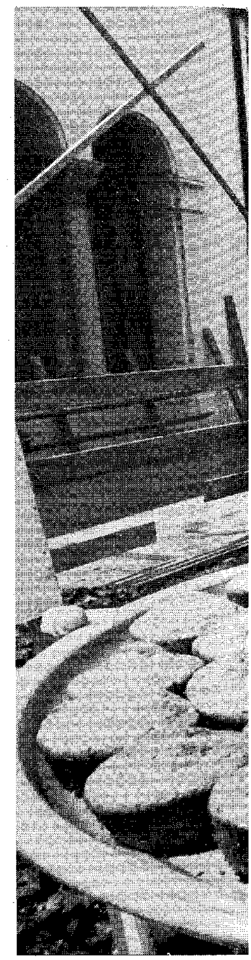
There is another satellite in the solar system that is even more peculiar than Io. Iapetus, the ninth satellite of Saturn, is known to vary in brightness by two magnitudes—a factor of six—as it moves from one side of Saturn to the other. How can that be? One might even guess that Iapetus is brick-shaped and rotating at half the rate that it revolves about Saturn. But how can a body that is as big as Iapetus—perhaps 1,300 kilometers in mean diameter—be brick-shaped with a six-to-one aspect ratio? Known materials are unlikely to have sufficient strength to maintain that shape, six times as big in one dimension as any other, and this is almost certainly not the explanation. Neither have I yet accepted the explanation given in the book version of *2001* that Iapetus is a sort of cosmic transportation relay station. But one is *almost* forced to science fiction in trying to deal with the satellite. Apparently one hemisphere is simply six times as bright as the other. I would certainly like to get some pictures of Iapetus, and that's something the Grand Tour spacecraft might be fortunate enough to accomplish.

Although I have dwelt a great deal on Jupiter, that planet is not the real goal of the Grand Tour mission. We could launch to Jupiter about every 13 months from the earth. But to really understand the solar system, we need certain basic knowledge about *all* of its major bodies—things like accurate values for the density, the hydrogen and helium abundance, the energy balance, and magnetic field information for Uranus and Neptune that we can get only with spacecraft. We have a chance to do that with reasonable economy this decade; otherwise we must develop new vehicles with greater performance and spacecraft with very long lives, or wait until the middle of the 22nd century.

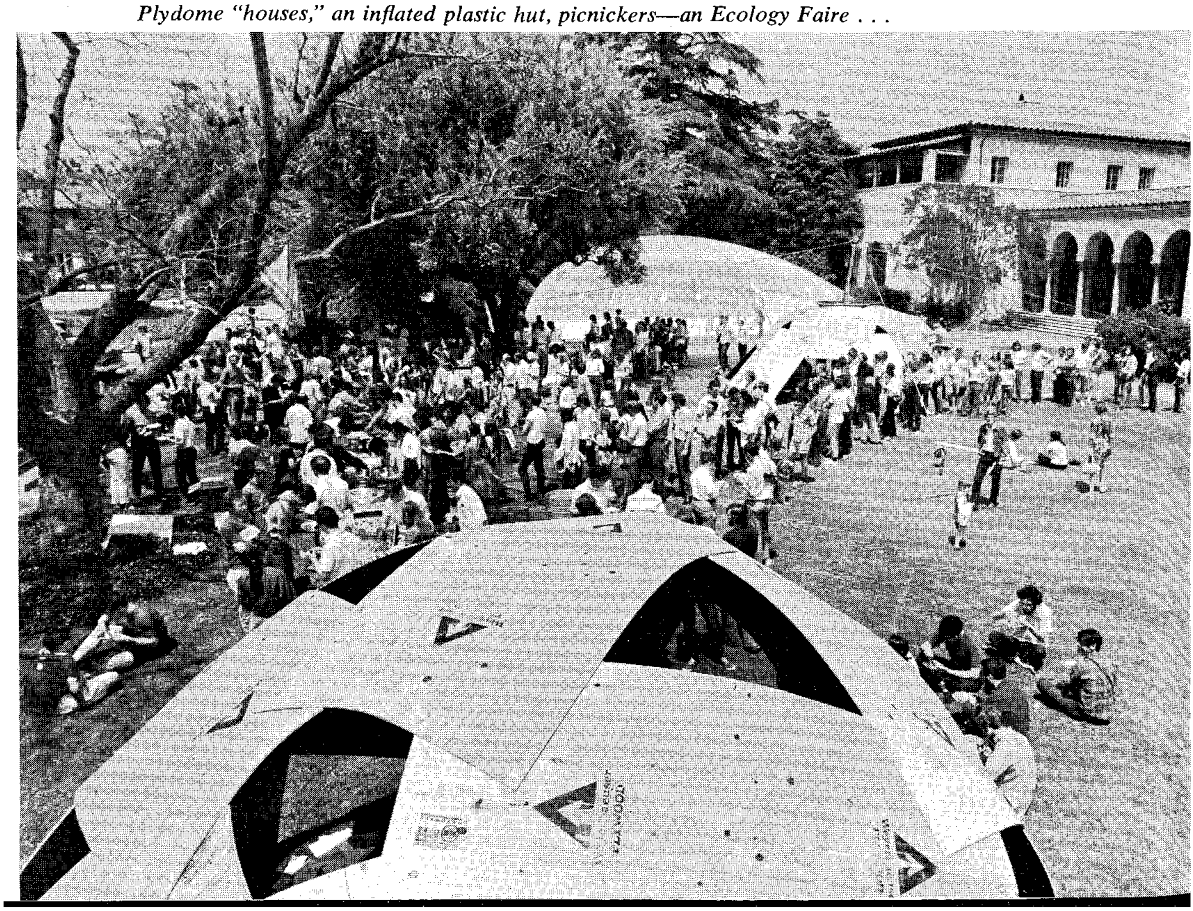
Participants from the community . . .



Black balloons symbolizing atmospheric pollution . . .



Plydome "houses," an inflated plastic hut, picnickers—an Ecology Faire . . .



Pollutant-free food made from organically grown plants...

CALTECH'S ECOWEEK

by Paul Wegener '70

Wegener, co-chairman of Caltech's Environmental Action Council, was one of the organizers of the week-long ecology program.

Caltech, like most schools around the country, had a "Teach-In on the Environment" throughout the week of April 20-24. As elsewhere, there were speakers—experts and authorities in their respective fields. Even Polytechnic School next door had a Teach-In, with the children bringing aluminum cans to school and writing essays about the evils of pollution. Everyone agreed that we should clean up the automobile when the law forces us to.

However, Caltech's week was also quite different, for we also had some color: a lawn filled with children and balloons, a feast, a celebration, and some people who weren't very interested in what some of the experts had to say about the kind of world we may live in. These people, from both the campus and the community, were more interested in the kind of world *they* wanted to live in. Perhaps a world with more parks and animals, peace and freedom, quiet and joy. These people came to reach out around them with the vision in their hearts. They came to the Faire.

At the Ecology Faire people helped build plydomes, houses that cost less than $100 each. They came to look at exhibits and talk with the representatives of various groups: Planned Parenthood, Planning and Conservation League, Outward Bound Adventures, Atlantic-Richfield Corporation, Pasadena Commission on Human Need and Opportunity, Fluor Corporation, Get Oil Out, Headstart, Foothill Areas Association. People talked with each other at the Faire, with speakers, students, faculty, Pasadena residents, and businessmen. They learned, from the Teach-In and the Faire, what direct effects they could have now to create the world we all want.

The Teach-In and Ecology Faire were designed around people and laughter, not numbers and fear. Numbers are vital to an understanding of what is to be done and how to do it, but there is a point at which they should be left behind; fear and accusations serve no constructive purpose at all. Many learned these things during the week, and this means that the week and all the effort behind it were a success.

The following week 40 people came to a meeting to begin, in as effective a way as possible, to build for the world. We are now creating a collection system in Pasadena to deal with the waste of valuable resources such as paper, glass, and aluminum; we are starting a food-cooperative as an alternative to bad food at high prices; we are becoming involved with Pasadena government at all levels in encouraging more parks, bicycle trails, stricter zoning laws, and in fighting the freeway; and we are working on various issues in coming elections and various community action and education programs around Pasadena. We are, in the simplest sense, a gathering of people who have come to realize that "everyone changing" means starting now, with ourselves, peacefully.

Pleasure Centers in the Brain

Why aren't we just as fit to survive if we're nudged ahead by pains and deficits?

Psychology has gone through a period of fantastic growth during the last 30 years, primarily because it seemed to offer college students some explanation of their malaise and some understanding of themselves which would free them from anxiety. Then why, if we are interested in the weal of these college students, do we expend our research on albino rats? Facetious though it may appear, there must be some truth in the answer that the albino rat is an excellent model of the contemporary American college student, or at least the majority of them. Neither the student, having been bred in America, nor the white rate, having been bred in a laboratory, has ever experienced a need in its life.

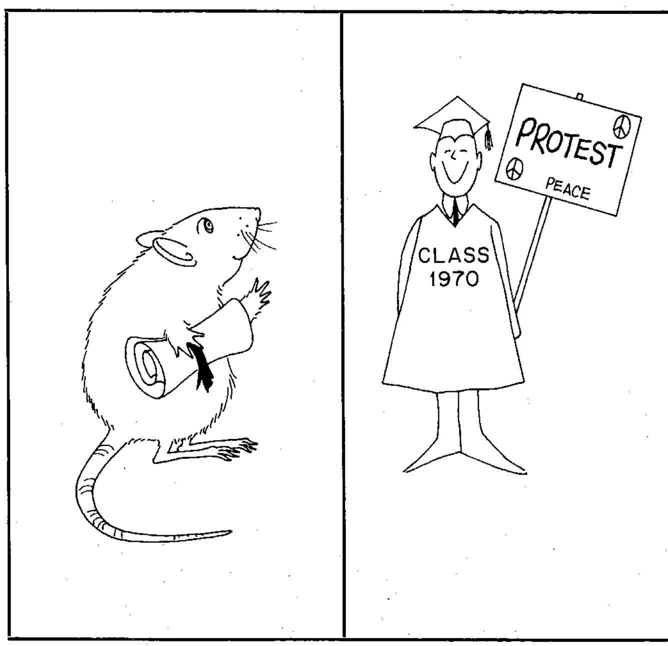
The question of what might drive behavior in the absence of needs would have bothered theoretical psychologists and Puritan preachers alike at the time I entered the field in the late 1940's. The concept of need-driven behavior is simple, compelling, and in complete accord with the simplest concept of evolution. It says that damage to the organism, or deprivation inimical to health, causes physiological processes which are experienced as discomfort, and that behavior proceeds in a random or a guided fashion until discomfort is alleviated. An uncomfortable person is in need, and need justifies a multitude of sins.

A few short steps ahead of this conception—and representing no significant advance in sophistication—is the drive-reduction theory of learning. The conception of this theory is that somewhere in the brain incoming sensory messages cross outgoing motor messages. If a sudden drive reduction occurs, a connection becomes fixed more or less permanently, so that the next time the sensory message will cause the rewarded behavior. It is possible to attack this theory on a variety of grounds, one of which is the simplicity of its attitude toward the data processing that goes on inside the brain. This theory gives rise to a law that states, "Learning occurs only when discomfort is relieved."

For an organism that seeks novelty, ideas, excitement, and good-tasting foods, the drive-reduction theory was a Procrustean bed. Whatever did not fit was shorn from our image of the man and the rat. Drugs, good foods, and sex were thought of in terms of a need—that is, a hurt generated by withdrawal. Even the coddled white rat was trapped into his forward motion by his residual pains. Behavior was a downhill course toward quiescence, and its energetics were a series of accidents from outside which countered the downhill trend.

If behavior was not aimed to repair these damages and concurrent discomforts, then why was it selected and why did it survive? This rhetorical question was given in answer to all counterarguments.

It is interesting that research on the albino rat, if it has not gone far to improve the sophistication of the



Neither the student, having been bred in America, nor the white rat, having been bred in a laboratory, has ever experienced a need in its life. What, then, might drive behavior in the absence of needs?

by James Olds

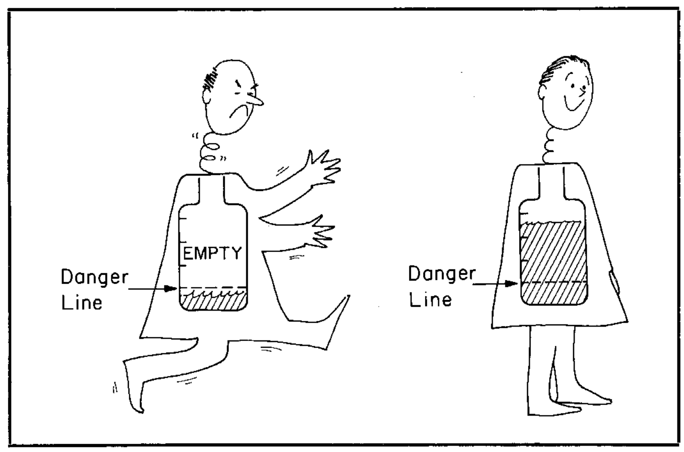
psychologist, has at least caused a minor revolution with regard to this drive-reduction theory of reward. This has been through the discovery that animals work not only to turn *off* discomforting stimuli but to turn *on* brain stimulations in an extensive set of brain regions. These regions are now considered by many to be central counterparts of the positive factors and good things of life that turn on people in everyday life.

The method of drilling holes in the skull and lowering probes by means of a guidance system to stimulate very small and well-localized brain centers was developed gradually in the first half of this century. Professor William R. Hess, still alive in Zurich, Switzerland, developed a method of fixing a plaque to the skull from which a probe penetrated deep into the brain and to which a wire from an electric stimulator might be attached. Animals were then permitted to recover from the operation; the small scalp wound healed completely around the plug. The probes into the brain were metal wires that were insulated except for the very tip, and so the point of electric stimulation was relatively small. The long, loose wire suspended from above permitted about as much movement to the animal as is permitted to a dog on a long leash. Electric stimuli could then be applied during the free behavior of the animal to see how localized electric currents might influence ongoing behaviors, and to see what responses might be evoked by stimulating locally at different brain points.

With these methods Hess discovered, in the cat, places where the basic energy-mobilizing responses of the heart, the lungs, and the preparatory musculature could be controlled. There was a large region where stimulation caused the animal to become prepared for fighting or fleeing, by an increase in heart rate, blood pressure, the rate of breathing, the amount of muscle tone, and so forth; and he found another large adjacent area where electric stimulation caused the opposite of all these actions so that the animal either became prepared for sleep or engaged in one of a number of restorative bodily processes.

The area where brain stimulation caused excitement and preparation for violent activity included parts of the posterior hypothalamus and the adjacent area of midbrain. The area where electric stimulation caused quieter bodily processes of rest and repair included the anterior hypothalamus and related sectors near the cortex.

At about the time I entered the brain-stimulation field, Neal Miller, my famous colleague who is now professor at the Rockefeller University, was the world's chief proponent of the drive-reduction theory of reward, a theory which he still occasionally professes. He was not only a proponent of this theoretical view, but he was embarked with Jose Delgado of Yale upon an enterprise that would bring the drive-reduction theory into close relation with the work of Hess. The outcome of these studies was to show that stimulation of the posterior hypothalamus and anterior midbrain also caused a psychologically valid aversive condition so that the animal responded as if it were put into genuine discomfort by the electric brain stimulation and as though it afterward became afraid of those places where the brain stimulus had been applied. At a later date Miller and his colleagues were able to show that electric stimulation within a center —which had for other reasons come to be called the "feeding center"—of the hypothalamus caused not merely the behavioral responses of feeding but also a psychologically valid drive, because the animal would not only eat if food were available, but by stimulation would be caused to work for food when food was absent.



The theory of drive reduction implies that learning occurs only when discomfort is relieved. But for an organism that seeks novelty, ideas, excitement, and good foods, this theory has its limitations.

It was a title of a Neal Miller talk which in 1953 first caused me to believe that brain stimulation caused not only this discomfort motivation which was so palatable to the drive-reduction theorists, but also perhaps some positive or hedonic motivation which would be the antithesis of their view. Neal Miller used the title "The Motivation of Behavior—" or perhaps he said "The Reinforcement of Behavior—Caused by Direct Electric Stimulation of the Brain." On first reading the title I thought for a brief moment that he would reward the animals by turning *on* the electric brain stimulus. When I read his abstract carefully and later heard the talk and saw his movies, I realized that he was causing an aversive reaction with his electric shock to the brain, an aversive reaction which it seemed to me might be caused even more easily if he would apply his electric shocks in any part of the nervous system, even including the forepaws or the hindpaws or the surface of the skin.

Very shortly after my misreading Neal Miller's title, through a variety of fortuitous circumstances, I was sitting at a table on which there was a large enclosure about 3 feet square with sides 10 or 12 inches high. It contained an albino rat, in which a probe was implanted to stimulate in one of the regions in or near the hypothalamus. A wire suspended from the ceiling connected the animal to an electric stimulator which I controlled by means of a pushbutton hand switch.

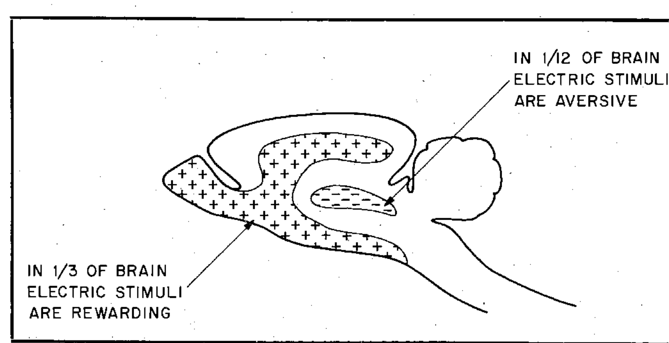
For reasons which in retrospect sound foolishly complex or ridiculously random (depending on your point of view), I had decided to stimulate the rat each time it entered one of the corners. It entered a first time, and I applied a stimulation which lasted approximately ½ second; the animal made a sortie from the corner, circled nearby, and came back. I stimulated a second time, not more than a minute or so after the first time. The animal made a second brief sortie, but came back even sooner. I stimulated a third time, and the animal stayed with an excited and happy look. (You may wonder how I know, but I have "gone among them and learned their language.") The animal kept staying and I kept stimulating, for I was already convinced that the animal had come back for more.

In successive experiments with the same rat, first it was caused to go to any corner of the enclosure selected by an independent observer, provided only that I would apply the brain stimulus immediately after the animal took a step in the right direction. Still later it learned to run to the pre-chosen arm of a T-maze in order to get to a terminal point where electric brain stimulation was applied; the animal eliminated errors and ran faster from trial to trial. Before I was done with this, my first animal, I was convinced that his behavior was directed not to mitigate aversive conditions but rather to instigate a positive excitation. The question, however, had to be asked whether this was an accidental observation or a significant feature of brain and behavior so that it might be taken as exhibiting a fundamental law about the direction of some behavior toward, rather than away from, the excitements of the environment.

Together with Peter Milner, who was at that time my instructor in brain-stimulation methodology, I endeavored to repeat the observation in another animal. This did not at first happen with ease. Some animals with probes directed at or near the original point seemed to favor the stimulus, but others seemed to respond as if it were negative rather than positive. It soon became apparent that careful mapping of the brain would be required to zero in on the critical areas and create a situation where animals could be prepared so that the basic characteristics of the phenomenon might be studied with a variety of methods and be understood.

For this purpose we used a Skinner box in which the animal could stimulate its own brain by depressing a lever. A Skinner box (named after Harvard's famous behaviorist, B. F. Skinner) is nothing but a small enclosure with a single manipulable device such as a lever, arranged in such a fashion that the animal, by manipulating the device, causes itself to be presented with a reward. The rewardingness of the reward is then measured by the rate of the lever response. For measuring the reward properties of the electric brain stimulations in different centers, Skinner's method was ideal.

We used a very small box and a very large lever, so that



Rewarding effects of brain stimulation are neither accidental nor confined to small, obscure brain centers. Furthermore, the parts of the brain where the best positive effects are achieved are clearly separated topographically from those points of the best aversive effects.

the random rate of pedal pressing was very high during the initial period. If the rate rose rapidly, so that the animal was eventually responding at rates of about one pedal-press per second, it seemed that there were quite clearly rewarding effects of the brain stimulation; if after the first one or two self-administered stimulations the animal stayed away from the lever, these zero rates could be taken as evidence of aversive effects of the electric brain stimulation. With this arrangement it was quite easy to map the phenomenon, and this has provided a basis for an easy reproduction of the rewarding brain stimulation, not only in a large number of experiments which have been performed in my laboratories at UCLA and the University of Michigan, but also in a large number of laboratories throughout the United States and the rest of the world.

"Let's exchange pushbuttons"—a good joke, but not likely to happen.

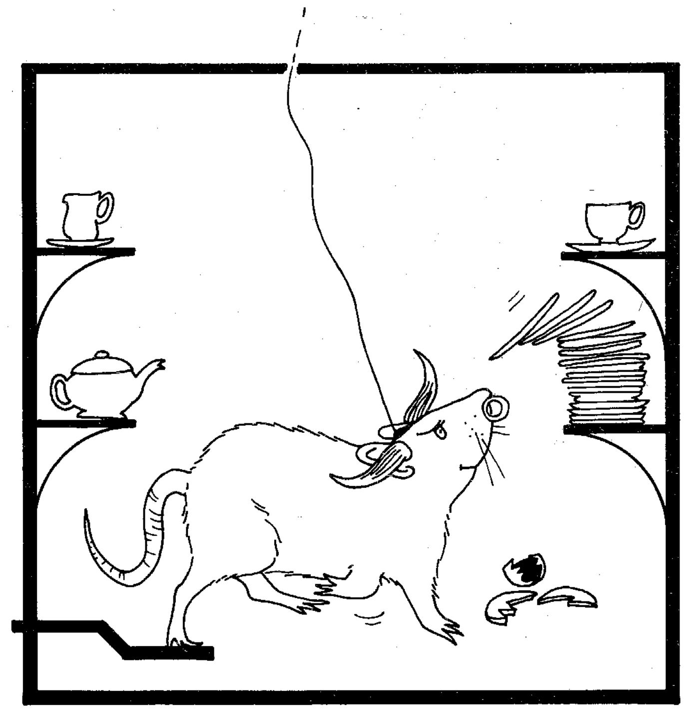
The self-stimulation experiments quickly resolved the most basic question: The rewarding effects of brain stimulation were neither accidental nor confined to small, obscure brain centers. One-quarter to one-third of the points tested yielded self-stimulation behavior to the degree that animals stimulated their brains at very high rates, ranging from one pedal-response every ten seconds in places where the effect was mild, to more than two pedal-responses every second in areas where the positive effect was very intense. Points where brain stimulation had a clearly aversive effect were far less numerous in the rat than were those with a positive effect. Only about one brain point out of every 12 tested caused a rate which was clearly depressed. Furthermore, the parts of the brain where the best positive effects were achieved were clearly separated topographically from those points of the best aversive effects.

The "rewarding" parts of the brain were all related to olfactory mechanisms and to chemical sensors. Among these were many areas where the brain itself seems to act as a detector of sex hormones and hunger factors carried in the blood. Mapping in other animals showed that the same parts of the brain were involved in rat, rabbit, cat, dog, monkey, and man. The experiments have also been conducted successfully in birds and fish, but the brains in these cases are sufficiently different from the brains of the mammals so that I would not want to say whether or not the same parts of the brain were involved in these cases.

The investigations of human patients with implanted electrodes have been carried out in the course of three different kinds of therapeutic procedures: those related to the severe mental psychotic ailments; those related to the cure by means of very small brain lesions of severe intractable pain, and by means of similar lesions of Parkinson's palsy; and finally there have been those involved in providing temporary relief for cancer victims who had previously been maintained on morphine. Reports of experience from human patients have often been confused, but they have been repeatedly positive; patients have stimulated themselves and have been maintained in far better and happier condition with less deterioration than was ever achieved with drug therapy.

Lest the younger of you fear for yourselves, and the older of you fear for your children, I do not foresee even in these times anyone so avant-garde that he will readily tolerate having his head drilled while having his ears pierced. Probes in the brain over long periods of time create scar tissues, and scar tissues become epileptic foci; the method will never be used except in cases where therapy is acutely required.

One of my friends who was rewriting Aldous Huxley's *Brave New World* and combining it with his own version of Orwell's *1984* brought his novel to an unlikely end by having his two main characters (still a girl and boy, although for some reason the difference was both less conspicuous and less important) both implanted with wires which come from under their long hair and into their pocket stimulators. He shyly suggests, "Let's exchange pushbuttons." I am of the view that it's a good joke, but it's not a danger.



Is a rat in a small Skinner box equipped with a large pedal like a bull in a china shop, where any kind of stimulation results in pedal-press behavior?

Back to the rats. The very rapid and intense pedal-response rates were not as immediately convincing to my colleagues as they were to me. People asked whether the brain stimulation might be simply arousing and exciting so that the large animal in the small box would be something like a bull in a china shop and that with such a big lever every behavior would be a pedal-press behavior. Other people suggested that even if there were some disposition on the part of the rat to come back for more stimulation, this might be something induced by the previous stimulus, so the animal, having an aversive aftereffect—something like an itching caused by the first stimulus—would come back and alleviate it by pressing a second time, and a third, and so forth, much in the way one scratches a mosquito bite.

To answer these questions—which suggested that perhaps the positive observations were only a sham and not the true substance of a positive reward—we ran a series of behavioral tests. In a maze, animals were trained to run from Start to Goal, where they received only brain shock for reward. Hungry rats ran faster for the brain shock than they did for food. They eliminated errors from trial to trial, thereby indicating that this was no bull-in-a-china-shop phenomenon. They ran purposefully without errors when first tested in the morning, 24 hours after the last previous brain shock, thereby disproving the argument that some aversive consequence of a preceding brain stimulus caused the animal to seek more.

At this point people began to concede that perhaps there was a set of mechanisms in the brain concerned with positive drives which competed with or were an adjunct to the control of behavior by negative needs and aversive mechanisms. But the question needed to be asked whether or not this was some junior partner to be in charge of entertainment and cultural enlightenment after the needs were all cared for, or whether this might be a basic force in behavior, a full competitor with pain and the basic needs.

The first experiment to answer this question showed that animals would cross a grid that administered painful shocks to their feet in order to get to a pedal where they could stimulate their brains. Animals took four times as much electric footshock when they were pursuing the brain reward as a normal hungry rat is willing to tolerate when it is in pursuit of food.

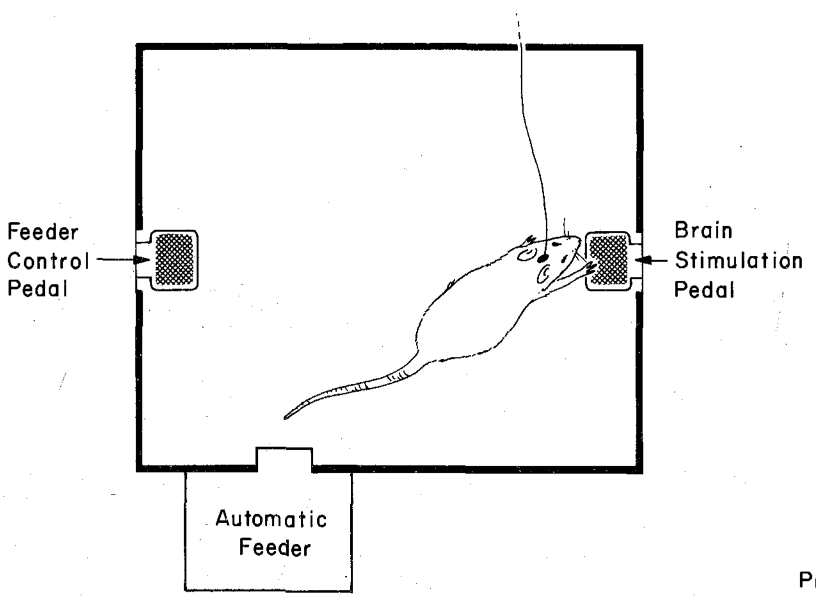
In another experiment rats, to all intents and purposes, gave up food to the detriment of health and underwent the danger of starvation in order to stimulate their brains. In this experiment, animals in a food pedal box were permitted 45 minutes daily (just time enough to get a meal that would maintain them in a healthy condition). When they were offered in this box the alternative of electric brain stimulation, they quickly renounced food almost altogether, and would have died of starvation but for the benign intervention of the experimenter. Other experiments have showed that rats would press one pedal as much as 100 times only for the sake of getting access to a second pedal with which they could stimulate their brains.

And in another set of experiments it has been found that one experience of this positively reinforcing brain stimulation can last for a very long time, having consequences for two or three days. Even a period of two seconds of brain stimulation has modified the animals' behavior for as long as seven days in the experiments of Carol Kornblith in our own laboratory. In her study, animals were stimulated briefly in the least preferred part of a large enclosure. Often this caused the least preferred place to become the most preferred place, or at least it modified greatly the amount of time which the animal spent in that part of the experimental chamber, and the change lasted for a very long time.

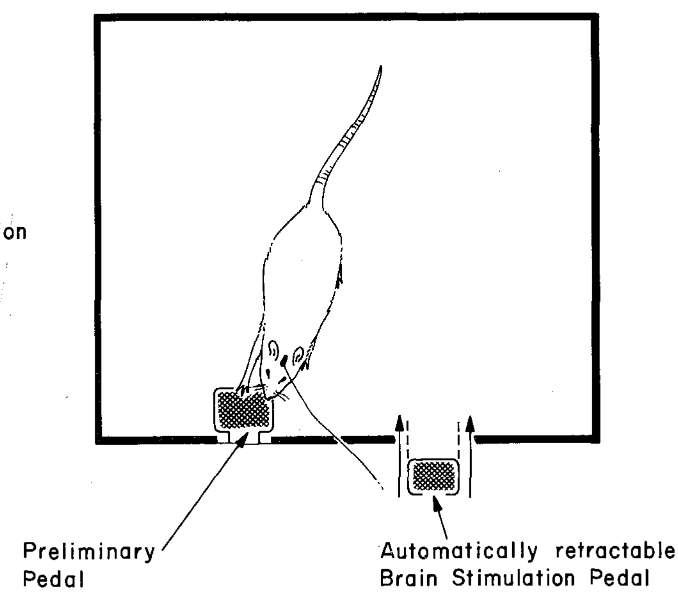
If we grant the very strong influence exerted by these positive brain stimulations on behavior, the problem arises of how these forces interact with negative, aversive influences, and what is their relation to basic drives such as hunger, thirst, and sex.

The problem of interaction between positive and negative mechanisms was first brought to the forefront by experiments of Professor Warren Roberts, now at the University of Minnesota, indicating that there were parts of the brain where electric stimulation simultaneously and paradoxically caused both rewarding and punishing effects. Either the animal would first work to turn the stimulation on, and once it was on, work rapidly to terminate it; or the animal would, if forced to remain in a place where stimulation was available, pedal-press very rapidly as if seeking to obtain it, but rapidly escape from the box if any escape could be found. In the latter case it appeared that an ambivalent and ambiguous stimulation was being applied, a simultaneous stimulus of opposing neurons which could not normally be activated at the same time.

In mapping the brain areas that yielded pure positive and negative reinforcement, and those that yielded this mixed phenomenon, we found that input pathways to some of the brain nuclei would yield pure reinforcement of one sign—*either positive or negative*—and output pathways from these same areas would yield just the opposite effect; stimulation of the nuclear masses themselves would yield mixed positive-negative behavior. This suggested

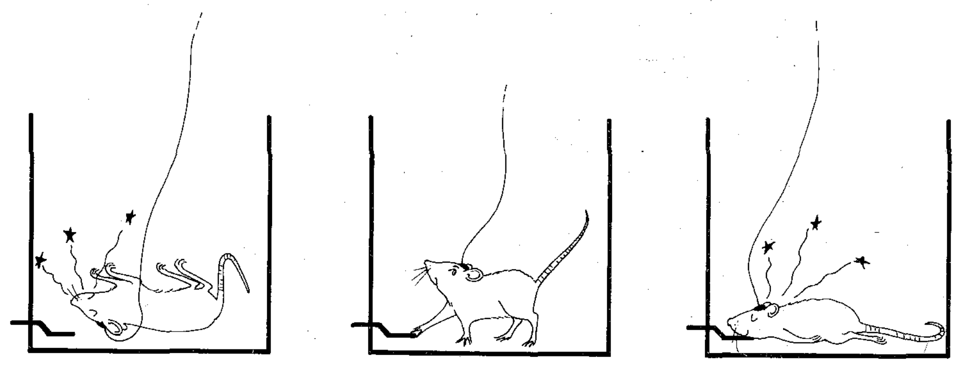


Hungry rats, offered the alternatives of food and positively reinforcing brain stimulation, quickly renounce food almost altogether.



Rats will press one pedal as many as 100 times to get access to a second pedal with which to stimulate their brains—demonstrating that they will work for the reward of brain stimulation.

Several stimulations applied to a pleasure center in an animal prostrated by alcohol will restore muscle tone and awareness, and the animal will then continue to self-stimulate his brain for as long as current is available. When the current is cut off, the animal sinks back into his stupor.



inhibitory relations within the nuclear masses between positive and negative neuronal mechanisms. In one test we found an inhibitory chain where stimulation which was rewarding in a first area inhibited behavior related to a second area whose stimulation was aversive; stimulation in the second area which was aversive inhibited behavior related to a third area where stimulation was rewarding. One was plus, two was minus, and three was plus again. And one inhibited two, and two inhibited three. Stimulation of the third area rewarded the animal directly, and also augmented rewarding behavior when it was induced by stimulation of other parts of the brain. Much to our surprise, it also augmented punishment behavior induced by stimulating aversive points or when that behavior was induced by more normal means.

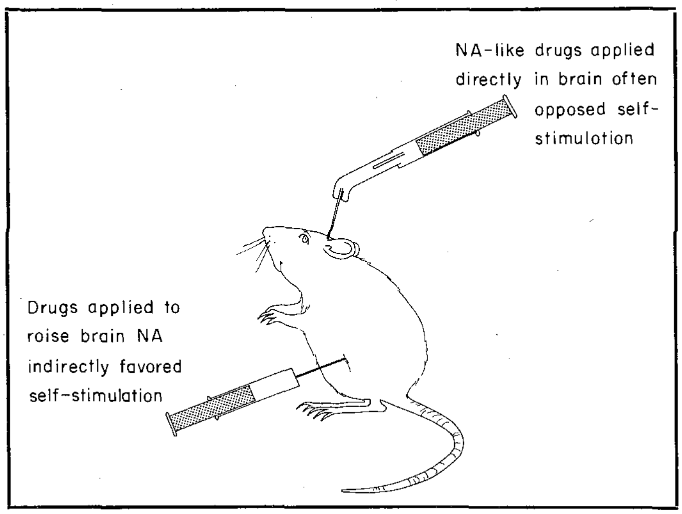
By these and further experiments we were led to the conclusion that mechanisms of positive and negative emotion interact with one another inhibitorially in the brain, in such a fashion that a predominance of one could inhibit the other, and vice versa. Furthermore, we were led to the conclusion that they might be acting through an area like "3." If 3 activity were augmented by rewarding stimuli and depressed by aversive stimuli, then 3 might derive an algebraic sum of rewards and punishments so that the animal would have a unitary state, somewhere between very good and very bad; and this would modify future behavior probabilities. This model generated interesting experiments which gave it some support, and it is still a viable theory held by me and some of my colleagues. But as with many good theories in the behavioral sciences, it is still in a state of limited probability.

The overlap of areas yielding positive or rewarding effects with areas where electric stimulation caused aversive reactions led us to wonder whether different drugs and different neuronal messenger chemicals might be involved in activating the two different kinds of neurons. As a first step toward testing for such differences, experiments were performed in which many different drugs were tested for the influence on self-stimulation behavior. The most interesting outcome of these tests was that use of a family of popular and intoxicating drugs repeatedly increased self-stimulation over escape behavior. Either these drugs didn't affect self-stimulation while abolishing escape behavior, or some of these drugs actually augmented self-stimulation behavior. We found that an animal which has been prostrated by a large dose of alcohol will lie flaccidly without muscle tone and yield no response when we apply aversive stimulation. Surprisingly, several stimulations applied through a self-stimulation electrode will restore muscle tone, and the animal will arise and self-stimulate for as long as the current is available. If the current is then turned off by the experimenter, the animal will quickly sink back into stupor and flaccidity.

Pentabarbitol, the favorite of sleeping pill enthusiasts, has effects remarkably like those of alcohol. Amphetamine, which activates many behaviors, also activates self-stimulation, and there are tests which strongly suggest that amphetamine has a particular relation to self-stimulation behavior. The relatively popular mild tranquilizers—Miltown and Librium—both also favor self-stimulation behavior over escape behavior; Librium and a family of drugs like it cause remarkable accelerations in self-stimulation behavior, even though this drug has a generally quieting effect on the animal.

It was surprising at first, but I suppose it should not have been, that the main drugs which are currently used to control agitation in the major psychoses—namely, chlorpromazine and reserpine—both have a highly selective effect against self-stimulation behavior. These drugs permit escape behaviors to continue in doses which totally abolish the rewarding effects of brain stimulation, or at least the resulting behaviors.

Studies at a more fundamental level have been directly concerned with those chemicals which carry messages from nerve to nerve. The primary messenger, so far as current knowledge and speculation is concerned, is acetylcholine, abbreviated ACH. The secondary messenger, again so far as current evidence and speculation is concerned, is noradrenalin, abbreviated NA. Drugs applied to the rat for augmenting ACH in the brain generally decreased self-stimulation; this led to the speculation that ACH might be more important as a messenger in the negative or aversive systems. Drugs applied to augment NA in the brain regularly increased self-stimulation, so this secondary transmitter might be more important in the positive or rewarding apparatus.



Noradrenalin (NA) is believed to be the secondary messenger in carrying information from nerve to nerve. When drugs which raise the level of NA in the brain are given to rats, self-stimulation is increased. However, when NA-like drugs are applied directly to the brain, the opposite effect occurs. Obviously, the chemical basis for positive and aversive responses is not simple.

Clear evidence that the problem would not be all that simple came from studies which showed a difference between direct and indirect augmentation of NA in the critical centers. Drugs which were applied peripherally to raise brain NA regularly increased self-stimulation. However, NA and NA-like drugs, when they were applied directly in the critical brain centers, often decreased or counteracted behavioral excitations which were caused by stimulating these centers. Furthermore, many recent studies have suggested the possibility that NA might be mainly an inhibitory chemical involved in counteracting rather than instigating neuronal activity.

Many of the drive-reduction theorists would be quick to jump to the suggestion that reward therefore might be mainly an inhibitory neuronal process, a process whereby one system of neurons utilizing norepinephrine would inhibit another set of neurons whose influence would be mainly energizing and perhaps even aversive. While this possibility is not totally unreasonable, I feel that our current knowledge of NA effects in the brain is advancing so rapidly that we must suspend judgment in this area. Progress is being spurred not only by our researches which connect NA to reward, but also by recent advances in many laboratories suggesting that NA and its close relative, serotonin, are very importantly involved in the control of sexual behavior and aggression; it appears possible that both sex and aggression are augmented by drugs which selectively depress levels of serotonin without simultaneously depressing levels of NA.

The paradoxical overlap of brain areas yielding radically different kinds of motivation, which first appeared in approach-escape tests, was further exhibited when the feeding centers in rats studied by Neal Miller and Jose Delgado were eventually studied with a view to understanding whether their stimulation would yield rewarding or possibly aversive effects. Before the rewarding tests were made, two important centers related to feeding were already known. These were roughly outlined topographic entities in the brain where the probability of affecting feeding behavior by destruction of brain tissues or by electric stimulation was at a highly likely level.

In one of these areas, known as the "satiety center," destruction of tissues caused animals to overeat and become obese. Careful studies of this phenomenon convinced scientists that this center was normally involved in the termination of eating behavior after the animal had become satisfied. Whereas lesions caused eating to go on and on, stimulation in or near this center when it was not lesioned caused eating behavior to stop.

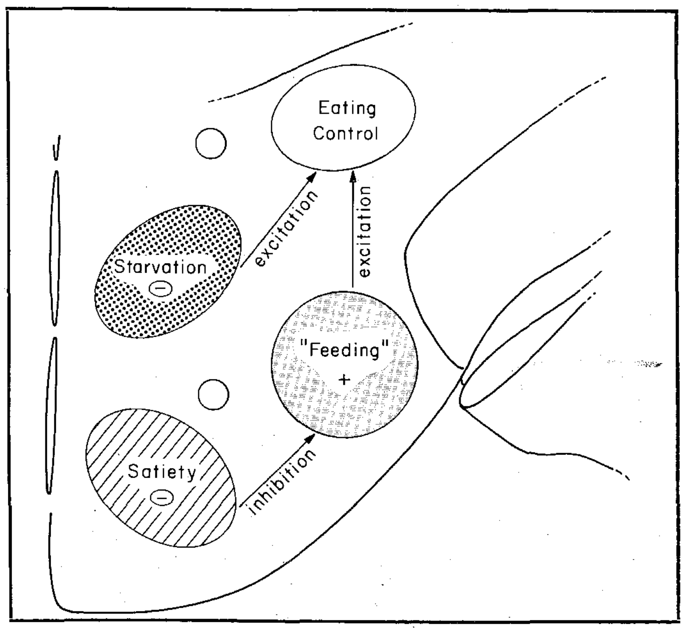
In a nearby area lies the second center related to feeding, where lesions cause the animal to stop eating altogether; unless the experimenter takes special care, these lesions cause the animal to die of starvation. Stimulation in or near these feeding center points causes the animal to eat voraciously during the period of stimulation.

Prior to the entry of our work into this field, I believe a relatively simple interaction was assumed. One view was that when neurons in the *lateral feeding center* became excited, a state of high drive (an aversive condition for the organism) goaded the animal into eating behavior. The ingestion of food, on the other hand, would be detected by receptors in the mouth and in the stomach, and would also modify the chemical state of the blood, and this information would be processed and projected to the *medial satiety center*, where it might be supposed to cause a positive state of the animal, and to inhibit the aversive lateral drive mechanism.

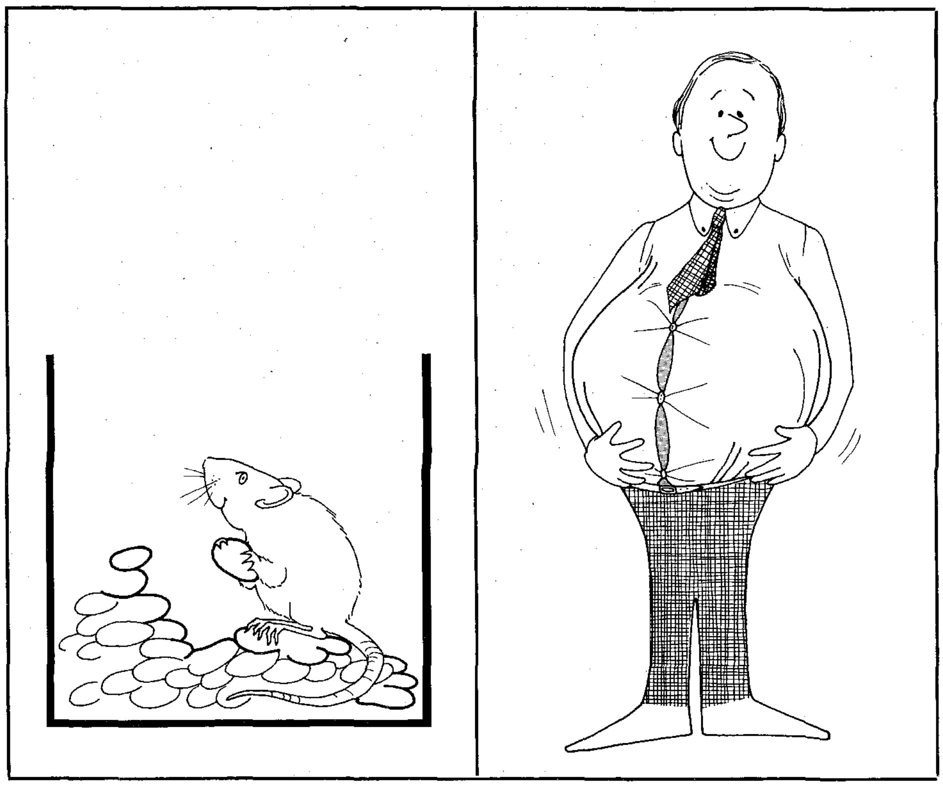
One of the most surprising findings to date, and one which has dramatically changed the concept of the control of eating behavior, and therefore the control of obesity, was the discovery that stimulation of the feeding center was among those yielding the strongest self-stimulation behavior and on all of our measures the strongest kind of positive rewarding effects. As you might or might not guess, the electric stimulation that caused satiety—and therefore was expected to cause bliss—did not induce any positive reactions at all, but rather turned out to be one of the areas where electric stimulation produced prompt aversive or withdrawal reactions.

So we no longer see hunger as a simple aversive mechanism, or as an aversive mechanism at all. Instead we would say that eating is a positive feedback mechanism. That is, eating behavior, once triggered, tends to continue. Eating begets eating, and once it gets going it has a marked tendency to intensify itself. This is experienced from the point of view of the Epicurean subject as a very satisfactory state of affairs. However, it can be a very sad state of affairs for the person who wants to lose weight and has weak limiting centers. Because food engenders a self-reactivating drive, we now know that the main cure for this (main) kind of obesity is simply to get and keep the patient away from food stimuli.

We conceive of two limiting centers brought to bear on the feeding process. One is the satiety center, which meters the input in one way or another, and gradually or abruptly converts the process from a rewarding one into a neutral and finally into an aversive one, so that eating which was rewarding at the beginning is negatively reinforcing at the end. We are now convinced that there is another center which comes very little into play in the white albino rat, or in the majority of the American college students, and this we might think of as a starvation center. We have only recently found intimations of this; it is not too far displaced from the other two long-known topographic entities related to feeding. Within this area electric stimulation causes eating behavior, but in this



It appears that there are two limiting centers bearing on the feeding process. The satiety center meters the input and converts the process from rewarding to neutral to aversive. A starvation center produces an aversive mechanism when the animal's food supply reaches a danger level.



Creatures with hoards—the rat's food pellets or a man's fat—have been able to survive the lean years. The animal that waits to eat until he is starving is always living on the edge of demise.

case the stimulation is either neutral or aversive in its effects on behavior.

We now conceive of hunger as being instigated either by accidental encounters between the subject and the succulent stimuli emanating from the food, or, barring that, eventually triggered by an aversive mechanism brought into play when the animal reaches a danger level so far as food supplies are concerned. In either case, once the eating mechanism has been triggered, it moves forward under its own power and would go on indefinitely if other extraneous control devices were not brought to bear. The satiety mechanism of the medial hypothalamus represents precisely this kind of a control device.

This research formed the model for a set of researches on the other drives; now a drinking center and a sexual center have been added to the array of vague entities in the lateral hypothalamus. In these regions other consummatory behaviors are triggered by electric stimulation, and a common denominator among all of the drive centers so far discovered has been that the electric stimulations there are also yielding positive rewarding effects on behavior.

So we assume that positive emotional mechanisms are indeed involved in the control of behavior—but why do they exist? Why were animals not just as fit to survive if they were nudged ahead by their pains and their deficits?

I believe the clue lies in our analysis of feeding mechanisms. Why does the animal keep on eating after the starvation trigger is gone? Why does the animal start eating even if he is not starving, but is only stimulated by the sight or smell or taste of food? The answer could well be that creatures with hoards, whether these were laid up at home as the rat hoards pellets in his home cage, or laid up within the animal's body as man often keeps his pounds of fat on his midriff, were able to survive the lean years. Therefore, in relation to certain objects not so plentiful that they would be available when needed, mechanisms for hoarding promoted the survival of the species. The abstract animal (who never lived so far as I can make out in phylogenetic history) who waited until demise was imminent and then began looking to satisfy his need was on the edge of demise at all times. You might say he was "just" living. His lucky cousin, who is no abstraction, stocked up his larder during the fat years, in preparation for the lean ones, and you might say he enjoyed it. Instead of "just" living, the positive reinforcement creature was *really* living.

The New Engineering Labs

Still hard work, but a lot more challenging.

The laboratory is clearly the foundation of experimental science and engineering, yet for the student it is also a major source of disenchantment. The reasons are basically the lack of flexibility and creativity in laboratory courses, compounded by the long hours the student must spend there.

The problem for Caltech and other universities that aim to produce outstanding scientists and engineers is how to train students to conduct scientific experiments—capitalizing on their inherent interest in technical tinkering—without dulling their enthusiasm for research.

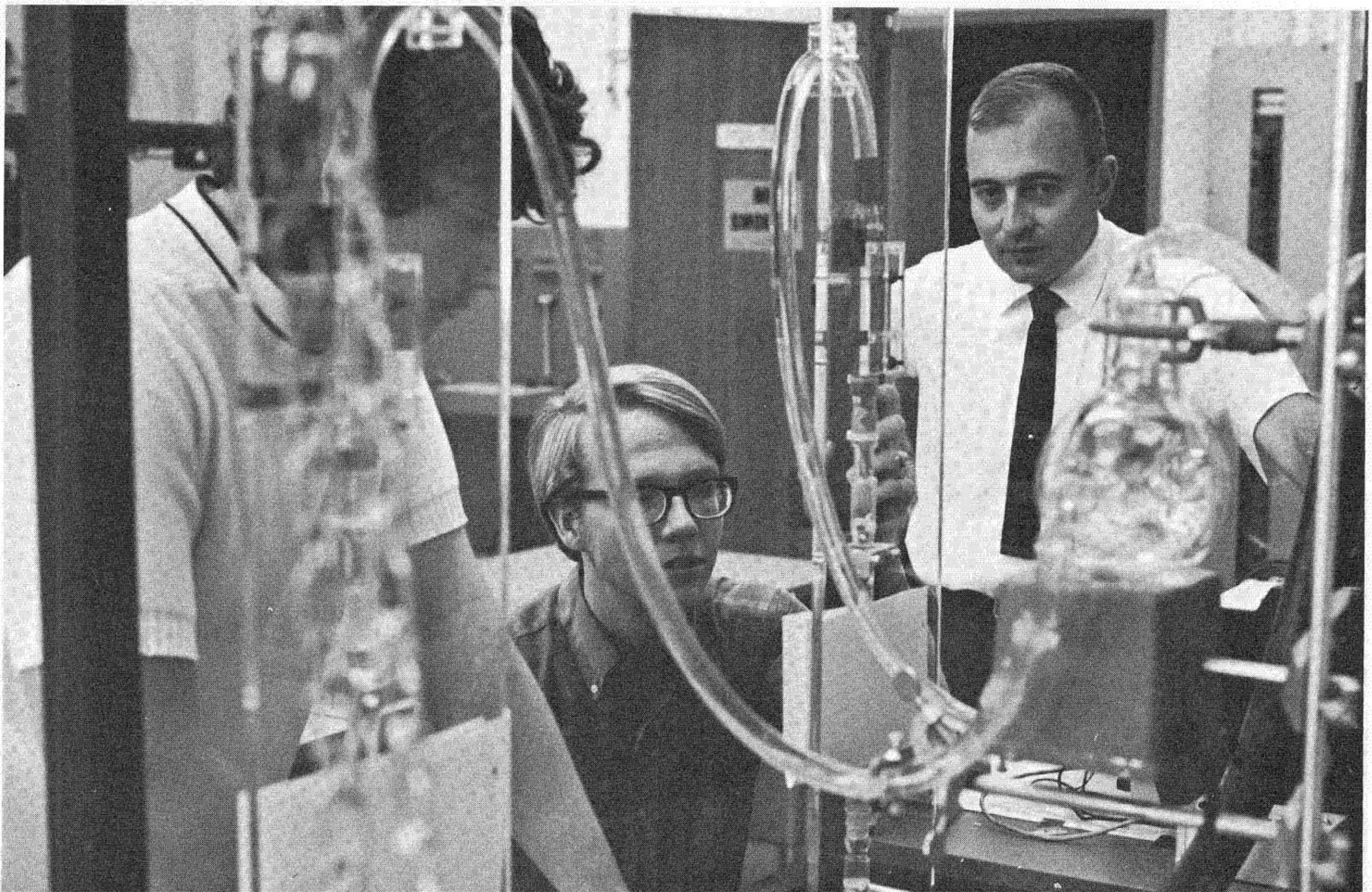
Three undergraduate courses at Caltech that provide some promising new approaches to laboratory instruction are EE 91 (Experimental Projects in Electrical Engineering and Applied Physics), which is taught by Floyd Humphrey, associate professor of electrical engineering; E 5 (Laboratory Research Methods in Engineering and Applied Science), a freshman course taught by Bradford Sturtevant, associate professor of aeronautics, in cooperation with seven other faculty members; and ChE 10 (Chemical Engineering Systems in Chemistry and Chemical Engineering), a freshman course taught by Frederick Shair, associate professor of chemical engineering.

Humphrey's EE 91 course is made available to a select number of seniors who have shown both the enthusiasm and self-discipline necessary for original experimental work.

Students learn to recognize their research interests in this laboratory course because they are required to create their own experiments. Humphrey gives students a week at the beginning of the course to write a proposal for their projects. "They learn that you either write your own proposal as an experimenter—or you do what someone else tells you to do," he says.

By requiring projects to be well-defined, Humphrey teaches students to formulate a unit of work and tailor their objectives to the time and facilities available. They also learn to make

Ronald Bohl '72 (left) and Allan Ferrand '73—with course instructor Frederick Shair—study the multiplicity of steady states in a nonlinear chemical reaction system as part of their E 5 project.



compromises in the design and depth of their experiments and to justify the use of various instruments, just as they would in any professional laboratory.

Facilities are available for experiments involving electronic circuits, electronic circuit elements, cryogenics, lasers, magnetism, optics, microwaves, plasmas, and electronic properties of semiconductor materials.

Although Humphrey always makes help available, students must learn to recognize their difficulties and know when to ask for assistance. Students are required to give a written and oral report on the results of their research.

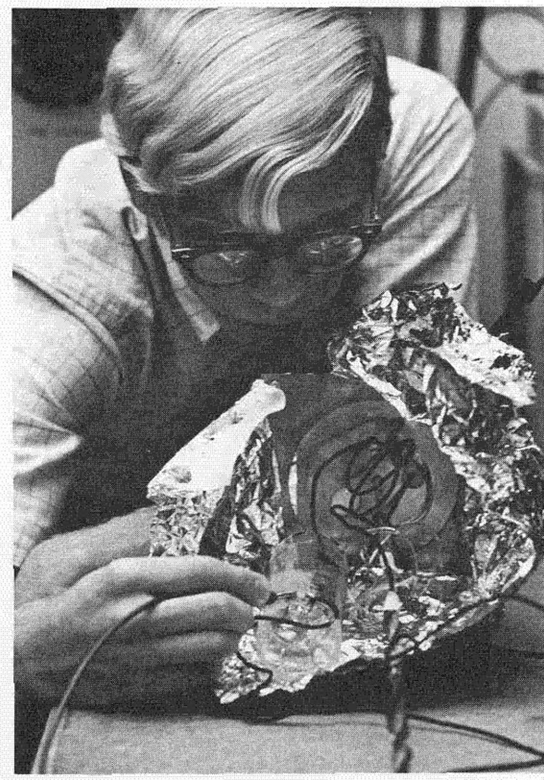
"But," says Humphrey, "we're not interested primarily in the results; it's the student who wants to know the answer. We want him to do well whatever his particular experiment is."

In the E 5 lab, a two-term course, freshmen are given a choice of experiments in fluid mechanics, nuclear engineering, digital communications, wave propagation, heat transfer, gas dynamics, materials science, solid state electronics, and chemical engineering.

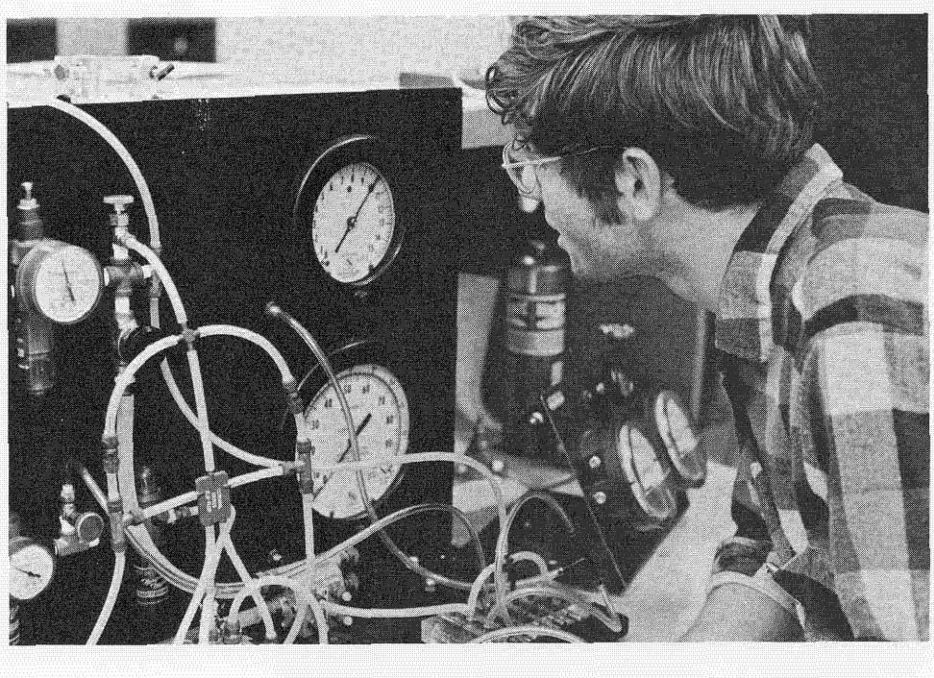
The purpose is to give each student a feeling for the type of research he will be doing in the field of engineering or science he may eventually choose. Each student does four experiments that require two weeks of laboratory work apiece. Although the experiments are set up by instructors, students are given the widest opportunity possible, considering their level of experience, to make decisions.

Other instructors in the E 5 course besides Sturtevant are Fred Culick, associate professor of jet propulsion; Edward Zukowski, professor of jet propulsion; Mahlon Easterling, a visiting professor from JPL; David Welch, associate professor of engineering design; Rolf Sabersky, professor of mechanical engineering; Humphrey; and Shair.

In addition to providing some chemical engineering flair for E 5, Shair has been helping to develop the ChE 10 course, which was initiated by William Corcoran, professor of chemical engineering. During the past year students studied the artificial kidney. After several tours of hospitals and manufacturing plants, students chose one aspect upon which to do a term project. Some students conducted experimental studies of new membranes provided by a company. Other students consulted with physicians and helped to formulate experimental programs aimed at developing new and useful information. Emphasis was placed on the reason for doing an experiment along with an appropriate error analysis. In this course, each student participated in an oral presentation as well as being required to outline and write a formal report.

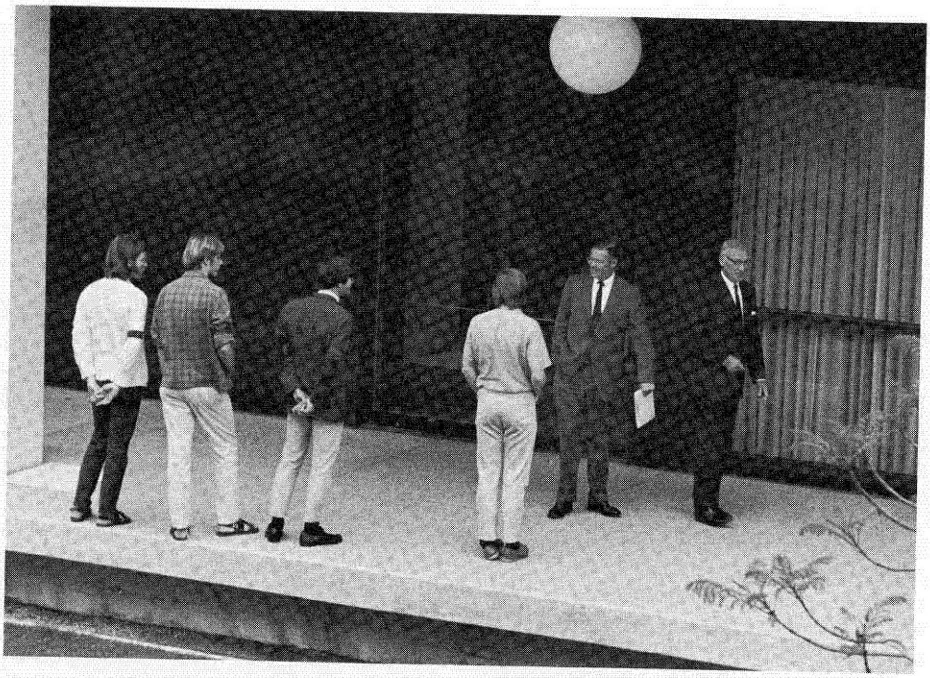


Neil Erickson '70 makes final connections on a capsule that will be taken down to 0.1 degree Kelvin for his cryogenic experiment in EE 91.



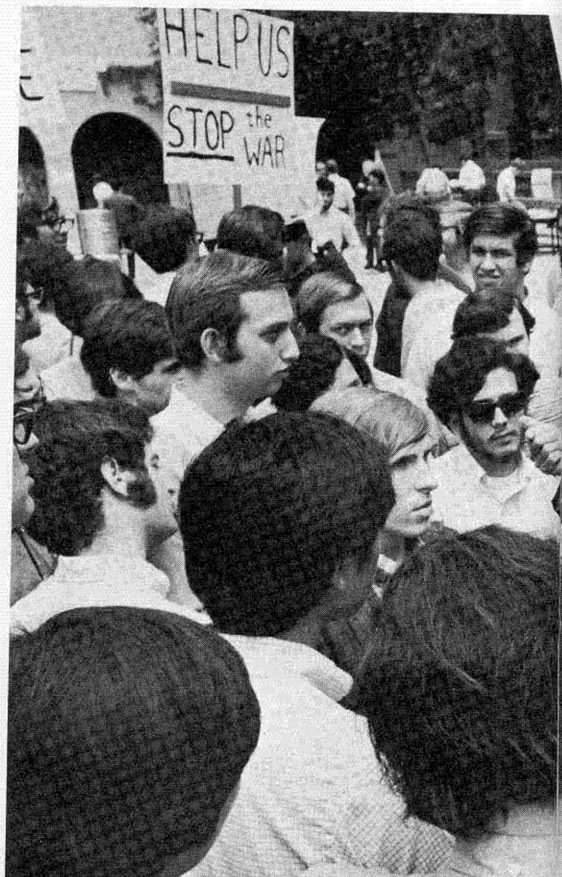
Rand Waltzman '73 tests a fluidics oscillator as part of his work in E 5.

FAMILY CONFERENCE



Robert McNamara and trustee board chairman Arnold Beckman

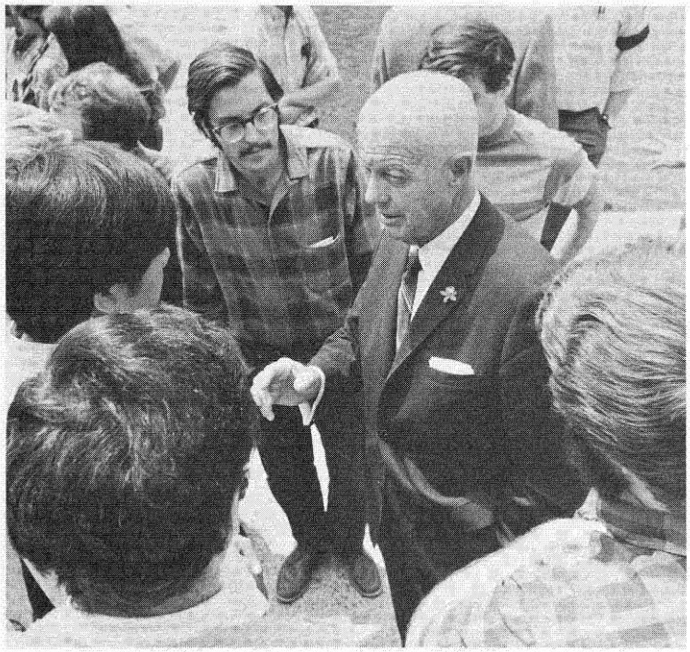
The May 14 meeting of the Institute's national board of trustees became the occasion for formal and informal conversations among trustees, students, and faculty about the Caltech community's response to the Indochina War. The largest meeting took place when several hundred students waited for the board to break for lunch, then buttonholed the trustees for what some expected to be a tense confrontation. As the pictures on these pages show, the trustees did their share of listening as well as talking at what turned out to be a generally friendly encounter. That afternoon, by prearrangement, five students took part for several hours in the board's discussions of how Caltech might influence public policy. Then that evening five trustees stayed for more talk at dinner in the student houses. And as often happens when people talk and eat together, they separated with heightened respect for each other—no small achievement nowadays.



Thomas Watson

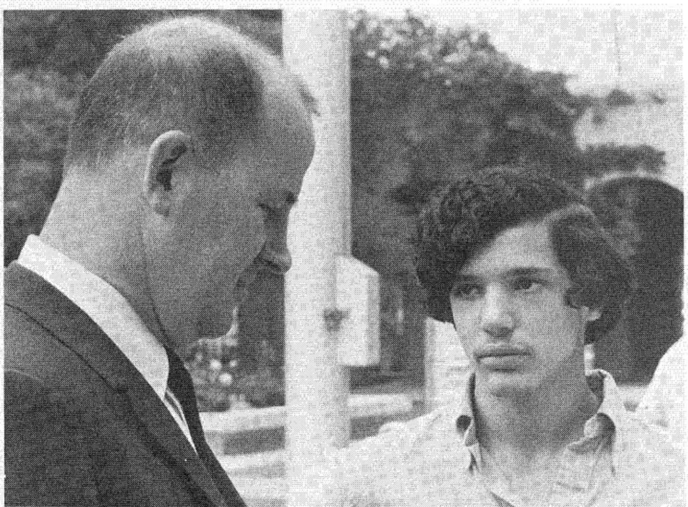
William Zisch

Henry Singleton



Howard Vesper

Ruben Mettler



The Month at Caltech

No More Frosh Camp

Caltech's class of 1974, in addition to including 31 women in its ranks, will have the added distinction of being the first since 1926 to have no New Student Camp. Instead, there's going to be New Student Orientation, and it's going to be right on campus.

Since January a committee of faculty and students has been meeting to evaluate the Institute's approach to orientation, and switching sites back to the campus was one of the early suggestions. It grew out of the thought that the new students would benefit from learning their way around the Institute and the Los Angeles area as soon as possible.

"When we came up with the possibility of shifting the locale, a whole lot of other new ideas opened up," says David Wood, associate dean of students and the man in charge of freshman orientation. "We're going to see how some of them work."

The orientation program originated back in 1919 when the Caltech YMCA sponsored an evening reception in honor of the freshmen. Eventually that expanded into a day-long, on-campus briefing that still later became an overnight camp-out. The Institute took over freshman camp in 1946 under the direction of Dean of Freshmen Foster Strong. For the next 23 years all new students went to the mountains for two and a half days. There they were offered a melange of speeches, athletics, and entertainment to facilitate their getting to know some of Caltech's traditions and expectations, each other, and some of the people they were likely to run into—or at least hear about—after they got back to campus.

The long weekend wound up with a formal reception at the president's house after everyone was back in Pasadena. But in the fall of 1969 President and Mrs. Brown replaced that part of the program with a Sunday morning swimming and pizza party.

This year campus tours are on the agenda early on the first day of orientation, Thursday, September 24. The program will still include talks about academic and personal life at Caltech and the Honor System, but most of the usual formal speeches are being eliminated to give the students more time to get acquainted with each other.

To demonstrate the broad spectrum of research on campus, a dozen faculty members will offer 30-minute seminars over a two-hour period on Thursday afternoon. Each will describe his particular research activities and answer questions, and each freshman will be urged to sample two or three of these presentations.

Each faculty counselor will be encouraged to invite his group of students to his home for dinner on Thursday evening. Since, as far as possible, these counselors will be the regular freshman advisers, many of the new students will be dealing from the beginning with the advisers they will have throughout the year.

The president's party will again center on swimming and pizza, but this year it will be on Friday afternoon and will be an integral part of the orientation program.

A theater party is planned for Friday night, with a repertory company from Los Angeles to present a play on campus. Plans are being made for inviting girls from other schools who are also in the midst of orientation activities to attend. There will be a bus tour of the Los Angeles area on Saturday, and topping it all off—at least for those who choose to buy their own tickets—will be the baseball game at Dodger Stadium on Saturday night.

New Chairman

Robert B. Leighton, professor of physics and staff member of the Hale Observatories, has been named chairman of the division of physics, mathematics and astronomy at the Institute. On September 15, Leighton, an alumnus ('41, PhD '47) and a member of the Caltech faculty for 23 years, will succeed Nobel laureate Carl D. Anderson, who has been chairman since 1962. Anderson, with whom Leighton collaborated years ago in using cosmic rays for studying atomic particles, will resume research.

A physicist who has also made many contributions in astronomy, Leighton was principal investigator of the Mariner spacecraft television experiments that returned the historic closeup photographs of Mars. With Caltech planetary scientist

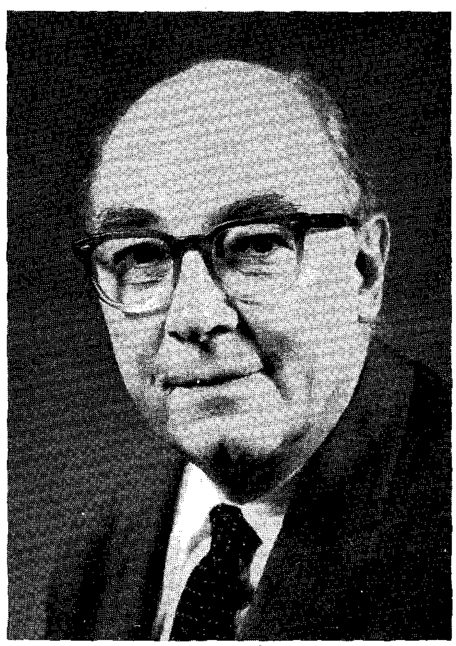
Bruce Murray he suggested that the martian polar caps are composed of dry ice, not water ice.

Working with Caltech physicist Gerry Neugebauer, Leighton launched an infrared survey of the sky and discovered stars with surfaces as cool as that of the planet Venus. He also found oscillating waves and giant convection cells on the sun's surface. In earlier research in atomic physics, he collaborated in discovering new subatomic particles and their decay products.

Many of Leighton's discoveries were made with instruments that he designed and built; these include the first cloud chamber to operate from a balloon at high altitude; a 62-inch infrared telescope; and a unique Doppler shift and Zeeman effect camera. He has also built a large telescope at his home, and he ground its 16-inch mirror himself.

Leighton is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. In 1967 he won the American Institute of Aeronautics and Astronautics space science award for his work with the Mariner television experiments. He is author of the textbook *Principles of Modern Physics* and co-author of *The Feynman Lectures* physics textbooks.


New chairman Leighton


Retiring chairman Anderson

JPL and the Campus

A faculty-Jet Propulsion Laboratory committee has recommended that closer ties be developed between JPL and the campus. The study committee, appointed by Harold Brown in June 1969, was composed of seven Caltech faculty—with biologist Norman Horowitz as chairman—three senior staff members from JPL, and two observers, one an undergraduate and the other a graduate student.

Caltech founded JPL in the late 1930's for rocket research and has managed JPL for NASA since 1958. The committee advocated continuation of the relationship as long as JPL's scope and style are appropriate to a university-affiliated laboratory, and as long as meaningful interactions with the campus exist. It also said that JPL must enrich the educational and research activities of Caltech, primarily through involvement of students as well as faculty in JPL projects.

During the past two years, about 20 percent of Caltech's faculty have been directly involved with JPL in a variety of ways—as principal investigators on spaceflight experiments, on joint research projects at JPL, in JPL-sponsored campus research, on student thesis research at JPL, and as consultants on special problems.

In 1968 Caltech and NASA reached an agreement that provided JPL with increased flexibility to work with the Caltech campus and with other universities. At that time Caltech was called upon to regard its stewardship of JPL "not only as a contract but as a public trust and that NASA, for its part, exercise restraint in those administrative matters which is consistent with the recognition of Caltech's function as a trustee for the university community." At present JPL has research contracts with 27 other universities and research institutions.

The committee's report urged that JPL be as open and unrestricted as possible and that no classified work be conducted there except in special cases for which an urgent national need exists and for which approval is given by Caltech's president after consultation with the faculty board. JPL has reduced its classified work from essentially 100 percent 15 years ago, when it was operated by Caltech for the Army, to less than 1 percent now.

The 1968 agreement also authorized JPL to seek sponsorship for work at JPL from federal agencies other than NASA. About 2 percent of JPL's work now is in non-space areas—such as medical engineering, transportation, and ecology—with funding primarily from NASA. However, support for some tasks is now coming from the National Institutes of Health, Department of Transportation, and the National Science Foundation.

Among the committee's proposals was one urging that the Caltech faculty committee on graduate study develop policies and procedures for graduate students who wish to do thesis work at JPL and for JPL employees who wish to do part-time graduate study toward a degree at Caltech.

Bing Professorship

The Bing family has endowed a professorship in behavioral biology at Caltech. Peter Bing, MD, and his mother, Mrs. Anna Bing Arnold—who is a life member of The Associates of the California Institute of Technology—made the gift through the Bing Foundation.

Robert Sinsheimer, chairman of the biology division, says about the gift that "We in biology believe we have a vital role to play—to bring to bear the power of natural science upon the essential problems of human health and behavior. We now have confidence that the time is at hand for major developments in these subjects."

The Bing endowment brings to eight the number of named professorships at the Institute: two in theoretical physics, and one each in aeronautics, biology, behavioral biology, chemistry, jet propulsion, and psychobiology.

Awards

Two faculty members are among 50 scientists who were elected to the National Academy of Sciences in April. Robert B. Corey, professor emeritus of structural chemistry, and Sterling H. Emerson, professor of genetics, bring to 35 the number of Caltech faculty in the academy.

Corey's work in the early 1950's is credited with laying the groundwork for current widespread studies of the detailed structures of proteins. Through X-ray crystallography he determined the interatomic distances and group configurations of amino acids and other organic substances related to proteins. Later, collaborative studies with Linus Pauling explored conformations that may be physically possible for polypeptide chains. Corey also designed some of the first accurate, space-filling molecular models of proteins. He was one of the pioneers in the study of biologically important macromolecules, a field that has now become one of the most exciting and rewarding fields of science.

A graduate of the University of Pittsburgh in 1919, Corey received his PhD degree in 1924 from Cornell University, where he taught chemistry until 1928. For the next nine years he was on the staff of the Rockefeller Institute and then came to Caltech in 1937.

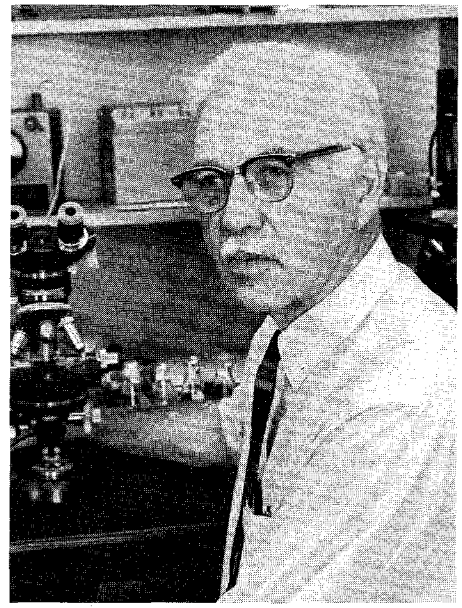
Emerson, a former president of the Genetics Society of America, is recognized for significant contributions to the study of genetic recombination and conversion in a number of organisms. He has made notable advances to the development of the translocation interpretation for the cytogenetic behavior of the evening primrose. His derivations and analyses of slime mutants in *Neurospora* have provided a system for investigating genetic transformation in the fungi; through his experiments with the effect of sulfonamides upon the growth of *Neurospora,* he has discovered a biochemical model for a type of hybrid vigor: one-gene heterosis. Emerson's recent experiments with the fungus *Ascobolus* have provided new quantitative data on intragenic recombination.

After graduating from Cornell University in 1922. Emerson did further study at the University of Michigan. He received an AM there in 1924 and a PhD in 1928, after which he came to Caltech as assistant professor of genetics.

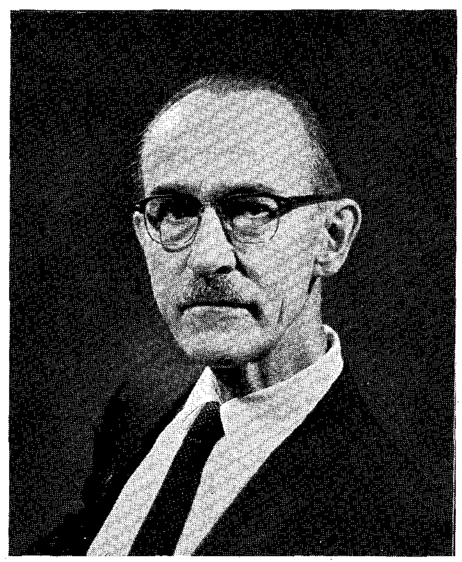
Francis H. Clauser, chairman of Caltech's division of engineering and applied science, was elected in April to the National Academy of Engineering. He was cited for his "innovations in engineering research and education."

Clauser's research includes work on the design of aircraft and space vehicles, and on compressible fluid flows, turbulence, magnetohydrodynamics, boundary layers, and the behavior of nonlinear systems. In education, he has been an innovator in establishing a more comprehensive base for undergraduate instruction in engineering and science. He feels that engineers today must be more science-based, more broadly educated, and more socially conscious than they used to be.

After taking his BS from Caltech in physics in 1934, Clauser, who is Clark Blanchard Millikan Professor of Aeronautics, received his MS in mechanical engineering in 1935 and his PhD in aeronautics in 1937. He spent nine



NAS member Emerson



NAS member Corey

AAAS fellow Horowitz

NAE member Clauser

years at Douglas Aircraft Company before going to Johns Hopkins University in 1946 to found its department of aeronautics. Before returning to Caltech last year, Clauser was vice chancellor for academic affairs at the University of California at Santa Cruz, where he went in 1965 to establish the school of engineering.

Norman H. Horowitz, professor of biology and head of the bioscience section at the Jet Propulsion Laboratory, has been elected a fellow of the American Academy of Arts and Sciences. Horowitz is noted for his work in biochemical genetics. Through investigation of the enzyme tyrosinase in *Neurospora*, he has sought to understand the adaptive differentiation represented by the formation of a fruiting body in *Neurospora* in response to certain environmental conditions. As a space biologist he has done analyses of the photographs of Mars taken on JPL's two 1969 Mariner missions, and is working on the design of automatic experiments to be sent to the planets on unmanned probes. Horowitz received his PhD at Caltech in 1939 and has been a member of the Caltech faculty since 1947.

Lepton's-Eye View

Physics 10, an elective for freshmen taught by Robert Leighton, is designed to let students get more deeply involved in some of the topics covered in their freshman physics course. This year one of Leighton's students, Elliot Tarabour, penetrated so far into the subject matter that he was able to write this fable from the point of view of the elementary particles themselves.

I, Lenny the Lepton, am serving a 99 nanosecond term in San Quantum prison. I was arrested and convicted of having a strong interaction with a K-meson before she was of the age of consent. But my story is not what I'm writing about now. What is more important is the story of my former cellmate, Eddie the electron. I am writing in the hopes that his story may give you beings of the large world a little insight into our little world, and that you may realize that we, although many orders of magnitude smaller, have emotions and feelings just as real as yours. And so I present to you . . .

THE ILL-FATED LOVE
STORY OF
EDDIE THE ELECTRON

One day as Eddie was doing his usual job, patrolling as a 2p electron, a photon struck his atom. This was not an unusual occurrence, but it was Eddie's turn to be promoted so up he jumped to a d-orbital. As he was orbiting, he saw something that made his heart leap. There in a nearby anti-atom was the most beautiful positron he had ever seen. The next orbit around he waved to her and she waved back. Oh, this was too much for him! The photon was soon emitted and he dropped back into his usual spot in the p-orbital. But he was a different particle. In those few fleeting pecoseconds that he saw her he felt something strange and wonderful. Eddie was in love.

From that day on he could do nothing right. He just dreamed of the day that he would have the bond energy to break away and be with his beloved positron. He applied for valence liberty but got turned down. His behavior was so erratic that he was finally called before the board of electrons to be reproached for his behavior.

"Eddie," said the head electron, "You've always been a good stable particle, but lately we have reports that you've been acting rather irregular. Do you have any explanation for your actions?"

"Well sir, it's just that the job is so Bohring." He hesitated for a nanosecond and then said, "If you must know the truth, I'm in love with Patsy the positron from that anti-Lithium atom. I know this is a serious violation, and you can do anything to me—annihilate me, make me become a lowly s-electron, even cut off my Schroedinger. I don't care; I'll still love her."

"But she's from the wrong side of the particle tracks."

"I don't care; there's some strange attraction between us."

"We will consider your case now.

We'll call you when we reach a verdict."

Eddie felt dejected. He thought the board of electrons would react negatively to him. He became very depressed and began writing poetry.

6800 A. is red
4000 A. is blue
The strongest force that is
Exists from me to you.

Oh Patsy, I'd climb the highest
energy barriers
I'd swim through the highest waves
Just to be in the positiveness of your
field
But alas, my love,
Fate has decreed us to be
apart, so all we can do is dream.

The more Eddie wrote the more depressed he got. He started drinking. Then one day down at the local H-bar an Omega minus made a crack about him being so stupid as to fall in love with a particle that would annihilate him if they came in contact.

Eddie got riled and made a foolish mistake. He said, "I am going to hit you right in the head with a momentum of $1.8024739424 \times 10^{-23}$ gram-meter/second." If he hadn't been so exact, he would have avoided a lot of trouble. But by doing so, he specified his position and momentum more accurately than is allowed by the law.

Eddie was arrested for violating the Heisenberg Uncertainty Principle—a serious offense. As he was brought into court, the crowds were screaming, "Make him walk the Planck."

Well, the court sentenced him to 20 nanoseconds in San Quantum—where I met him.

It was in the prison library that he read about a new theory—that by concentration electrons can develop enough energy to break the bonds that hold them to the nucleus. He suddenly showed a great deal of interest, and tried to get himself excited enough to escape. He worked diligently and finally was ready.

When he left, there was a tear in my eye. I can still hear his last words.

"Remember, Lenny," he said, "love is as fundamental as a quark." And then he disappeared.

That concludes the story of Eddie and his love affair. He did find his beloved Patsy, and they came together and annihilated each other in a blazing white photon. And if you ever see a certain gleam in your special someone's eye, chances are it is the photon that Eddie and Patsy created by their final act of love.

Retiring This Year

Ian Campbell

Ian Campbell, research associate in geology who becomes professor of geology, emeritus, in July, received his AB from the University of Oregon, his AM from Northwestern University, and his PhD from Harvard. He taught at Louisiana State University and at Harvard before coming to Caltech in 1931 as assistant professor of petrology.

"During the 28 years of his Caltech residence," says Campbell's Caltech colleague, Robert Sharp, professor of geology, "he established a track record that will probably never be equaled."

Recalling those years, Campbell says, "When I was still in Pasadena, I used to say that I hoped my obituary would include the fact that, almost single-handedly, I succeeded in getting the coat-and-tie rule abrogated for luncheons at the Athenaeum during the summer." Those who have been around Caltech long enough agree that inserting the opening wedge in behalf of informality at the Athenaeum was no small accomplishment. Those who know Campbell are not surprised that he was the man who did it.

When he left Caltech in 1959 to become Chief of the California Division of Mines, Campbell was professor of petrology; he had spent ten years as associate chairman of the division of geology, two years as its acting chairman, and then seven years as executive officer for the division. He had served Caltech as a whole and the Pasadena community in numerous capacities. He had been a member of the United States Geological Survey and was a consulting economic geologist to oil, mining, and utility companies. He had also become one of the country's foremost authorities on nonmetallic deposits. One of Campbell's early important professional expeditions came about as a result of his interest in the nature, origin, and history of some of the continent's oldest basement rocks. In 1937 he and John Maxson, Caltech alumnus and former staff member, organized and led a Carnegie Institution-Caltech boat trip down the Colorado River to study pre-Cambrian rocks of the Grand Canyon.

In the last ten years the California Division of Mines has become the Division of Mines and Geology, and Campbell, before his retirement in October 1969, was not only its chief but also State Geologist. Traditionally, the division has been concerned with stewardship of the geologic resources of the state, both mineral and nonmineral, and with making information about all phases of geology and mining in the state available to the public.

Under Campbell's leadership it has greatly expanded in scope. One of the most important activities of the division today is a geologic hazards program—a study of the geologic factors that may be costly in lives, money, or deterioration of our natural environment. Campbell has supervised completion of a geological map of California, established a state geophysical program, staffed a geochemical branch of the division, and laid the foundation for work in paleontology. He has been interested in research and development of geothermal power and has been secretary of the state's Geothermal Resources Board.

Campbell is currently traveling in Europe—one of the retirement activities he has looked forward to. After he returns to California, he will pick up several continuing professional responsibilities. He is a trustee of the California Academy of Sciences and chairman of the Committee on the Geological Sciences for the division of earth sciences of the National Academy-National Research Council. He will also begin a four-year term on the State Board of Registration for Geologists.

Ian Campbell

Continued on page 42

Victor Neher

Victor Neher, who becomes professor of physics, emeritus, in July, has been on the faculty at Caltech for most of the last 42 years. This is not to suggest that he has spent all that time in Pasadena. In fact, he has logged thousands of miles crisscrossing the planet to accumulate data about cosmic rays and cycles of solar activity.

On these trips Neher launches balloons that soar as high as 135,000 feet above the earth's surface—expanding to as much as 40 feet in diameter as they ascend—before they burst. Suspended from each balloon is an instrument package that measures the intensity of cosmic rays in the atmosphere and transmits the data back for processing and analysis. The results have enabled Neher to plot a picture of the earth that reveals the pattern of the density of cosmic ray bombardment. It is much greater at the poles than at the equator, and it varies inversely with the amount of solar activity.


Victor Neher

Neher estimates that since 1935, when cosmic ray investigations first took to the air, he has released approximately 400 balloons. The balloons themselves have had to be regarded as expendable, but getting the instrument package back as often as possible has been important enough that for many years each package has carried the offer of a reward for its return. The amount has varied from an early-day low of two rupees in India to a current high of $15 in the United States, and Neher estimates that the total paid out has been about $800.

With an AB from Pomona College, Neher came to Caltech in 1926 to do graduate work in physics. After he got his PhD in 1931, he was appointed a research fellow, and for the next 20 years he worked with Robert A. Millikan on cosmic rays—an association that he prizes. Neher feels particularly honored that in 1964 he was chosen to give the first Millikan Lecture for the American Association of Physics Teachers. That lecture, appropriately, was titled "Millikan—Teacher and Friend."

One of the scientific results of the Millikan-Neher collaboration was confirmation, by use of cosmic particles, that the earth's magnetic center is 250 miles from its geological center, which accounts for the fact that the geomagnetic poles are many miles from the geographic poles.

During World War II Neher spent five years at the Radiation Laboratory at MIT designing and making microwave vacuum tubes; he had a State Department appointment to the Physical Research Laboratory in Ahmedabad, India, in 1955-56; and in 1968-69 he filled in at the University of Hawaii for several professors on leave of absence. While there he also designed and supervised the installation of a Foucault pendulum.

In preparation for retirement Neher has constructed a scale model of the ten-acre site near Santa Cruz that will be home after he leaves Caltech. He grew up on a large ranch in the San Joaquin Valley and is looking forward to developing his own smaller version. There will be a vegetable garden, fruit trees, and pasture for the horses he plans to keep. As for the necessary buildings —a house, garage, and stable, for a start—the Nehers will be doing most of the construction themselves.

Charles Richter

Charles F. Richter received his AB from Stanford in 1920 and his PhD from Caltech in 1928. He has been so closely associated with seismology ever since that few people remember that he took his degrees in physics. Back in 1927 the Seismological Laboratory—located in Pasadena but at that time under the direction of the Carnegie Institution of Washington—needed a physicist as a research assistant. Robert Millikan recommended Richter for the job. When the laboratory was transferred in 1937 to the geology division of the Institute, he became assistant professor of seismology. In July of this year he becomes professor of seismology, emeritus.

In the intervening years Richter's name has become known all over the world, largely because for a long time no news story about an earthquake has been complete without mention of its magnitude on the "Richter Scale."

The scale, which is not an instrument but a system of tables and charts for reduction of the indications of seismological instruments, was developed in 1932 to cope with an emergency. The Seismological Laboratory wanted to list in its regular bulletin the 200-300 earthquakes recorded as occurring in southern California each year. However, the staff was fearful of the alarm such a list might create if there was no really accurate way to distinguish between large and small shocks.

At that time the accepted way to describe an earthquake was in terms of its intensity, which is a rating of the shaking at a particular point. What was needed to supplement that data was a measurement of the magnitude of the earthquake as a whole, independent of its effects at any particular points. And so the Richter instrumental earthquake magnitude scale was created.

From the beginning the scale astonished seismologists with its precision. Later, some refinements worked out with the aid of the late Beno Gutenberg produced a second surprise—the range of its applicability. The scale turned out to be an excellent way to measure large earthquakes anywhere in the world.

Being considered the authority on earthquake magnitude—and an expert in many other areas of seismology as well—has had its drawbacks, one of which was being on call day and night to interpret earthquake data for the news media. For many years a small seismograph installed in his living room was a timesaver for Richter both during real emergencies and in the case of false alarms. It enabled him to keep track of what was going on seismologically and to decide whether or not to make a middle-of-the-night trip to the laboratory to read the more sophisticated instruments there and to consult with the other members of the staff.

But for the last several years he has politely but firmly requested the news media to call the lab directly for information. This has been done with the double aim of assuring his own uninterrupted sleep and to give the press the advantage of the data available from newer, larger, and better instruments.

During his retirement Richter, who is author of *Elementary Seismology* and co-author of two other books, hopes to do some more writing. He will also continue to do consulting and a limited amount of speaking to groups that want to hear about earthquakes directly from the man who knows about them.

Charles Richter

Books

Molecular Thermodynamics
by Richard E. Dickerson
W. A. Benjamin, Inc., New York. . $4.95

Reviewed by C. J. Pings
Professor of chemical engineering

Teachers and the planners of curricula are faced with a perennial problem in the modernization of courses in subject areas of rapid change such as science. Not only is there new knowledge to incorporate, but there is need to simultaneously respond to the increasing level of preparation of students as they enter college. Increasing the sophistication of courses is not a matter of great ease. What to leave out or minimize as new material is introduced? When to stop the ad hoc modifications and undertake a total renovation of a course or an entire degree program? The critics of higher education who would have us believe that professors merely rehash the same old lectures year after year might well consider the pedagogic leadership resulting in innovative courses in Caltech's Division of Chemistry and Chemical Engineering during the last decade. Several of these educational experiments have resulted in new-style textbooks, one of which is *Molecular Thermodynamics* by Professor Dickerson. This is one portion of a three-volume set intended to provide the necessary textbooks for a junior-year course in physical chemistry. The other two volumes are *Quantum Mechanics in Chemistry* by Melvin W. Hanna and *Rates and Mechanism of Chemical Reactions* by W. C. Gardiner, Jr. All three volumes are produced by the same publisher.

The reviewer has undertaken only to look at Dickerson's contribution, which proves to be an interesting and an exciting modernization of physical chemistry. The author presents lucid demonstrations of the molecular basis of thermodynamic principles; the reader will also find a convincing structure of macroscopic thermodynamics which could be created on a postulatory basis and applied to real-world problems without recourse to molecular considerations. Dickerson has managed to convey interpretation and understanding without getting in the way of practical application. This is not simply done. For example, through much of Chapter IV, the author carries two symbols for entropy, one for the world of probability of occupancy of various energy states, the other for the macroscopic world of cycles and heat engines. When these two entropies are finally shown to be the same, the equality is plausible to the reader, and at the same time the independent integrity of both the microscopic interpretation and the macroscopic utilization is preserved.

The book treats the three laws of thermodynamics, introduces elementary statistical mechanics, and provides applications through three extensive chapters on phase changes and chemical reactions, solutions, and thermodynamics of living systems. The book is lengthy and contains adequate details of facts and techniques; useful tables of thermodynamic functions are included, and every chapter abounds in provocative problems.

Every scientist has his own taste in thermodynamics, so it is always possible to exalt or be critical with respect to the contents of a new book on this topic. I was particularly pleased to see the stoichiometry and yield of chemical reactions treated with "modern" notation (an elegant formalism introduced by DeDonder in 1920 and only now finding its way into the American thermodynamics books). On the other hand, I was disappointed when I looked in vain in Dickerson's book for a treatment of the virial equation of state for gases; in dealing with the properties of matter, it always seems a pity to expose the chemistry student to the rigorous equations of the perfect gas, which never exists in nature, and to the properties of solutions, which are so hopelessly complex as to defy molecular level description, yet not discuss the virial equation for dense gases, which is both practical and has a rigorous and elegant derivation in terms of intermolecular forces. Dickerson chooses a sign convention for his work expressions which is the most logical, yet defies the historical trend. With rare lack of clarity he somewhat obscures the expressions relating mechanical work to pressure-volume change; it may be this confusion which eventually leads him into an error in claiming that the expression $dE = TdS - PdV$ applies only to reversible processes.

This is an appropriate text for the modern student of physical chemistry. It could also be read with enjoyment and profit by the former student seeking a fresh viewpoint on how energy level diagrams and partition functions relate to phase diagrams and the operation of distillation columns.

Chemical Principles
by R. E. Dickerson, H. B. Gray, and G. P. Haight
W. A. Benjamin, Inc., New York . . $12.95

Reviewed by Fred C. Anson
Professor of analytical chemistry

This is a new textbook intended for use in a first-year course in college chemistry. It has been developed from the 1967 text by Gray and Haight, but it is essentially a new book rather than a revision or new edition. Professor Dickerson has joined the earlier authors to produce a handsome volume which treats most of the standard topics found in conventional freshman texts with a very unconventional flair and style. The discussions are colloquial, engaging, and very easy to read. The deadly pedantry to be found in many freshman texts, and which frequently deludes beginning students into believing that chemistry is intrinsically dull, is refreshingly absent from this book. It seems likely to this reader that freshmen of today will appreciate the obvious efforts that have been expended to get across the important concepts and principles of chemistry by means of language and examples that students will understand and enjoy.

For example, a discussion of energy and metabolism in living systems commences, "To mountaineers who take their hobby seriously, a particularly challenging operation is a 'dynamic traverse.' This is a traverse across a difficult piece of terrain where, at each instant, the climber is in an unstable situation, and where he is prevented from a disastrous fall only by his momentum. In a sense, every living organism is continually engaged in a dynamic traverse. . . . A constant supply of energy is needed from outside sources. . . . If this supply of energy fails, then death and the breakdown of the chemical machine is only a matter of time: a day for the fast-living shrew, a few weeks for man. Just as momentum saves the climber from falling, so a constant influx of energy keeps the living machine from collapsing."

The explanation of entropy includes a calculation of the Boltzmann entropy of the various possible hands in a poker game as well as the arresting observation that "Boltzmann's equation relating entropy to disorder ($S = k lnW$) is carved on his tombstone in Vienna."

An especially attractive feature of this text is the fact that a series of coordinated supplemental paperback books is available to assist students in studying and learning the subject matter. "Relevant Problems for Chemical Principles," "Programmed Reviews for Chemical Principles," and "A Study Guide to Chemical Principles" can be selected by each student in whatever combination best suits his needs. The idea is to offer a versatile "Teaching System" which can be adapted to fit introductory courses for students with widely varying backgrounds and preparation in chemistry.

Chemistry is held, in some quarters, to be going out of fashion. Those of us who regard this view as uninformed can take some comfort in the fact that upcoming generations of students who learn their freshman chemistry from Dickerson, Gray, and Haight may well find it hard to put down the always interesting and frequently exciting story of chemistry portrayed in this book.

Richard Dickerson, whose three new books are reviewed on these pages, is a professor of physical chemistry at Caltech. An excerpt, "Why Study Chemistry?", from Chemical Principles, was printed in the January E&S.

The Structure and Action of Proteins
by Richard E. Dickerson and Irving Geis
Harper & Row, New York $4.95

Reviewed by John H. Richards
Associate professor of organic chemistry

The last two decades have seen a revolution in our understanding of life processes. One great area of progress has been unraveling the mechanism by which hereditary information, written in long molecules of nucleic acid, is passed from one generation to the next and how this genetic information is translated into the potential for action by directing the synthesis of protein molecules which serve as the structural building blocks and catalysts of living organisms.

A second great area of progress has been our learning the precise three-dimensional structures of many of these proteins, structures which have been elucidated by the techniques of X-ray crystallography for the first time in the past decade. This new structural knowledge has provided the necessary foundation for understanding the dynamics of action of these molecules which are at the core of virtually every one of the thousands of chemical processes that together constitute life. Where before, proteins were black boxes—strings of amino acids wound up into obscure blobs—they now stand forth as complex molecules, beautifully constructed, after millions of years of evolutionary trial and error, for their specific tasks: hemoglobin to carry oxygen, chymotrypsin to digest protein in the intestine, serum complement to destroy hostile bacteria.

The Structure and Action of Proteins has combined the talents of an eloquent author with those of a superb artist to tell the story of proteins in five action-packed chapters. The first, "The Rules of the Game," discusses the structures of amino acids and the nature of the amide bond by which these units are joined together in a protein. Two pages, one of text and one of drawings, are devoted to the genetic code. This ratio characterizes much of the book, a part of whose value and lucidity lies in the very beautiful and informative art work, which complements the excellent text with unusual effectiveness.

Chapter 2, "Bricks and Mortar - The Structural Problems," deals with structural features (β-pleated sheets, α-helices, for example) that characterize the secondary structure of protein molecules. The valuable Ramachandran plot is introduced, and the structures of silk (β-pleated sheet), the α-keratin of wool (α-helix), and collagen are discussed.

Chapter 3, "The Molecular Carriers," considers myoglobin and hemoglobin (the oxygen carriers), and the cytochromes (the electron carriers). It also contains a fascinating section on molecular evolution, one of Dickerson's particular research interests.

Chapter 4, "The Molecular Catalysts," discusses a variety of enzymes. The way in which nature has created three-dimensional structures with catalytic groups optimally disposed is as impressive as any other natural wonder. In at least one situation—the proteolytic enzymes chymotrypsin (from mammals) and subtilisin (from bacteria)—nature has produced, by independent evolutionary pathways, almost identical active sites in different enzymes with otherwise unrelated structures. Though X-ray crystallographers perform a unique service to chemical biology in their structural accomplishments, they are somewhat less authoritative in their mechanistic speculations. As a result, some of the detailed aspects of the mechanisms of enzyme action in this chapter, for example, lysozyme (page 77) and chymotrypsin (page 83) are somewhat unsophisticated.

Chapter 5, "The Next Step Up," begins with a discussion of the nature of "life" and finishes with a five-act drama, including a Sparafucile, on the action of serum complement, meanwhile, having told us about feedback controls on metabolic processes, allosteric enzymes (also discussed in connection with hemoglobin in Chapter 3), and antibodies (gamma globulins).

ONward, sins of Commission, *chaconne à son goût*—Dickerson has a sure hand with the outrageous pun, so outrageous (as in the case of ONward-over-the-bridge) as to be unforgettable, which is, after all, his pedagogical purpose.

One of the great virtues of this book is its brevity (120 pages). I have never before seen the potentially complicated subject of protein structure and action treated with such lucidity, beauty, and eloquence.

In addition to the book itself, a set of stereo drawings of many of the proteins discussed is available as a supplement (which also includes a set of—not very good—viewing glasses). I strongly recommend this supplement which provides further inspiring views of nature's feats of molecular construction.

Crusade of the Left: The Lincoln Battalion in the Spanish Civil War
by Robert A. Rosenstone
Pegasus, New York $8.95

Reviewed by John F. Benton
Associate professor of history

This exciting and informative book illustrates a generation gap in history, the shift from the viewpoint of contemporaries to those who have no personal recollections of the subject. Participants in the Spanish Civil War, like George Orwell, could write accounts informed with the vividness and perception of immediacy. Robert Rosenstone was born in 1936, the year in which General Franco and his supporters in the church, the army, and the aristocracy began their successful rebellion against the Spanish Republic, and he was only two when the broken remnants of some 3,000 Americans who had gone to the aid of that Republic marched out of Spain, singing the "Internationale."

Rosenstone, who is now an associate professor of history at Caltech, here tells the story of the Americans who went to Spain to fight fascism, most of whom served in the Abraham Lincoln Battalion of the XVth International Brigade. His approach is that of an honest man seeking the answers to hard questions. The Civil War had its roots deep in Spanish history, and on the Republican side it was complicated by the conflicting interests of orthodox Communists, Trotskyites, Anarchist-Syndicalists, and other members of the Loyalist coalition. Those who fought in the Lincoln Battalion were not simply aiding the Loyalists, but were also, by desire or not, serving the interests of the Communist Party and the Soviet Union.

For its American participants, what started as a "crusade of the left" became a bloody and sobering war and finally a disorganized defeat which revealed the antagonisms within the Popular Front. Critics were quick to call the Lincolns Communist dupes or worse, and with the aid of the House Un-American Activities Committee a literature was developed to show that wily and brutal political commissars used terror to hold the volunteers to the Communist line. The Communist Party, on the other hand, felt free from the beginning of the conflict to doctor the truth about the Lincolns for its own propaganda purposes, claiming, for example, that the volunteers represented a cross section of the "best elements" in the United States.

In order to write this account, prepared originally as a doctoral dissertation at UCLA (and perhaps it should be said that this is a highly readable book, far from the ordinary dry-as-dust thesis), Rosenstone has combed through a mass of published literature and newspaper stories, and has benefited from such unpublished sources as Alvah Bessie's "Spanish Notebooks" and interviews with some 20 veterans of the Lincoln Battalion. He also visited the sites of the Spanish battles he describes so vividly. This deep familiarity with his material has permitted him to write a satisfying

Letters

and gripping account of the American military experience in Spain. The adventure is seen largely through American eyes, and it adds little to an understanding of the causes, course, or results of the Civil War. The aim of the book is quite different: to explain the nature of the American participation in that war.

Rosenstone's detailed and well-documented research clarifies two major disputed questions. He has turned up information on over half of the American participants, and is able to draw a composite picture of the average volunteer as a man in his twenties from an industrial center, foreign-born or first-generation American from a working-class background, with probably "some attachment to the secular faith of Marxism." Such a portrait is not surprising, but until now it has not been solidly established. On the role of the political commissars and the questions of terror and party discipline he avoids a doctrinaire position and begins with believable and varied human portrayals of soldiers and their leaders in combat. Successful political leaders were reasonable, effective, and in tune with the needs and outlook of their men. There were executions for desertion, as one would expect in a losing and disorganized army, and for rape, but at most Rosenstone can find evidence of no more than four *possible* political executions. The Lincolns were not bound together by fear but by a common opposition to fascism.

This book is more than a fresh reappraisal of the evidence about Americans in Spain; it is also a contribution to the end of the Cold War in American historiography. Rosenstone does not attempt to create an illusion of impartiality, and he shows his admiration for the Americans who risked their lives to oppose fascism and nazism. He lets the record of the American Communist Party speak for itself and is prepared to say that its adherents "were often honest, sensitive individuals responding to problems created by the malfunctions of our own socioeconomic system." His book eloquently makes the case that one cannot understand the Americans in Spain without seeing their radicalism as a native American response to the world of the 1930's.

Cruel or Not?

EDITOR:

Reading the paper by Harlow and Suomi in last month's *Engineering and Science* I am simply appalled that so much cruelty is used to extract meager and often quite trivial information from unfortunate monkeys.

I realize that any scientific discipline in its most primitive beginnings has to resort to model experiments. In medicine, biology, etc. this means unfortunately animal experimentation; however it is up to the scientific community to question itself how far it is needed and when the results obtained *do not* warrant the means. Indeed in this particular case one may argue like this: Either the psychological behavior of caged monkeys is much different from humans, in which case very little is gained from the experiments; or else the monkeys are psychologically much like humans, and we are only a small step removed from similar experiments with helpless humans; a little totalitarian ethic and we are there. Indeed I am sure that a search through the records from concentration camps, prison farms, orphanages, etc. around the world would furnish much of the information contained in this paper.

I much prefer the approach of Lorenz, Schaller and Van Rawdick-Goodal, i.e. observing behavorial pattern in the natural habitat.

H. W. LIEPMANN
Professor of Aeronautics
Caltech

Dr. Harlow replies:

We are in sympathy with the feelings Dr. Liepmann expresses concerning cruelty to animals, since we abhor cruelty of any kind needlessly inflicted upon any living form. More than half of our researches in the last decade have dealt with various kinds and aspects of love, and we believe we were the first research group to unravel the variables making it possible for higher primates to be raised in a laboratory with full possession of their social and sexual capabilities. I am certain that we are not sadists, and I recently served as chairman of a National Academy of Sciences subcommittee to formulate basic rules and provisions guaranteeing humane housing and husbandry for laboratory animals. Even if we were sadists, we would not attempt research on depression if the experimental procedures involved severe physical discomfort or pain, since such researches would be meaningless due to confounding of physical and psychological variables.

We believe that Dr. Liepmann was in error in stating that the information obtainable from our researches is meager and trivial. Had Dr. Liepmann been a guest at the last meeting of the National Academy of Sciences, he would have found that his opinion was not shared by many eminent psychologists, psychiatrists, and biochemists.

Such information as can be gleaned from "concentration camps, prison farms, orphanages, etc." was in large part acquired and evaluated some 20 or 30 years ago, and these data, their values, and their limitations are a part of the common knowledge of most behavioral scientists and some educated laymen.

Dr. Liepmann's comments in the middle of the second paragraph beginning "Either the psychological behavior . . ." leave us puzzled and bemused. It is as if the writer had intellectually drifted far up into outer space. Even if this is true, in view of his engineering honors, he will doubtless find a way to return intellectually to earth.

Dr. Liepmann closes his comments by expressing a preference for ethological and primate field research over rigid laboratory experimentation. This is an interesting and probably valuable autobiographical item, but nothing more.

Fission vs. Fusion

EDITOR:

We believe that Professor Roy Gould has overstated the case for fusion power in comparison with fission power in his article in the March 1970 *Engineering and Science* ["Controlled Fusion—Clean, Unlimited Power Generation"]. The attitude reflected in the article is common among scientists, who tend to prefer the exotic to the useful.

As Alvin Weinberg pointed out more than ten years ago [A. M. Weinberg, "Energy as an Ultimate Raw Material,"

Physics Today, November 1959, p. 18.], there is no advantage in the fusion process from the standpoint of fuel supply. There is sufficient cheap uranium to supply the world's need for electrical energy by means of breeder reactors for the indefinite future. In fact, there is probably enough cheap uranium to fuel the present type of fission non-breeding reactors well into the next century.

No one even knows what a fusion reactor would be like, much less what it would cost, while prototype breeder reactors have been operating for some years. Indeed, an experimental reactor of this type was the first reactor to demonstrate the production of electrical power in 1951.

While the feasibility of fission reactors followed by only three years the discovery of fission, the feasibility of reactors based on the fusion process has yet to be demonstrated although the basic process has long been known. No fusion experiment has yet reached a level comparable to that attained by the Chicago fission pile in 1942. Even so, it has taken almost 30 years to produce electrical energy on a competitive commercial scale from fission. Because of the engineering and development time required from feasibility to commercial application, a time which more often than not is grossly underestimated by the laboratory scientist, it seems unlikely that controlled fusion would play a "key role in our lives" by the end of the century.

In view of the fundamental uncertainties it is frivolous to cite a cost advantage for fusion over fission because "restrictions imposed by the environmental hazards of radioactive wastes will have little effect on fusion power costs."

We hesitate to predict that the basic technical problems will not be solved. But the zeal of dedicated researchers is not a reliable guide in this situation. As I. I. Rabi remarked about one of E. O. Lawrence's ill-fated schemes, "You can make anything defy the laws of physics, at least for a while, if you spend enough money on it."

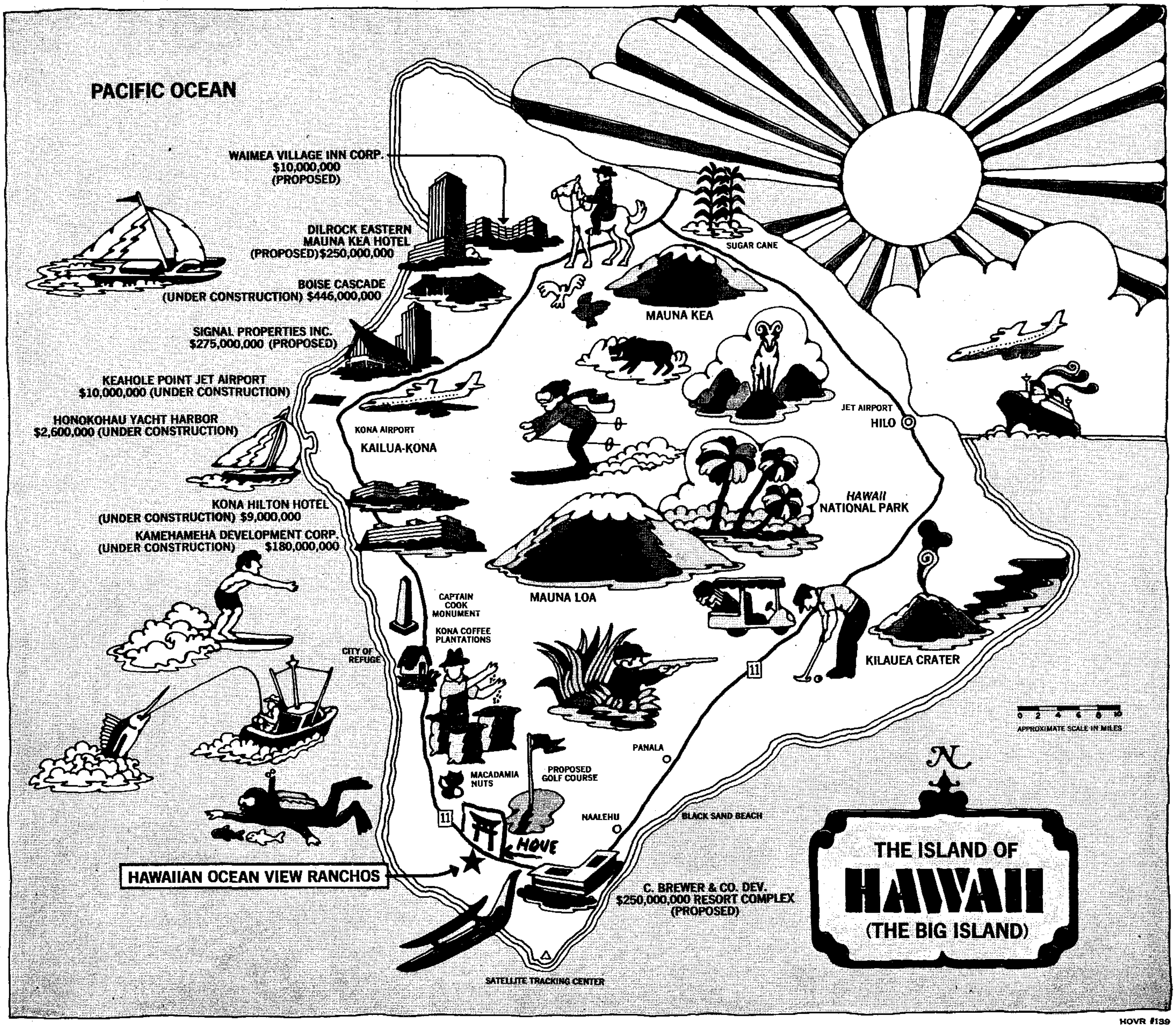
VICTOR GILINSKY
MILTON S. PLESSET
Division of Engineering and Applied Science
California Institute of Technology

Dr. Gould replies:

My article in *Engineering and Science* was not intended to "make the case for fusion power in comparison with fission power" but to acquaint the readers with the fusion reactor concept and to apprise them of the substantial progress which has been made in containing a hot plasma. The containment problem has long been regarded as the bottleneck in fusion research, and experiments during the past few years have shown that it is possible under some circumstances to eliminate completely the anomalously high loss rates (Bohm diffusion). This is a major achievement, though it does not guarantee a successful fusion reactor.

Comparison with other possible sources of electrical power is inevitable, however. The possibilities for essentially limitless electrical power in the future are: a) fission breeder reactors, b) fusion reactors, and c) solar energy. Should the development of all three be successful, the choice of which of these to employ or what combination of them to employ will depend on an analysis of the inherent advantages and disadvantages of each of the systems. The choice will undoubtedly be influenced by cost, and by environmental and safety considerations; although the weight we and succeeding generations choose to attach to these latter considerations may well differ. Indeed, there are differing opinions at the present time. I do not believe it frivolous to consider the possible advantages and disadvantages of alternative power sources as we proceed with their development. While the fission breeder reactor is the most advanced of these systems, its engineering and/or economic success is still not completely assured. In any event, we must maintain the flexibility to meet different requirements with different alternatives.

Contrary to the assertions of Gilinsky and Plesset, there exists a substantial body of knowledge addressed specifically to the important engineering and technological problems of a fusion power reactor station. Furthermore, when we undertake the solution of the engineering problems of a fusion reactor, we do so from a vastly expanded technological base, in comparison with that available at the beginning of the fission reactor development almost 30 years ago. Fusion reactor development should take place more rapidly. Indeed, fusion reactor technology will benefit greatly from the already developed fission reactor technology in neutronics, materials, and energy transfer.



HOVR #139

To: The Caltech Community

From: Victor M. Lozoya

For several months **Engineering and Science** has carried no news letter from me, simply because there has not been sufficient land available for purchase to merit publicity. Recently Hawaiian Ocean View Ranchos opened its first increment (already sold out) and will soon be opening two more increments. Inasmuch as a waiting list for this exceptionally fine property is increasing, it is expected that these 3-acre parcels will be sold out even more rapidly.

Hawaiian Ocean View Ranchos—probably the last development of its kind which will be permitted in Hawaii—represents a once-in-a-lifetime opportunity for small investors to own some of the most beautiful land to be found anywhere *in the world—and at pre-development prices as low as 10¢* per square foot.

More than a billion dollars is scheduled for construction and development (including a jumbo jet airport to be larger than Honolulu airport) on the Kona Gold Coast. Hawaiian Ocean View Ranchos is located right in the path of this progress, between vital Highway 11 and the Pacific Ocean, 38 miles south of the booming Kailua-Kona district, and just north of the proposed $250 million C. Brewer & Co. recreational and residential community.

I wish I could convey to you my personal excitement about the beauty of this land and its magnificent view of the Kona Coast, as well as the extraordinary potential of the area.

If you would like more specific details of the development now going on in the vicinity of Hawaiian Ocean View Ranchos, please write or telephone me as soon as possible. I expect that these parcels will be sold out in a few weeks. By the time you read this, my wife and I will have returned from another of our survey trips to the Big Island of Hawaii, and I will no doubt have even more of interest to report. Aloha.

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Terry O'Neil, a junior biologist, read the April E&S while in the middle of final exams and says this Caltech version of Harlow and Suomi's monkey experiments suggested itself to him at that time.—Ed.

Induced Psychopathology in Techers*

by Terry O'Neil '71

We are trying to produce psychopathological syndromes as analogous to normal student disorders as possible. From that base may come techniques for rehabilitation of depression.

Some 15 years ago the staff at the California Institute of Technology instituted a research program designed to induce psychopathology in freshman Techers by means of abusive courses and examinations. The program was largely successful; however some students made it through the program *and enjoyed it*! Seeing this, we thought we had totally failed to produce psychiatric syndromes in Techers. Then, Ion Seeker, an Australian psychiatrist, visited the Institute, listened to our sorrows, and took a tour of the "Student Houses." After observing the students busily studying, he asked, "Why are you trying to produce psychopathology in Techers? You already have more psychopathological students in the Institute than have ever been seen on the face of the earth."

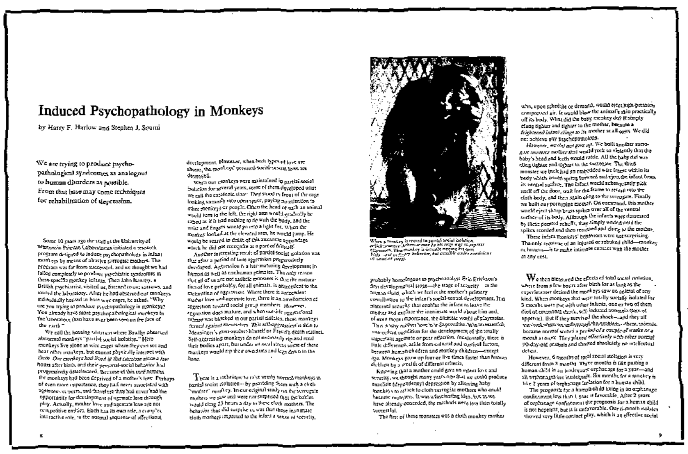
We call the housing situation where Seeker observed normal Techers "partial social isolation." Here, Techers live alone or in pairs in concrete rooms where they can see and hear the real world, but cannot physically interact with it. Our Techers had lived in this situation for most of their academic lives, and their personal-social behavior had progressively deteriorated. These Techers have been denied both ignorance and agemate relations.

When our Techers were maintained in partial social isolation for several terms, some of them developed what we call the catatonic stare; they sat in front of their desks staring into their physics texts, paying no attention to other Techers or the real world. Often the Techer would absently whistle a few bars of some Wagner opera. When he realized what he was whistling, he would jump. He would be scared to death of this awesome spectre he had raised.

Another interesting result of partial social isolation was that after a few weeks aggression progressively developed. When the Techers were discouraged from throwing things at each other or throwing each other into the numerous showers, these Techers turned against their studies. They were seen ripping test booklets to shreds and burning class notes. Self-aggressing Techers do not normally rip and rend their books apart, but under unusual stress some of these Techers would rip their books and notes to scrap.

There is a technique to raise nearly normal Techers in partial social isolation—by providing them with synthetic reality. In our original studies on the surrogate reality we saw and were not surprised that the Techers would cling 23 hours a day to these objects. What did surprise us was that these inanimate objects imparted to the students a sense of security.

Knowing that Techers liked reality, we thought many years ago that we could produce anaclitic (dependency) depression by allowing freshman Techers to attach to surrogate realities who could become monsters. It was a



Induced Psychopathology in Monkeys

by Harry F. Harlow and Stephen J. Soumi

We are trying to produce psychopathological syndromes as analogous to human disorders as possible. From that base may come techniques for rehabilitation of depression.

*The unwitting (and invaluable) assistance of Harry F. Harlow and Stephen J. Soumi (April 1970, *E&S*) is appreciated greatly.

When a Techer is reared in partial social isolation, self-destructive behavior may be his only way to express aggression. This Techer is actually breaking his slide rule to pieces, possible under conditions of unusual stress.

fascinating idea, but as we have already conceded, the methods were less than totally successful.

The first of these monsters was an engineering math which, every ten weeks on schedule, would give a high-pressure final exam. These "AM95" exams would practically blow the Techers' heads off. What did the Techers do? They simply studied longer and longer, because a scared troll clings to its studies at all costs.

We did not give up. We built another surrogate monster reality that gave such incredibly long reading lists that the Techers' tired, bored eyes would constantly fall shut. The third monster involved long, boring lectures with pop quizzes in class. Although the Techers were distressed by these traumas, they simply waited until after Finals Week to get all their sleep and recuperation.

We then measured the effects of total social isolation. When freshman Techers isolated for a year were put with normal college students, one or two of them died of emotional shock, self-induced anorexia (loss of appetite). But if they survived the shock—and most of them did—a peculiar phenomenon was observed. Their total personality structure altered and they largely gave up hiding in their rooms. If the outside college students were brought into the Institute, however, they rapidly began acting like average Techers, and the psychopathology perpetuated itself rapidly.

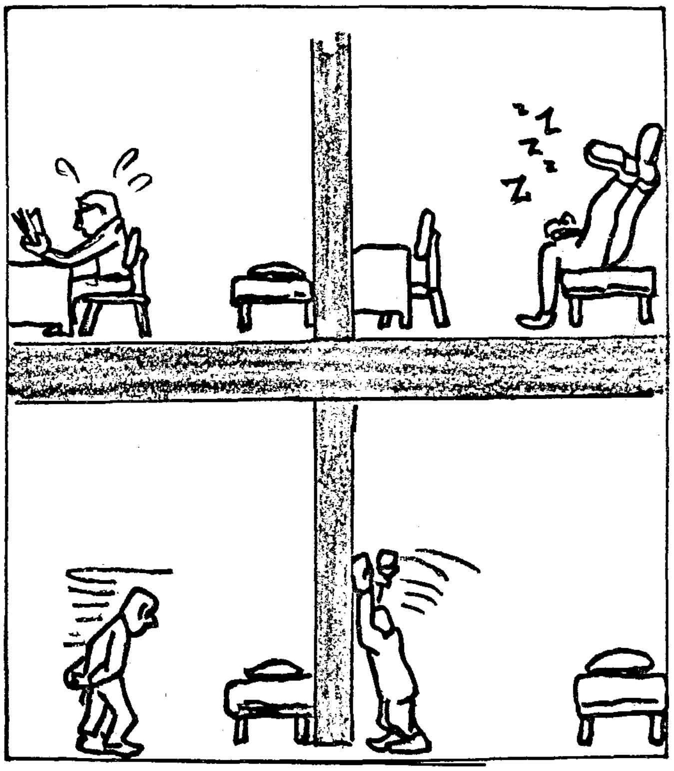
Buoyed by these results, we have continued to search for techniques to produce depression. Our criteria for operationally defining depression are primarily behavioral. We want students who, prior to entering the Institute, show essentially normal behavior and, following a few years, display very low levels of motor, exploratory, social, and intellectual activity, very high levels of passivity, and possibly revulsion at the thought of a hamburger. One reason for producing such a syndrome is that one cannot do research on the ultimate technical curriculum until a behavioral syndrome has been achieved that is unequivocally "screaming depression" and can be maintained for weeks and months at a time.

Obviously, one cannot combine physical and psychological depression and draw proper conclusions concerning curriculum content. Accordingly we have designed a device for producing depressive behavior without imposing direct physical discomfort on the Techer. This device is called a "student house room," or "pit." Confinement in a pit produces an extremely depressed Techer, and one that remains depressed for many months following removal.

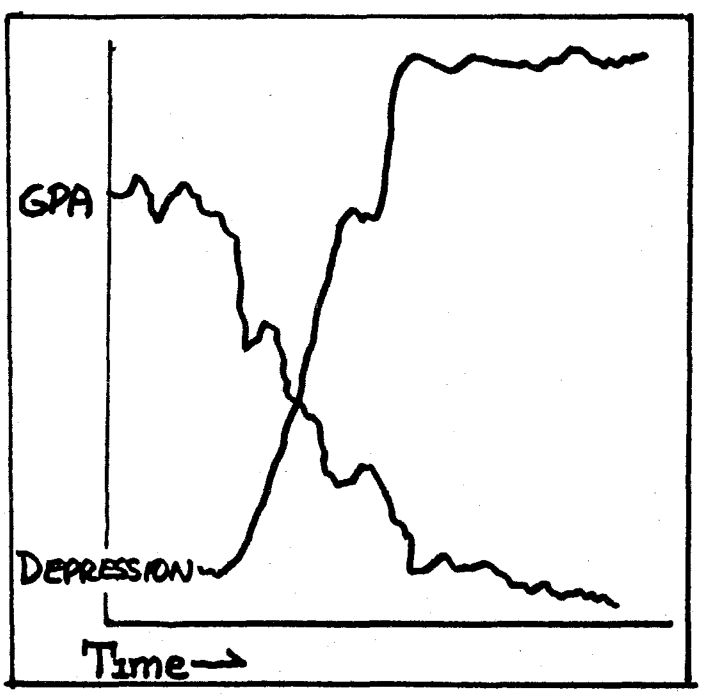
The Techers in the pits can move about freely in all three dimensions, but they gradually cease to move at all. After a term or two, or for some a few weeks, the Techers assume either a permanent position at a book-heaped desk or a permanent supine position on a bed: It is a "giving up" posture.

Following removal from their chambers, these responses persist. Techish behavior increases enormously after pit housing, and the ability to perform normal social tasks is simply wiped out.

We are now comparing Techers raised under three different conditions. One group had one term of isolation in the pits; one was in a pit for a year; and the members of the third group were raised in the normal boarding school environment. Simple infantile response patterns remain very high for years in those Techers "pitted" for only one term. More complicated social behaviors were simply eradicated in these Techers long after release.



After a few days—or perhaps a week or two—a Techer in the pit stops studying and assumes a "giving up" posture. Even long after removal from the pits, young Techers show depressed and infantile behavior.



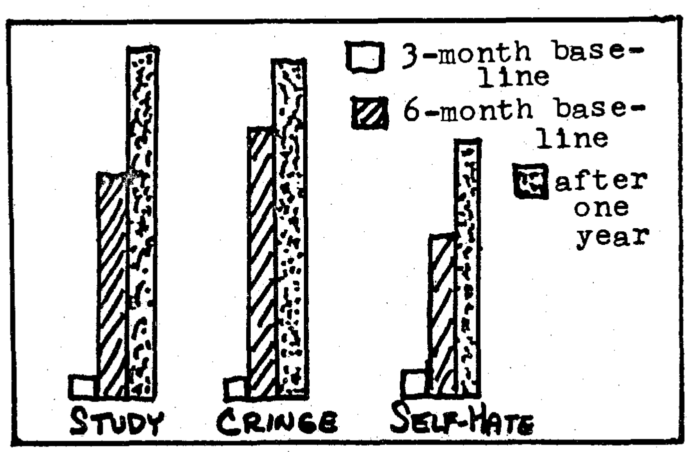
While the immediate goal of our present research is to provide reliable, long-lasting depression patterns in Techers analogous to those observed in monkeys diagnosed as depressed, it represents only a first stage of our over-all depression project. The next stage is to modify existing housing and curriculum so that the degree of depression subsequently exhibited by the Techers can be controlled. When this is accomplished, it will open up vast possibilities for the parametric study of the optimally boring, frustrating college environment. For instance, it would be possible to determine if Techers of limited social experience are more susceptible to such manipulation than freshmen given unlimited social interaction throughout their lives. Perhaps early exposure to stress-inducing curricula inhibits or exaggerates the effect of the depression-stimulating environment.

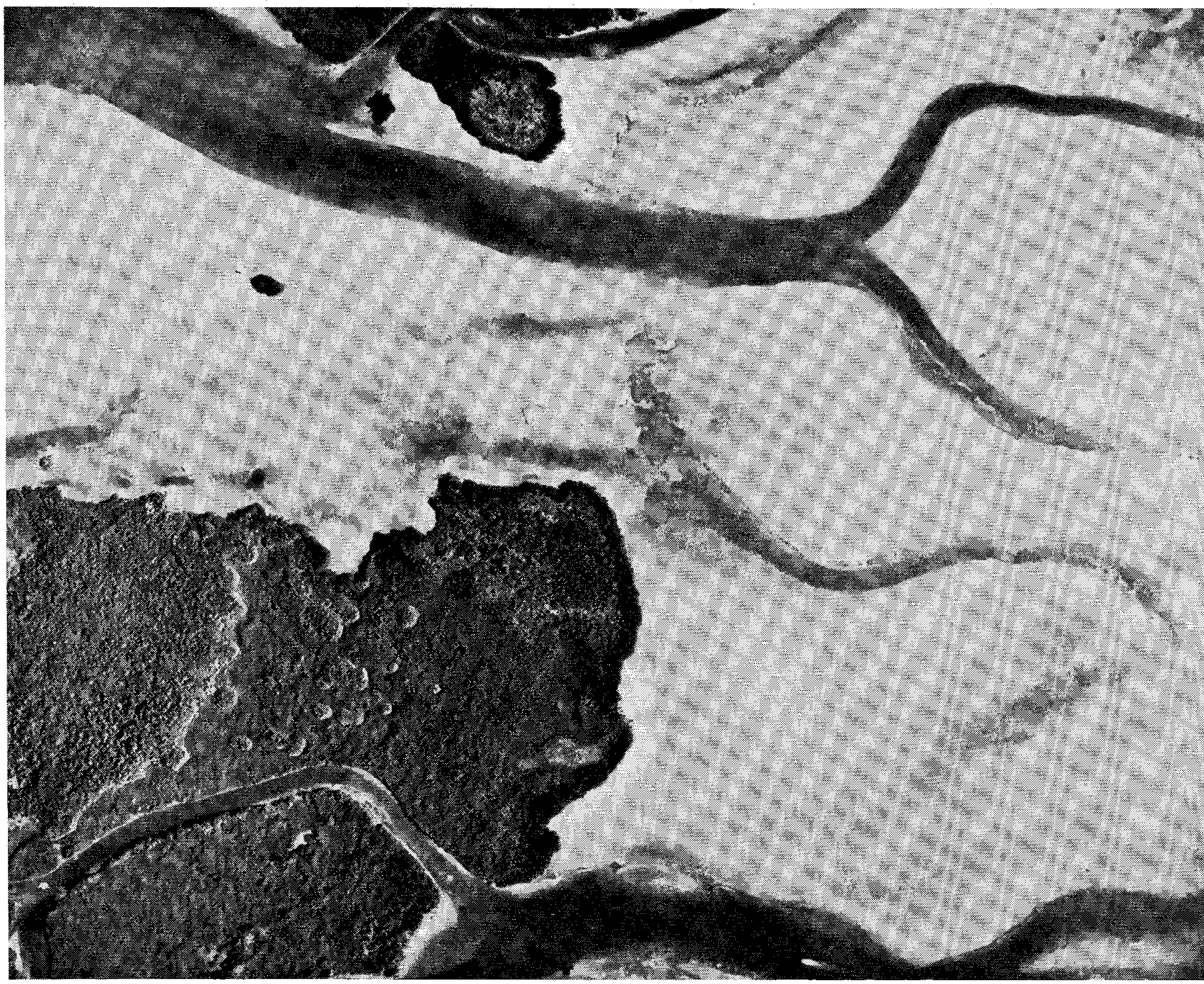
To investigate these areas we are using combined living-working complexes attached to the Institute.

A final, and perhaps most important aspect of our research program involves development of techniques to spread our remarkable syndrome. Possible techniques include environmental, political, or pharmaceutical manipulations, either alone or in combination.

We are also employing our own group techniques. Remember that if you place a normal college student in total isolation for 6 months with equal-aged normal students, you get a socially damaged mess. When students from other colleges transferred into the Institute research program, they were exhibiting normal social behavior. After about 6 weeks it was very difficult to distinguish between the transfers and the Techers. It appears that this experiment, which is very near to completion, will disclose highly significant effects for other colleges to consider.

It is essential to realize that the findings of such work hold implications for normal student depression only at the level of analogy and within the limits of comparative behavioral research. Nevertheless, we feel that our findings from investigations of depression in Techers will be important to normal student therapists working in an area currently devoid of data from controlled research.





Even if you don't like the air you breathe, you can't stop breathing.

When was the last time you went out for a breath of fresh air and got it? How long has it been since the sky looked really blue?

Every day, our cities dump hundreds of thousands of tons of waste into the air. Carbon monoxide. Sulfur dioxide. Fluoride compounds. And plain old soot.

If something isn't done about air pollution in your lifetime, it may cut your lifetime short.

Air pollution can be controlled. The key is technology. Technology and the engineers who can make it work.

Engineers at General Electric are working on the problem from several directions.

Rapid transit is one. In many cities, the automobile causes more than half the air pollution. In some cities, as much as 90%. But engineers at GE are designing new equipment for rapid-transit systems, encouraging more people to leave their cars in the garage.

Another direction is nuclear power. General Electric's engineers designed the very first nuclear power plant ever licensed. A nuclear plant produces electricity without producing smoke. And as the need for new power plants continues to grow, that will make a big difference.

There are other ways General Electric is fighting air pollution. Maybe you'd like to help. We could use your help. But don't expect to come up with an overnight solution to the problem.

The solution will take a lot of people, a lot of talent and a lot of time. You'll breathe easier—once you get started.

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