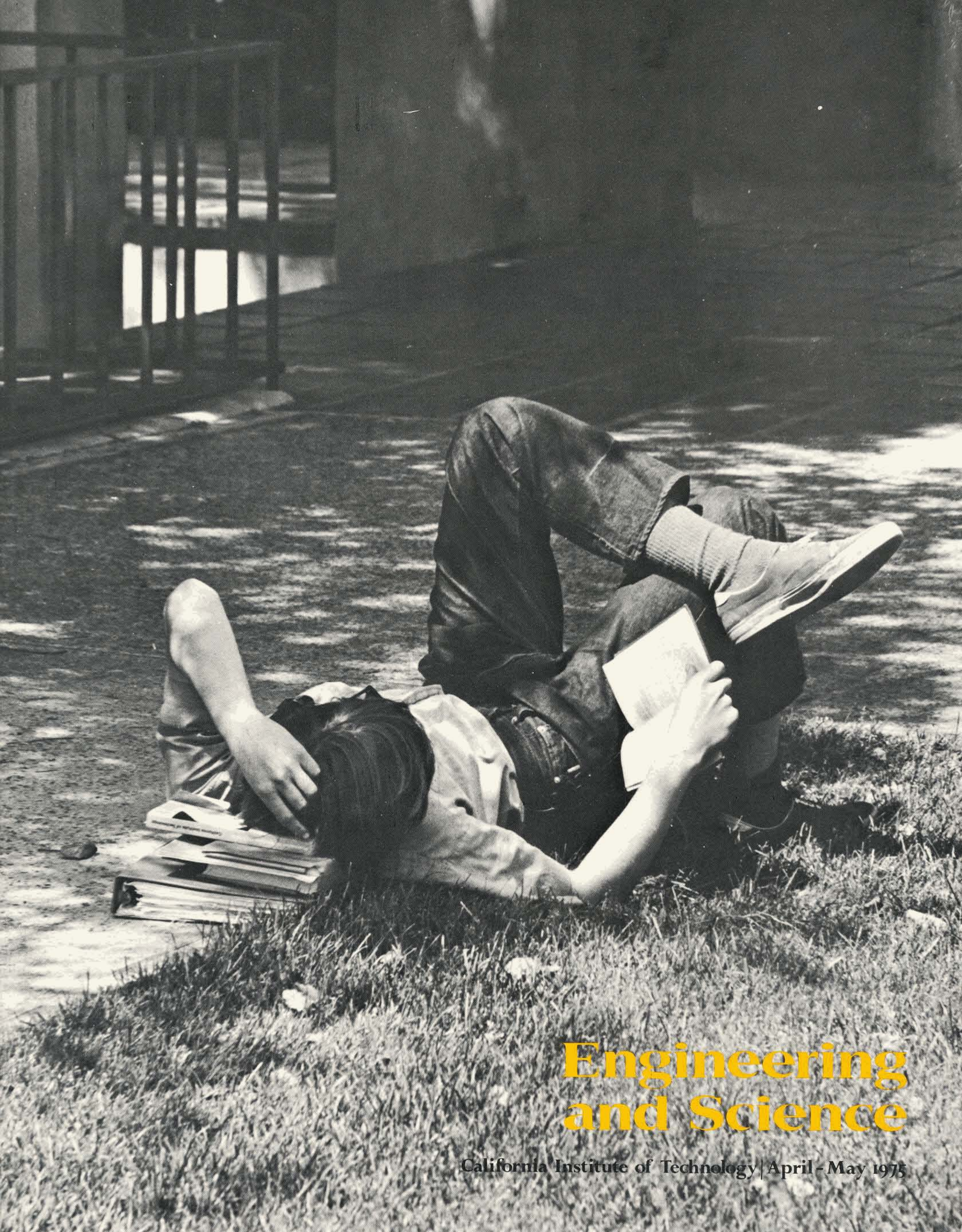

Engineering and Science

California Institute of Technology | April - May 1975

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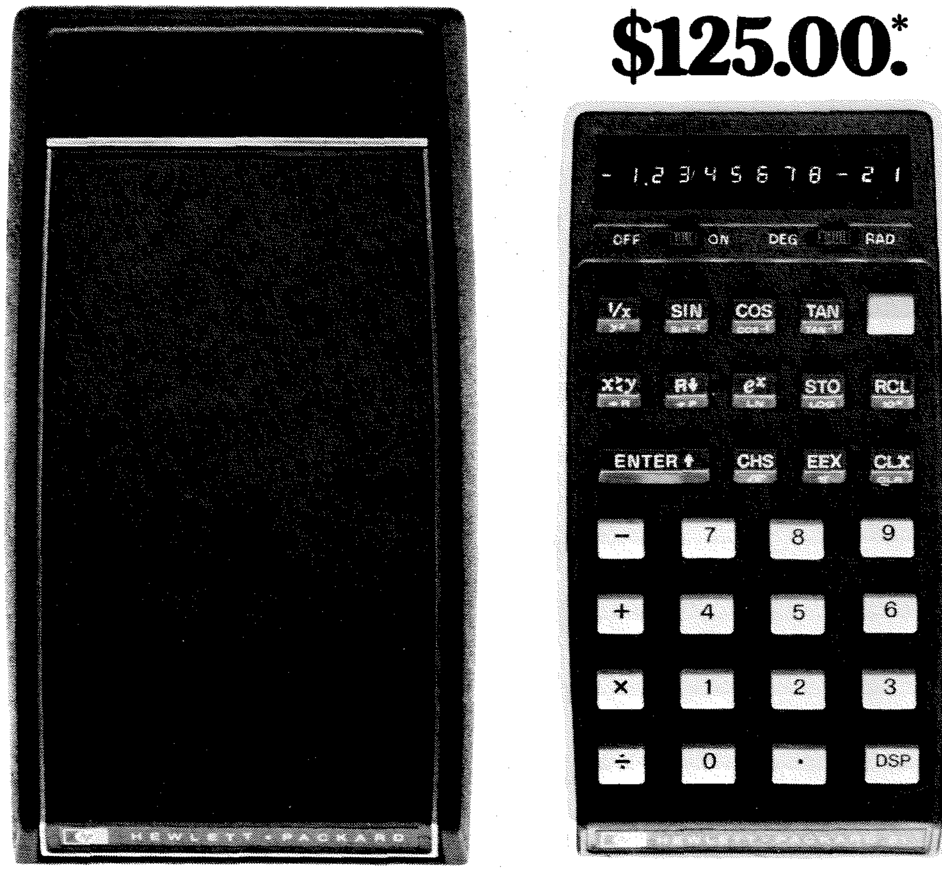

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Engineering and Science

April-May 1975/Volume XXXVIII/Number 4

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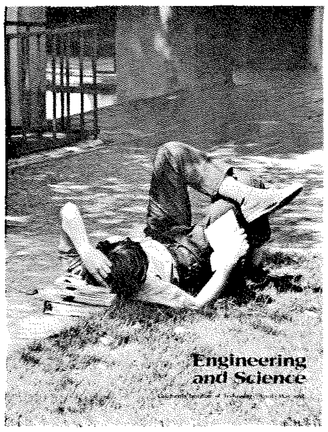


Family Planning

On the cover—a representative member of the Caltech family and the main subject and chief concern of Institute Psychologist Nancy Beakel in "What Makes Caltech Tick?" (page 17), which is adapted from her Watson Lecture on March 3.

After graduating from the University of Texas with a BFA in drama, Nancy started her professional life as an actress, and the seven years she spent on the stage gave her a special opportunity to study human behavior. It probably sharpened her perception of the importance of clear communication as well. Her dissertation for her PhD in psychology at UCLA was on the subject of nonverbal communication in families. After five years at Caltech, counseling 15 to 30 troubled students every week, she's spotted plenty of nonverbal communication in the Caltech family too.

Nancy Beakel does a lot for Caltech in addition to counseling. She is currently vice chairman of the Caltech Y, an instructor in the Division of Humanities and Social Sciences, faculty sponsor for the Caltech Women's Coalition, and a board member of the Child Development Center, which is a school for children of Caltech families.

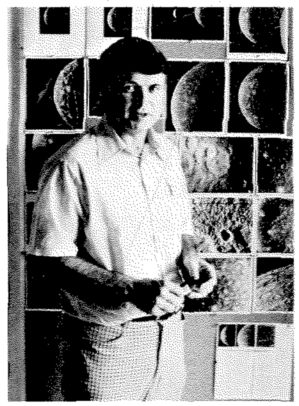
Energy Conservation

In view of the seriousness of the near-term energy problem, it seems somewhere between simply over-optimistic and downright foolhardy to say that there is a way out. But one man who is willing to point out one reasonable way through the turmoil is Caltech's Lester Lees, professor of environmental engineering and aeronautics.

Lees came to Caltech in 1953 and spent his first several years here in research and teaching in the field of aeronautics. However, he became more and more interested in the development of an interdisciplinary program to attack problems of environmental pollution. When the Environmental Quality Laboratory (EQL) was formed in 1970, Lees became its first director, resigning only recently to become senior staff member.

He is an authority on air pollution control and on the problems of reconciling energy supply and demand. "Energy Conservation: Will It Work?" (page 3) is adapted from a recent talk he gave on that subject.

The views expressed are the author's own, and are not meant to represent the position of either EQL or Caltech.



Scientific Boundaries

Bruce Murray graduated from high school in Santa Monica and then went east—to MIT—for his college education, receiving his PhD in 1955. He spent three years working in the petroleum industry on the Gulf Coast and then two years in an Air Force research unit. In 1960 he came to Caltech as a research fellow and has since become professor of planetary science. He has been active in the Mariner spacecraft program, most recently in the successful Mariner 10 mission to Venus and Mercury. He has just received a Guggenheim fellowship in recognition of his research in comparative planetology of the Earth-like planets—Earth, Mars, Moon, Venus, and Mercury.

Murray is highly articulate on scientific subjects and thoughtful about their implications, and he recently combined those talents in a lecture at Beckman Auditorium. "The Limits of Science" on page 9 is an informal adaptation of that talk.

continued on inside back cover

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Energy Conservation: Will It Work?

LESTER LEES

Whenever anyone talks about the energy "problem" in the United States, we have to wonder whether it isn't a kind of cop-out. As we know, we use 35 percent of the world's energy, but we have only 1/16th of the world's population. That means that on the average we use eight times as much energy per person as the rest of the world. So, even if the world rate of energy consumption (except for the U.S.) were to quadruple in the next 35 years or so, and even if the world population outside the U.S. would only double (which is the best we can hope for), it turns out that the world consumption per capita would still be only about one-fourth of the *present* U.S. consumption per person.

We have been forcefully reminded recently that the already high energy consumption per capita in this country cannot continue to grow at the rate of the 1960's. I'm not talking necessarily about zero energy growth, or about a static society, because I don't understand what that means. I'm talking about a dynamic situation in which we progress from what we knew over a period of 25 years—from the end of the Second World War to the present—to a new era in which we learn how to do with a lower energy growth rate than anything we've been used to.

Remember I said growth *rate*. What I'm concerned with is not the limits to growth but the limits to the rate of growth, which is a different story. It is the central question of the next 25 years. How *are* we going to get through the next 25 years, and especially the next 10? (Some people would say the next *year*, but I would not be that pessimistic.)

What I mean by energy conservation, which is one of the ways to get through this transitional period, is a little bit broader, perhaps, than we're used to, because it includes more than the obvious element of efficiency of the uses to which we put energy. We waste energy in every way possible in this country—in automobiles, in buildings, in industrial processes, even in the growing of food. That will have to come to an end. We will have to learn how to use energy efficiently at its end point.

But there are other effects which are equally interesting, and I call these "saturation" effects. In other words, how many more automobiles can we have after we get up to about 0.8 automobiles per person, which is about one automobile for every person capable of driving a car? If we start getting any more automobiles per person, the automobiles will have to drive themselves around the streets. So there are saturation effects in the sense that we can see a slowdown in the *rate of growth* of certain physical commodities—like the number of square feet of floor area of commercial floor space, the number of residential dwellings, the number of people.

Then there are certain time scales for supply. In order to build new drilling rigs to get more oil, we have to have steel; but in order to have steel we have to have energy. If we have a shortage of energy, we can't have the steel, so we can't build a rig, so we can't drill for the oil, so we can't have more energy. And pretty soon we get ourselves into an impossible situation like the Red Queen in *Through the Looking Glass* who said that we have to run as fast as we possibly can just to stay in the same place.

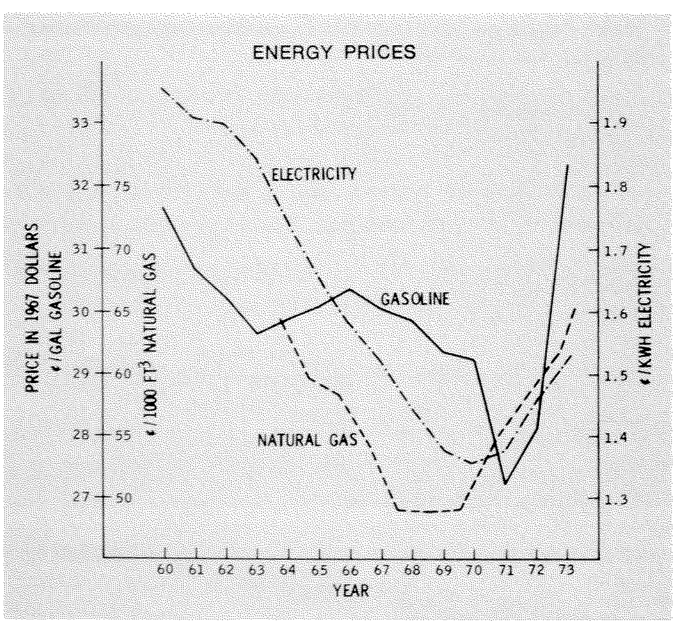
Then my economist friends would have me remind you that there is such a thing as price elasticity, both for demand and supply. By that I mean if the unit price of energy goes up relative to all other things, you're probably going to be a little more careful how you use it. And also if the price of energy goes up in relation to other commodities, those who wish to supply you with energy may be more anxious to do so.

But finally there is an aspect of conservation that has to do with the use of renewable resources rather than non-renewable resources—the use of solar energy, for example, instead of fossil fuels, which are finite. This is a finite planet. Barbara Ward reminded us of that in her book *Spaceship Earth* more than a dozen years ago. And recently I found that on September 6, 1945, President Harry S. Truman sent a special message to the Congress of the United States asking for a National Resource Planning Agency. He didn't get it. But he saw even in 1945 that we would have to plan for these elements of conservation and these elements of supply that I have just mentioned. There was also the famous Percy Commission of June 1952. Its report was largely ignored. It was a very comprehensive piece of work, produced by very able people. Nobody paid any attention.

Interestingly enough, anybody could have predicted what was going to happen. Our domestic production of crude petroleum was rising more and more slowly, our exports were dropping, and our imports were rising by the early 1960's. So anyone could have plotted the curves and predicted what was coming. But apparently we never do anything until a crisis is upon us.

When we look at the last 120 years, we see how total annual energy consumption in the U.S. grew from an equivalent of about 2½ million barrels of oil per day to about 35 million barrels in the early 1970's. Not only did the total energy grow, but there was a vital transformation in the way we *used* energy.

Wood was our primary source of energy in the 1850's. Then coal came along, and its use grew rapidly to equal and surpass wood, then flattened out, and it has stayed flat for about the last 40 years. Oil showed up as a significant source of energy in the 1890's, even though the first strikes were much earlier. It took 20 to 30 years



Energy prices (shown here in terms of 1967 dollars) actually declined until we had a turnaround in the late 1960's. The latest expectation of electricity prices for residential use is about 4¢ per kilowatt hour (which is 2½¢ in 1967 prices).

before oil production equaled wood production of energy. Then oil took off, and from 1960 to 1970 we produced more oil in the U.S. than in the preceding 110 years.

Paralleling the growth of oil was the use of natural gas as a clean-burning fuel—its price kept down artificially to stimulate its production (though we're paying the price for that now). Hydropower has had a very interesting history. It has seemed to flatten out at about the equivalent of 1½ million barrels per day, yet its potential is much larger; but because of the environmental consequences of hydropower, we have turned to the other sources.

Another interesting point is that nuclear power in the early 1970's was producing less energy than wood—though it has, of course, now surpassed wood.

In the U.S., the energy consumed *per person* has increased by a factor of about 3½ over the last 120-130 years. In 1850 we consumed about 30 times the human caloric intake per person—about 100 million Btu's per year, or the equivalent of about 2 gallons of oil per day. In 1973 each of us consumed the energy equivalent of about 7 gallons of oil per day.

Can we go on growing like this? We know we cannot, because at the moment we're importing about 7 million barrels of oil per day from outside the continental borders of the United States and Alaska. We're beginning to run down on our supplies of natural gas. And the fossil fuels that have been produced in such enormous quantities over the last 125 years are beginning to run out as far as the United States and its possessions are concerned.

When you look at where energy is coming from, you discover why our imports would continue to grow indefinitely—if we continue to insist on growth in these sectors—and why our dependence on overseas supplies and our imbalance of payments would grow indefinitely. But there are a number of reasons why this will probably not happen. First of all, there's the question of price. If we trace the real price back into the 1960's, for example, we find that this price—the fixed price in 1967 dollars—of electricity, gasoline, and natural gas in the southern California area actually declined (left). In some cases this was because of economies of scale; that is, we were building larger and larger power plants, which were also more and more efficient, so the price of electricity dropped from roughly 2¢ per kilowatt hour to 1.4¢ (in fixed 1967 dollars). But we had a turnaround in the late 1960's, and today the latest expectation of electricity prices for residential use is about 4¢ per kilowatt hour. When we reduce that to 1967 prices, it's still about 2½¢.

Gasoline prices have climbed very rapidly even in 1967 dollars, and natural gas is about to take off—because we're running out of it. Even the Federal Power Commission has recognized that fact. We're running out of it in

California because it can be sold in Texas for $2.00 a thousand cubic feet, but across the state line it can be sold for only 56¢ a thousand cubic feet. So I give you the choice—if you were a businessman, what would you do?

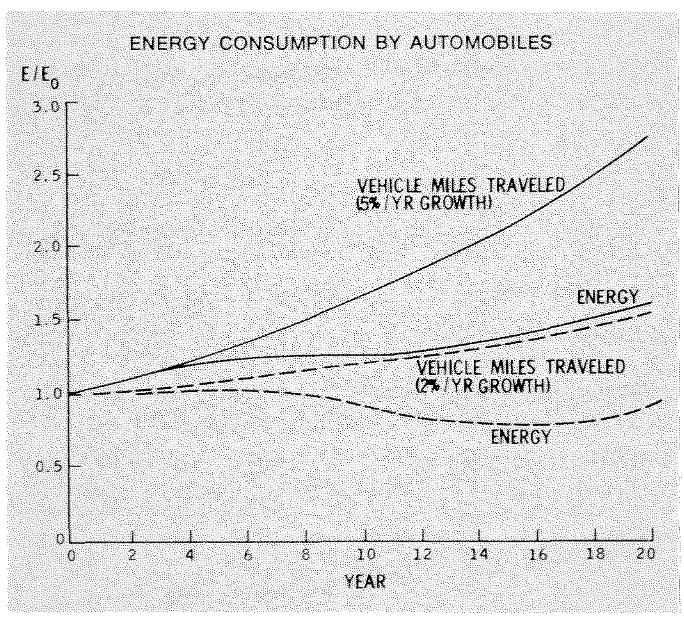
One factor that is going to be important in our lives is that energy is going to be neither cheap nor abundant. When we divide our expenditures for gasoline, electricity, and natural gas by our personal incomes, we can see what fraction of our personal incomes we are spending on energy. During the 1960's it was remarkably constant at about 7 or 8 percent in California, and a little higher in the East where the weather is colder. But *if* the energy growth rate of the 1960's were to continue *and* the present price rises were to continue (largely because of the quadrupling of the oil price by the Oil Producing Exporting Countries, and because of the fact that we're going into deeper and deeper oil wells, the costs of doing business are going up not only in 1975 dollars, but in real terms), then the percentage of our incomes that would be devoted to energy would be on the order of 15 or 20 percent.

You know that's not going to happen. As we realize in our pocketbooks that our expenditures for energy are becoming a larger and larger fraction of our disposable income, we're going to do something about it. The economists predict, for example, that what would happen in the case of electricity would be that the rate of growth in usage would decrease. This is an indication of what's going to be happening over the next 10-15 years. The utilities are already noticing a very slow rate of growth, if any growth at all—and this is making their cash flow problem extremely difficult, so that they are not building as many new plants as had been planned for just a few years ago.

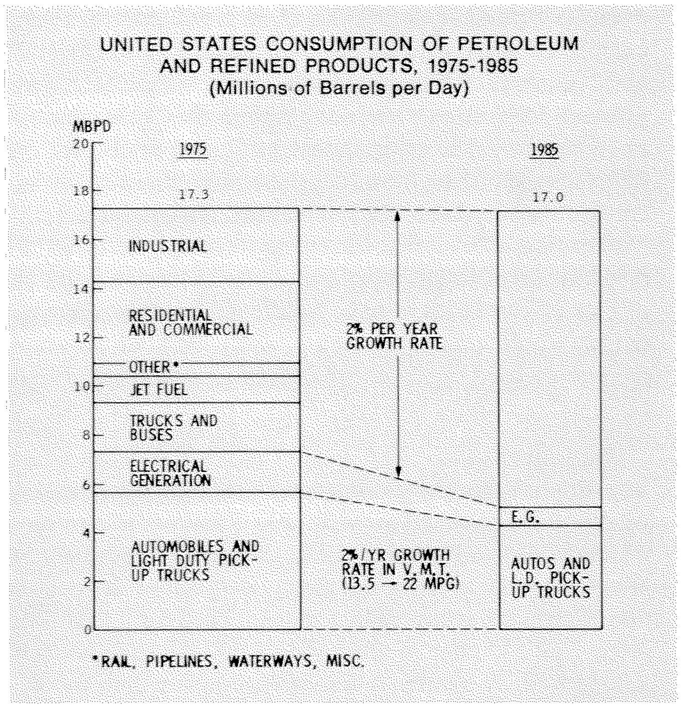
When we come to the question of the efficiency of end use and the question of saturation, the automobile is the chief villain, because it uses about 16 percent of our primary energy. Suppose we started today with the gas guzzlers that get about 13 miles per gallon and began to introduce into the car population efficient cars that got twice that amount—26 mpg. Adopting a very conservative production schedule (we could do much better than this, actually), in the first year we would produce 90 percent gas guzzlers and 10 percent efficient cars. The second year it would be 80-20 percent; the third year, 70-30 percent—until by the tenth year we would no longer produce any more gas guzzlers, and the production lines would roll off only the 26-mpg cars. It would take some time for this to have any effect, but by the tenth year the "mix" would be about 50-50, and the "fleet average" would be 20 mpg, not 13 (the average of 13 and 26).

What would happen to the energy? Suppose that the vehicle miles traveled were to grow at 5 percent a year, which is about what it was doing in southern California over the decade of the 1960's. If we stuck to these 13 mpg cars, in 10 years we'd be using 50 percent more gasoline, in 20 almost 2½ times as much. In the United States we now use 5.6 million barrels of gasoline per day, so that in 10 years we'd be using almost 9 million barrels per day. However, if we introduce these new efficient cars at this very leisurely production schedule, which is easily attainable, at first the energy consumption would rise (because it takes a little while for the rising population of new efficient cars to have an effect), but then the energy would actually decrease, and even after 20 years the energy used by the entire fleet of automobiles, which by that time would have grown by 4 percent per year, would be only about 20 percent greater than it is now.

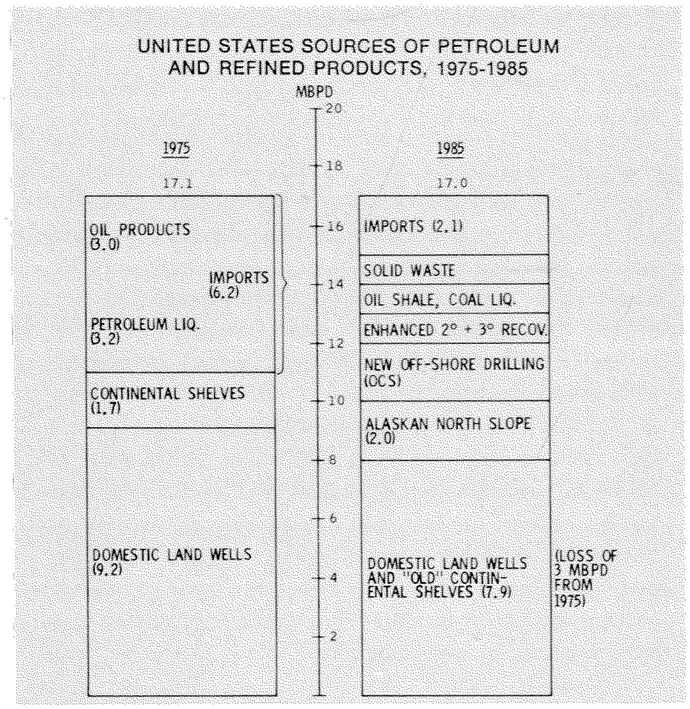
But suppose that the growth rate is *reduced*, i.e., the vehicle miles traveled grow at only 2 percent per year—which would still leave room for a 1-percent-per-person growth in vehicle miles traveled. (Remember the population is growing at less than 1 percent per year.) Gasoline prices and a change in attitudes would lead us to use our automobiles in a much more intelligent way than we do now. We would be combining trips; we would be using public transit; we would be using more efficient cars. The remarkable thing is that after 10 years we'd be using about 70 percent as much energy for driving around as we do now; and after 15 years we'd be using only half as much (below).



The automobile uses about 16 percent of our primary energy. The top curve here shows how energy consumption would rise with present-day cars and our present growth rate of vehicle miles traveled per year. More efficient cars (second curve) would reduce consumption. Reduced growth rate—using present-day cars (third curve), and more efficient cars (fourth curve)—would reduce it even more.



UNITED STATES CONSUMPTION OF PETROLEUM AND REFINED PRODUCTS, 1975-1985 (Millions of Barrels per Day)



UNITED STATES SOURCES OF PETROLEUM AND REFINED PRODUCTS, 1975-1985

We'd save in 10 years about a million and a half barrels of gasoline per day, or more than half a billion barrels a year—which is the equivalent of $5 billion a year—just by doing this one thing with the automobile—namely, either by incentive, by regulation, or by a change in attitude, going from the gas guzzlers to the efficient cars that are technologically available.

If by measures such as this we can keep our total petroleum consumption (above) about the same over the next 10 years (say about 17 million barrels per day), can we match that supply (above, right)? The old wells naturally get pumped out, and we would lose about 3 million barrels per day by 1985, but we could make it up from the Alaskan North Slope (about 2 million barrels per day), new offshore drilling (and I mean environmentally safe offshore drilling), and enhanced secondary-tertiary recovery (meaning injection of steam and other materials to get out more of the oil than we do now), oil, shale, coal, and solid wastes for a total of about 15 million barrels per day. (The most recent expert estimates throw some doubt on the possibility of reaching a goal of 18 million barrels per day by 1985—which only serves to emphasize the need for both conservation and a rational supply policy.)

Our imports would then be down to about 2 million barrels a day, which means we'd be paying oil importers to the U.S. about $7 billion per year instead of $24 billion, and we would have a balance of payments surplus instead of a deficit. So you see we needn't talk about energy self-sufficiency; that's a nonsensical idea. All we have to talk about is a stable position, and that stable position can be achieved by cutting imports from 6 or 7 million barrels a day to 2 or 3 million barrels a day by providing these domestic supplies and combining this with a strong conservation program.

There *are* other ways to do it, but the message is loud and clear: A total national energy policy should seek to freeze the total U.S. consumption of oil over the next 10 years, and should seek to build up our supplies to the point where our imports are no longer a drain on our economy, but, on the contrary, where we have a balance-of-payments surplus. We could even think of being an energy-exporting country in the long run.

The problem of conservation of energy in homes and in buildings is also an urgent one, because of the growing natural-gas shortage, as well as the high price of petroleum imports. We don't have much time either, and unfortunately it takes time to conserve energy.

We asked ourselves the same question that we did for automobiles. Suppose we start building homes, apartments, and commercial buildings that use half as much energy per unit as the current ones. How do we do that? By cutting down on lighting levels in commercial buildings by a factor of at least two, by making sure the air conditioning and the heating systems are not on at the same time, by re-inventing openable windows, by watching the rate of infiltration of air so that we don't take in cold air on cold days and warm it up, or take in hot air on hot days and cool it down any more than we need to, and by glazing, shaping, and shading buildings. There are at least 15 different methods that would, according to the best architectural information we have, reduce energy consumption in commercial buildings and residential buildings by a factor of two if the technologies we know now were put into effect.

Assume that the population of homes and apartments grows at about 2 percent a year, which is its normal rate of growth, but the energy per living unit grows at 3 percent, so that the overall growth is 5 percent. As we introduce buildings and living units which use half as much energy as the current ones, the rate of growth slows down considerably. If we maintain the 2 percent net rate of new construction, but allow the energy per living unit to grow by only 1 percent per year (which is about as fast as the population is growing), then even with no rehabilitation of older homes, the energy use will remain almost constant for 20 years. By updating existing buildings we can reduce the amount of energy we consume by 20 to 30 percent. This is technically feasible. The question is: Is it economically feasible? Are there incentives, are there institutional changes, are there desires on the part of the public to see a national energy policy that has these objectives?

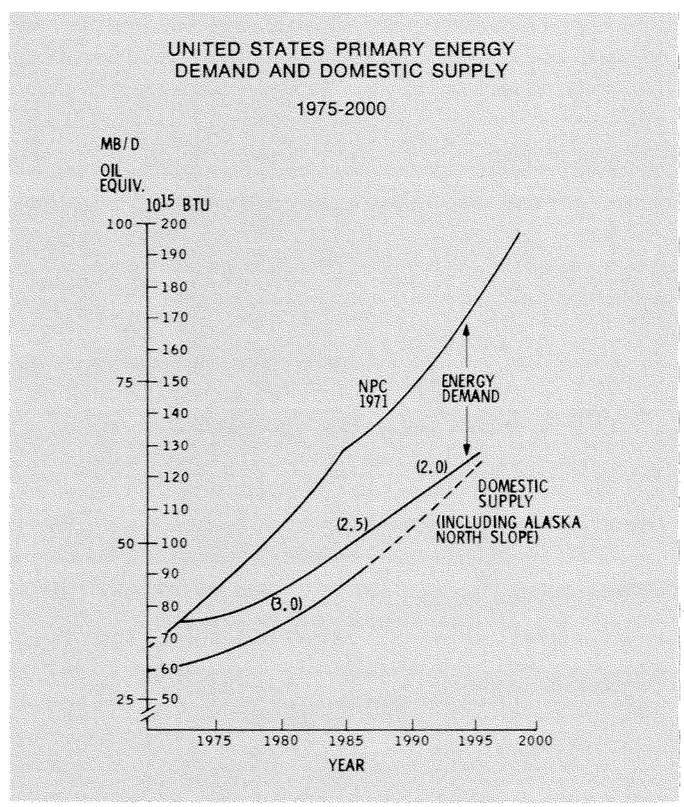
One of the most intriguing of our renewable resources—solar energy—has an element of conservation. Some of the data that have been measured at the Jet Propulsion Laboratory in cooperation with the Southern California Gas Company show incident solar energies of the order of 1 kilowatt per square meter in this climate, or of the order of 4 kilowatt hours per square meter per day. This means that for 100 square meters, or about 1,000 square feet, we're talking about 400 kilowatt hours per day of incident energy, and when we use that solar energy and convert it to heat (not to electricity; this is a thermal conversion system, which is as old as the Egyptians—heating water, using the greenhouse effect, and then converting that water into a system of circulation), we get 60 to 70 percent of the solar energy out.

In southern California, we find that a gas-assisted solar hot water heater would use about 70 percent of the sun's energy and about 30 percent of the gas energy—so the gas company would have a little less of a problem here. That's one of the reasons they're interested in it, and there is now a joint project financed by the National Science Foundation with JPL and the gas company, shifted over to the new Energy Research and Development Administration.

Let's now look at the whole U.S. energy situation over the next 20 years. In 1971 the National Petroleum Council looked at the next 25 years and predicted a 4.2 percent rate of growth in demand up to 1985 and a 3.2 percent rate of growth in demand thereafter up to 1995. The difference between demand and supply would grow indefinitely until our reliance on imports would be intolerable (below).

We are now in a recession, so our energy use has actually dropped. I predict that when it does resume it will do so at a growth rate of roughly 3 percent per year, drop to 2.5 percent per year by 1985, and to 2 percent per year by 1990, if we do all the things I've said.

As to the import situation, the National Petroleum Council predicted that by 1985 we would be importing on the order of 20,000,000 barrels per day from the rest of the world—and by the 1990's it would be a little more

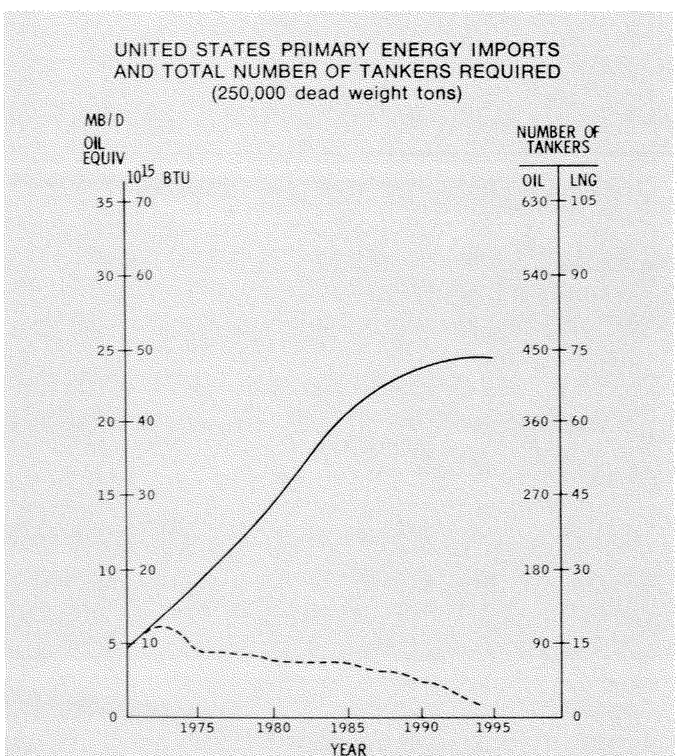


Two projections of energy demand—one made in 1971 by the National Petroleum Council (top curve), and one made by the author (second curve) on the basis of a conservation strategy. The bottom curve is one estimate of our possible growth in domestic energy supply.

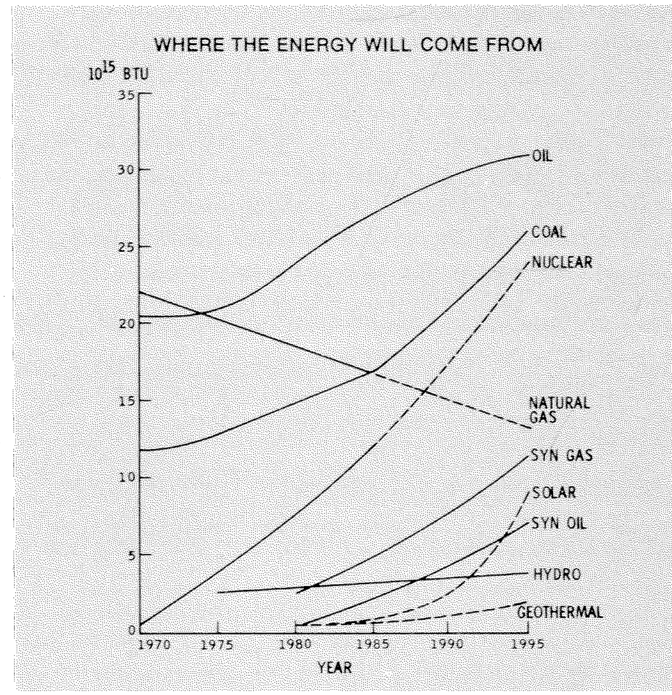
than that, as shown in the chart below. However, if the growth rate follows my prediction, which starts up at about 3 percent per year and goes over to 2.5-2 percent per year by 1985, then there would be a steady drop in imports until by 1995 we would have almost a balance of imports and exports of energy.

We have developed a very optimistic scenario that tells where all of this "domestic" energy is going to come from (right). The oil will come from the Alaskan North Slope, plus offshore drilling where it is environmentally acceptable. The coal will involve a complete change in technology. We can no longer mine coal in the old way; we will probably have to do it semi-automatically or fully automatically with hydraulic machinery—robot machinery that goes underground. That's a long story, but we must indeed try to double our coal production. We estimate production of about 200,000 megawatts of nuclear power by 1985 (or about four times what we have now), which would be at that time about 30 percent of our total electrical output. The remainder would be synthetic gas and synthetic oil from coal, and one of my favorite sources—solar energy—as well as geothermal energy and hydroelectric energy.

The message here is that it takes about 15 or 20 years from the time of introduction of any new technology until that technology is contributing as much as 10 percent of



Two projections of energy imports—one (the upper curve) based on the 1971 National Petroleum Council projection of demand shown in the chart on page 7, the other (lower curve) based on the energy demand with conservation shown on the same chart.



the total energy in the country. In the case of nuclear energy it's taking longer than that. Our first successful reactor appeared 25 years ago, and still we are only producing about 11 percent of our electricity with nuclear energy, which is in itself only 3 percent of our total energy.

So we have this infernal time scale staring us in the face. Ten or fifteen years seems to be about as fast as we can do anything. Perhaps we can be clever and invent new institutional mechanisms, as we did during the Second World War and in other national emergencies. This is a different world, but I commend to you the fact that this country can do what it wants to do when it makes up its mind to do it. It isn't necessary to go back to washing clothes by hand, and reading books by candlelight, and trying somehow to keep your food from spoiling by using salt and throwing out your refrigerators. What is necessary is to cut down on the rate of growth—not on the use, but on the rate of growth of energy use, and that's a fundamental, philosophical, technological, and institutional distinction. And there are means available for shifting over toward synthetics, clean fuels, toward renewable resources, reducing the rate of growth in our energy consumption, and coming out with a world that will look quite different from the one we have now, but will still be a very good world to live in as far as the United States is concerned. □

The Limits of Science

BRUCE MURRAY

In science, only reproducible, or at least recurrent, observations can be dealt with rigorously. How, then, can scientists assess purported phenomena such as ESP, UFO's or religious miracles?

Up until the last century, most of Western society had a point of view about life that was strongly conditioned by religious precepts. There were religious explanations of both how and why things worked out the way they did. In this century that point of view has been greatly altered by the development of science and technology, so that many people now find themselves at least vaguely familiar with the *how*, but often baffled about the *why*.

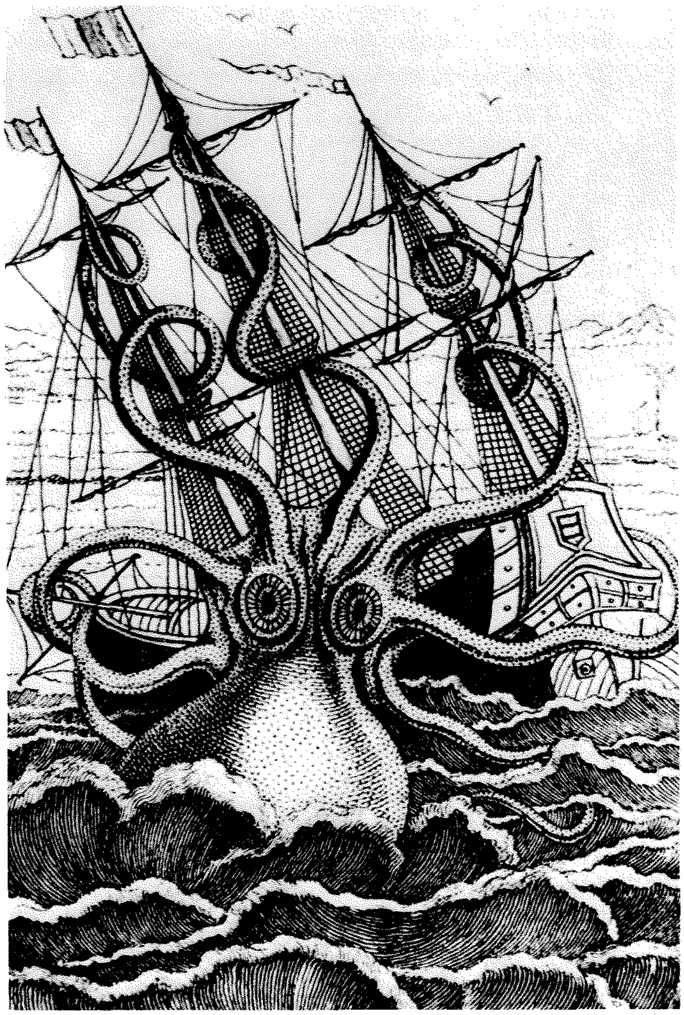
The result has been a rise of irrationalism at the very time when we have the most educated population in the history of the world, in terms of science and technology. For example, the average person's knowledge of astronomy in the United States today is higher, I am sure, than it has ever been at any time in any large country. And yet astrology, which is completely inconsistent with the most elementary understanding of astronomy, is widely popular and practiced. This phenomenon suggests that many people don't really care if a belief is apparently irrational, so long as it contributes to explaining the *why*.

Indeed, we are finding that at the time in man's history when he is supposedly liberated to understand the modern world in modern terms, he seems to grasp at many peculiar, semi-irrational things. I interpret this as both a lack of understanding about the limits of science and a need for a source of values he does not find within science. So there is a need to understand how science can be applied—and what are its limits—in order to establish the proper domain of scientific authority. Most important, understanding the limits of science also implies understanding the unique role of human judgment, feelings, intuition, and values. Unless the boundary is rather well understood, there can be an attempt to try to apply science to unscientific situations, and sometimes to rely on human intuition in scientific situations. Both circumstances can lead to confusion in the lives of individuals—and tragedy in the histories of nations.

One way to identify the limits of science is to study problematical phenomena—phenomena and events about which there is no clear-cut opinion, even among scientists.

Basically, a scientist can only pass judgment on something if he can observe it and if it can be observed by others. And a phenomenon or an event must be repetitive, or at least recurrent, in order for it to be reobserved. So problematical facts arise in those cases where the phenomena are not recurrent or repetitive, or at least have not been so far. Ultimately, of course, these sorts of things, if they are real, can be brought into the realm of science through long-enough studies, accidental occurrences, and the like. We geologists always like to enumerate and categorize things. So I have made a list that I call a classification of problematical subjects.

The first category has to do with Questionable Living Animals—that is, are such animals alive? All these creatures were at one time doubtful or are doubtful now—giant squids, sea serpents, gorillas, the unicorn, the Abominable Snowman, Big Foot of the Pacific Northwest, the Loch Ness Monster, and the living coelacanth, a very primitive type of fish found only in extremely ancient strata.



This unlikely looking sea monster is a fanciful representation of a creature that really exists—the giant squid, which can attain an overall length of up to 80 feet. Though the squid normally lives deep in the ocean, now and then it is sighted on the surface—and then its size and appearance can be frightening.

The next category is Conjectured Historical Events—events that were conjectured and have since been disproven, or were disbelieved and have since been proven, or are still problematical. They include continental drift, the island of Atlantis, Pleistocene man, the Velikovsky theories of drastic changes in the orbits of the planets explaining historic terrestrial events, pre-Columbian contact with America by European peoples, the antiquity of the earth, man's evolution from ancient primates, dragons, and the Seven Cities of Cibola—a legend prevalent at the time of the Spanish conquistadors that led to the search for mythical cities of gold.

The next category is Purported Natural Phenomena—the extraterrestrial origin of meteorites, germs as the cause of disease, alchemy, the question of canals on Mars, unidentified flying objects, the phenomenon of ball lightning (natural plasma discharge), the question of whether advanced civilizations exist elsewhere in this galaxy, the issue of life on Mars. The most recent phenomenon in this category is a purported substance called polywater—a new form of water, reported in the scientific literature less than a decade ago, which has led to considerable scientific interest.

The last category I have noted is Purported Human Phenomena, and here I include hypnosis, which was at one time believed not to exist; ESP or extrasensory perception, which is a controversial subject at present, and which actually has many subdivisions; as does the subject of religious miracles, which range from purported events involving individuals to miracles affecting the ocean, the sun, and the sky. Then come ghosts, astrology, and Freudian psychology, which was considered to be a nonscientific subject when it first emerged. Phrenology was at one time considered to be a valid scientific way of relating physiognomy to personality by the bumps on the head. Faith healing, a widespread activity in the early Christian era, has had a renaissance recently, it seems. And there is finally acupuncture, which is back in the news as a result of our Chinese diplomacy.

A list like this only serves to emphasize how diversified these problematical phenomena are, and to show how different aspects of human affairs and human thought overlap the range of these phenomena. Take sea monsters, as an example. Everyone has seen woodcuts showing some monstrous creature attacking a ship. The one shown at the left, which looks like an octopus, used to have the name in medieval literature of kraken, and it was not considered to be real—until three of them washed ashore in Newfoundland in the late 19th century, the largest of which was 80 feet long. They turned out to be giant squid. The giant squid lives deep in the ocean, away from the shore, and normally its body—which contains very few hard parts anyway—is not recovered. In this case the ocean currents happened to bring these things onto the shore, where they could be measured. Stories of these monsters attacking ships have been reevaluated, and now it appears that there *are* squids large enough to be frightening to people in a small sailing vessel, and they *do* on occasion rise to the surface and float there.

So here is a case of something that was considered mythical as late as the second half of the 19th century being certified as real. Because there was no hard physical evidence that could be examined by different scientists—until the squid were actually found—there was no way to trust the description of these things. So they were written off as sea stories.

Nobody has ever found a sea serpent, and none has ever washed ashore to be examined by scientists. But there are still reports of them. For example, the basking shark is a giant animal, and when it washes up on a beach, it looks a little bit like a sea serpent. These have often been reported, but then competent zoologists have examined the specimens and determined that they really were not anything unusual.

There have also been some very weird fakes, in one case utilizing fossil bones in conjunction with modern ones. Such cases should remind us that whenever one has folklore, it can easily turn into fakelore. I think we have to remember, in evaluating all these reports for which we cannot find hard physical evidence, that there is a natural tendency—whatever the origins, and however honest the early sightings may be—to generate the fakes, as a hoax, with a commercial motivation, or whatever. And so one cannot rule this out when dealing with such things as UFO's, for example.

In the case of purported land monsters, there is hard physical evidence of something in the form of tracks. There is one so-called monster or animal purportedly living in the high Himalayas called the yeti, and its tracks have been reported and photographed in the snow at very high altitudes. The tracks measure about 18 inches long and 13 inches wide. Photographs have been taken by people whose credibility is beyond doubt. They did not know what they were seeing, but it clearly was not something wearing shoes because the print has toe marks on it. This has led to quite a long discussion of the yeti track, the general assessment being that there are a variety of evaporation phenomena at high altitudes which tend to enlarge normal animal tracks in snow and give them peculiar shapes. Also, in the case of certain bears, when they are going at a proper gait, the prints of the front and back feet combine to look like a single foot with peculiar human characteristics. And, believe it or not, human pilgrims have been observed walking across these mountains, barefoot in the snow, as high as 19,000 feet.

But in the absence of unambiguous physical evidence, such as a skeleton, the existence of the yeti becomes less likely as alternative explanations continue to emerge and the real thing fails to show up.

The yeti is a kind of oriental Big Foot. We have an occidental Big Foot in our Pacific Northwest and in western Canada, where the Indian name for the legendary beast was Sasquatch. Its footprint (again, it is barefoot) has an hourglass shape. The prints are very large, and they are seen over a wide area. John Napier, an expert in primate biology, feels it would be very difficult to produce these widely occurring footprints as a hoax. So he is inclined to allow that there could be something real and unknown there. Yet he is convinced that there is not adequate food supply in that area for any large primate. I guess that is where one has to leave Big Foot for the present, remembering the horrible possibility of folklore turning into fakelore.

Let me go on to a far more emotionally charged example—UFO's. This is a subject that seems to be capable of supporting a rather substantial population of paperback books. For a reasonably good writer who can produce some fake pictures, there is a real market for this stuff, which vastly complicates the job of trying to determine whether there is anything to UFO reports. Fakelore so dominates folklore in this situation that it generates a lot of false stories about problematical evidence. Worse than that, it plants the idea of UFO's in peoples' minds so that if they see something they do not understand, they already have the concept of what it might be. One does not find a naive brain, so to speak.

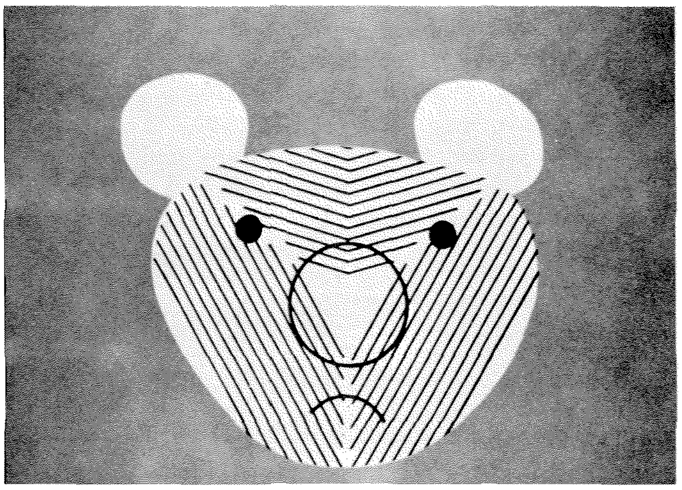
For myself, I am in the middle of the road—mildly negative on UFO's. I do not think there are little green men, but I also do not think you can prove a negative very well. And I do believe there are a lot of honest, sober witnesses who have had the daylights scared out of them by flashing lights or something else happening at night that was real. It was not their imaginations; something was there. But to associate that with spaceships from an alien civilization is a big jump that I think is unsupported.

The existence of UFO's gets to be a debate of almost theological proportions, involving heresy and faith, and that is not very scientific. The reason is that when one is presented with reports of phenomena that do not make sense, some people cannot stand the uncertainty. It is just like the situation in ordinary social affairs, where there is a tendency to want to have an answer right now, right or wrong, and if the only choices are between, "It's nothing," or, "It's the most bizarre thing in the world," you choose one of those two answers. Well, the answer really is that you probably do not have the right answer yet, and so you should not make a choice.

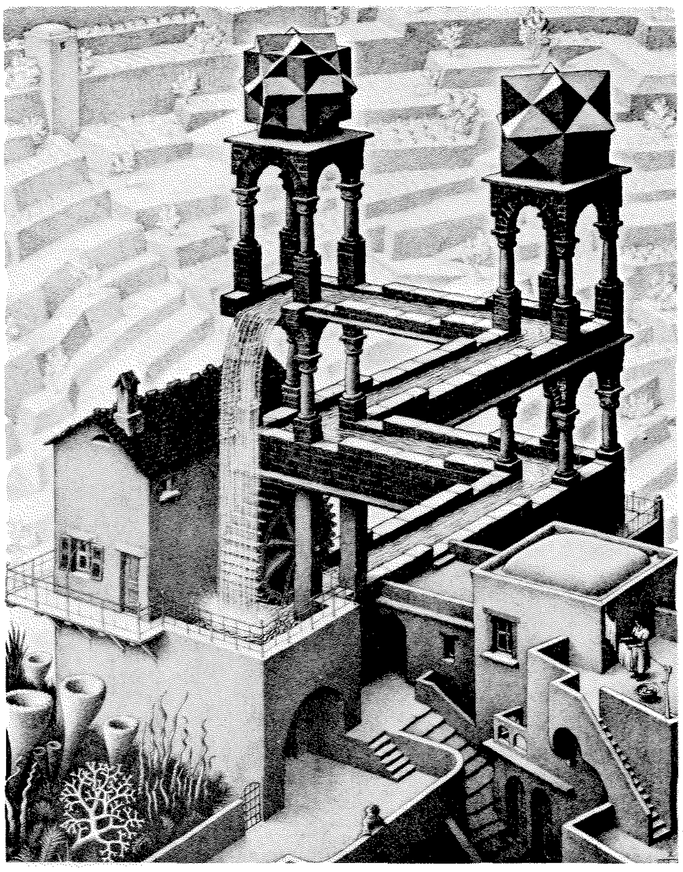
One point I want to emphasize about UFO's and other problematic phenomena is that if there are a lot of emotions involved, on both sides—the debunkers and the advocates—then the situation has gone far beyond the domain of scientific inquiry. The very fact that there is an emotional component indicates the matter involves more than objective evaluation. One can wonder why a scientist feels so compelled to disprove the possibility that something unexplained could be involved. Is he so concerned about his holy church that he cannot stand a little bit of heresy? Similarly, one can question the objectivity of a person who has a conspiratorial theory about how the government is covering up evidence of UFO's. What's the angle? Why is he so emotionally absorbed in this thing that he has to develop such an idea?

However, the real issue with UFO's, or with some of the other purported phenomena, can be stated in this way: Is seeing believing? Can you really trust what you see? Or can you believe an honest, sober person who says he saw something like a spaceship set down in the desert?

From **Take Another Look** by Edward Carini. Copyright 1970. Published by Prentice-Hall, Inc.



In spite of how you see it, the bear's nose in this drawing is a perfect circle. It does not appear so because the illusion created by the perspective of the drawing keeps the eye from transmitting an accurate image to the brain.



The only way to keep water always flowing downhill, no matter what heights it has to scale, is by optical illusion—as artist M. C. Escher has obviously discovered.

One way to inquire into the reliability of visual reports is to consider optical illusions, where obviously the eye is not transmitting a faithful image to the brain.

The bear's nose in the drawing at the left is an exact circle. It doesn't look like a circle, and no matter how hard you try, even when you know the answer, you cannot make it look circular. This is an illusion of perspective. *And it is telling you something: Somehow the eye is not* processing information and transmitting it to the brain accurately.

In a different kind of illusion, the question is, which way is up? This approach has been used by the artist, M. C. Escher, whose drawing (below) could be bothersome because the stream seems always to be flowing down. Perhaps Escher has produced a perpetual-motion machine.

Let's try a reversal illusion. In the Escher drawing on the opposite page, do you see white angels? Or black devils? It just depends on which you want to see, but I defy you to see both at the same time. What this says is that the brain can choose which image it can assimilate, but the eye-brain combination normally cannot simultaneously perceive both images. It has to have some information to tell us which one to choose.

These illusions are not confined to the abstract world of art. Consider the Mariner 9 picture of Mars across the page. Do you see blisters—or pits? Well, there are no blisters on the picture. The sun is coming from the right, and so the bright things you see are surfaces sloping downward, facing the right. The dark things are surfaces sloping downward, facing away from the sun to the left. This is very important, because it illustrates that you need some *a priori* information—you need to know where the sun is coming from—in order to make that reversal illusion choose the right sense.

In fact, everything we see not only has to be processed and handled by the eye-brain combination, but it must be compared with remembered images or coded signals of some kind in the brain. Otherwise, the brain is helpless. It just says, I don't know. If it is scared, it can say, I'll just take the thing in my memory that looks most like it, and choose that instead. It is very hard for the brain to say, I just simply don't know. So it tends to pick the best guess it can get from what is already in its memory.

Why doesn't the eye image correctly what is outside in nature, so the brain can then ponder what it sees and make a decision as to the reality of what it is looking at? Well, it turns out that you can do simple arithmetic that is helpful. In order to transmit a television picture by wire a special cable called a coaxial cable is needed. Such a cable is equivalent in capacity to at least 500 telephone lines that only carry voice. A television picture simply cannot be put down a telephone line. It won't fit, so to speak.

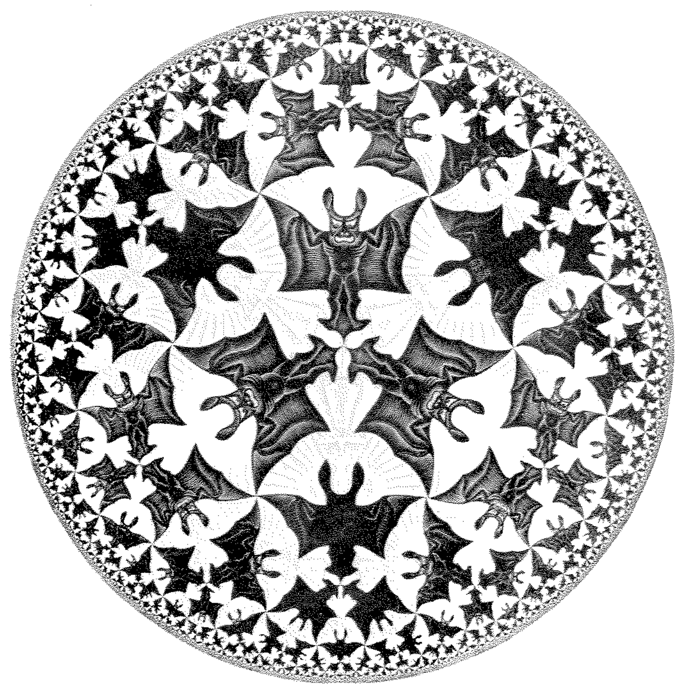
There are wires from the eye to the brain, too. They are called neurons, and they transmit pulses of information, but it takes tens to hundreds of neurons to do the work of one telephone line. So, in order for the brain to "receive" a television picture using neurons only, somehow the information in the picture must be broken up, encoded, and transmitted down as many as several hundred thousand neurons and then reconstituted. That is very hard to do. When you think about it, then, it is not at all surprising that optical illusions and evidences of other kinds of aberrations arise. The eye-brain combination is doing a fantastic job of processing a picture, breaking it down into its elements somehow, transmitting the information, and then reconstructing a "picture" from both eyes in order to get stereo. At the same time it compares the picture with remembered images so the brain can make a decision about what it is looking at.

To quote John Napier, although we do not always know what we see, we tend to see what we know. It is the same as saying we have to choose what we have seen or known about before. And we tend to perceive the conceivable. I would say that it is very difficult for us to perceive the inconceivable.

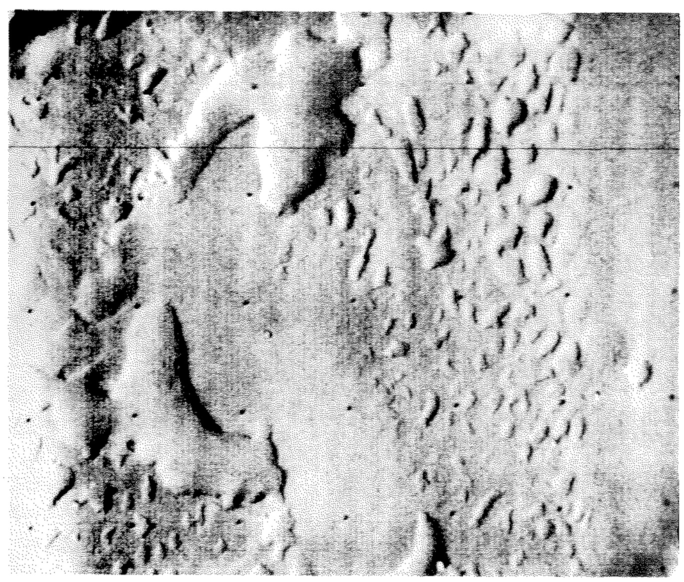
To take an example, a theoretical physicist at Caltech was driving up the Owens Valley on a vacation when he saw off to his left, in the late afternoon, a bright luminous object that was much larger than a star or planet, and—he believed—much brighter. It was near the mountains, and it maintained its shape for a while and then it disappeared. He told me about it later and we checked the astronomical tables. We found that Venus was, at that instant of time, just setting below the crest of the Sierra. This is a place where the world's glider record has been set, because the atmospheric conditions over the Sierra exhibit a lee wave—very peculiar atmospheric effects in which the air is bent in strange ways. Clearly, what had happened was that the image of Venus was being refracted in a very peculiar way, which produced an image of Venus that was unfamiliar even to him.

Had this been somebody who was already preconditioned to believe in UFO's, he would undoubtedly have said that he had seen something that was unlike anything he had ever seen before, or heard described. So it must be a UFO.

In dealing with things like UFO's, or to some extent ESP, where the criteria of reproducible or recurrent observations are not available, one cannot say that such things exist physically—and they do not exist scientifically. Depending only on eyewitness reports is not good enough. Furthermore, if there are emotional elements, not to mention theories of conspiracy and suppression of evidence, then the subject can become hopelessly distorted.



It is possible to see either white angels or black devils in this Escher drawing of a reversal illusion, but the eye-brain combination cannot perceive both simultaneously.



Optical illusions don't all come from the world of art. This picture of the surface of Mars, for example, looks blistered instead of pitted—unless you know that the sunlight is coming from the right, illuminating the bright downward slopes that face it. The dark areas are downward slopes facing away from the sun.

I would like to turn back to my list of problematical phenomena now. Across the page I vote my conscience on whether each of these subjects is significant—yes, no, or maybe so. In each case I have started an arrow at the place on my scale where I think the phenomenon was at some earlier time. The point of the arrow shows where the phenomenon belongs now. I think that what is useful about this exercise is that it illustrates in a sense some of the fringes of science, some of the limits of science. Thus, the giant squid did not exist at one time, but now it does. In earlier times, sea serpents were widely believed to exist; now it seems less likely, but still not all the way to no. One of them could drift up on the sands of Nova Scotia, and that would change our whole opinion. I do not know any way to prove that this could not happen.

There were not supposed to be gorillas at one time; they were thought to be wild men. Now, of course, we know they exist. The unicorn, on the other hand, is a mythical beast; the legend may have developed from reports of the Arabian oryx, an antelope. When seen from the side, it appears to have only one horn—and there are certainly no special powers associated with that horn. The Abominable Snowman, or the yeti, was seriously considered at one time, perhaps, but now is taken much more skeptically. Big Foot, again, was probably once plausible, and though it is less so now, it is still difficult to account for its footprints. The Loch Ness Monster was once plausible, but people have looked and looked and they seem not to find anything that you can come home with. But then it is hard to find something in a deep lake like that, so we will leave a little possibility that something could turn up. The living coelacanth was clearly extinct 200 million years ago—until it turned up alive in a fisherman's net off the east coast of Africa.

Continental drift was rejected by science at the turn of the century, but now it is one of the cardinal beliefs of modern geology. Atlantis was considered to be a myth lingering from the time of Plato, but now it appears that the island of Thira in the Mediterranean might in fact have been the site of ancient Atlantis. The Velikovsky theories never had anything going for them, and they still do not. The pre-Columbian contact with America is now confirmed by hard archaeological evidence that the Vikings established a temporary colony here. There is suggestive evidence that much earlier contacts were made, perhaps even as early as the Phoenician days. The antiquity of the earth, of course, used to be set at 6,000 years; it is now more like 4.5 billion.

Darwin triggered a debate over whether man evolved from primates, and it still develops here and there, but is really well over; there is a convincing paleontological record showing that man has evolved from ancient primates—not from modern apes, but from ancient common ancestors.

Dragons, on the other hand, used to be accepted and then were cast out. But there are still some possibilities. The stories of dragons might in fact reflect cultural memories of the last of the large Pleistocene animals that died away, so you cannot just throw them out as only a fantasy.

The Seven Cities of Cibola was a myth that was fakelore in part, in the sense that there were Spanish adventurers who wanted to promote an expedition, and so they put out the idea that there were seven cities of gold in what is now New Mexico and Arizona. There was a basis of truth in this, in the sense that the Indian Hopi and Zuni settlements there were in fact little cities, though not at all what the Spanish imagined.

The idea that meteorites were of extraterrestrial origin was condemned by the French Academy of Science in the late 17th century. They are now, of course, recognized as rock fragments from elsewhere in the solar system, based on a lot of confirming evidence. But this is a case in which science itself has had to move over.

The same is true of impact craters on the moon and the earth, which also were not believed initially to be of extraterrestrial origin. Germs as the cause of disease, of course, is an article of faith for modern sanitation and public health as well. It was not always so.

Alchemy at one time was widely believed, but once the atomic theory of matter was generated, it was recognized that alchemy was not possible in the chemical sense but only in the nuclear-physical sense. Lead could never have been turned into gold in medieval times.

Canals on Mars were originally "canali"—linear features on that planet that were accepted as observed by the 19th century Italian astronomer Schiaparelli. The American astronomer Percival Lowell then turned them into "canals," meaning creations by intelligent beings—which was rather skeptically received. After the Mariner mission to Mars, we know that the "canali" are not there, much less the canals. They never were there, in fact. It was an artifact of pushing too far the limits of visual observations through a telescope.

The dashed line for UFO's on my list means that various things that are reported have various degrees of probability. I think the possibility that there are occasionally atmospheric phenomena involving electrical discharge, for example, or plasma effects, has not been ruled out. It might account for some things that have been seen, but little green men in saucers are very improbable, not just on an *a priori* basis, but on the basis of reports, which are not very convincing, and there is never any hard physical evidence.

Ball lightning, which is a natural plasma discharge, was

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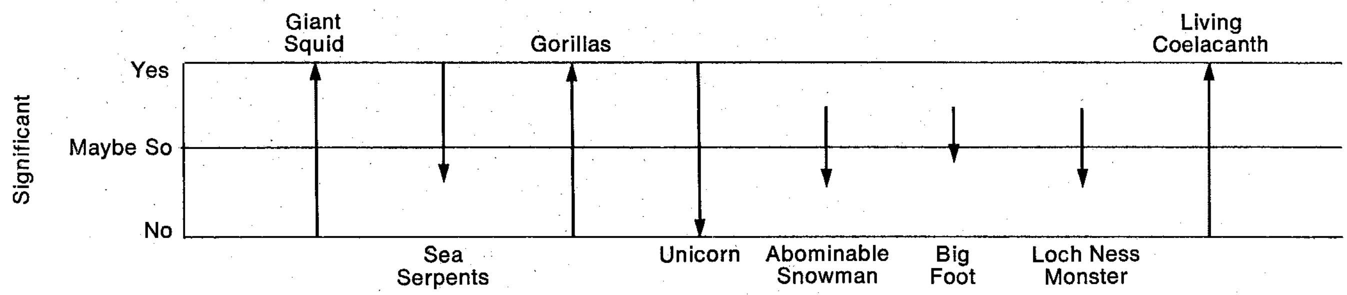
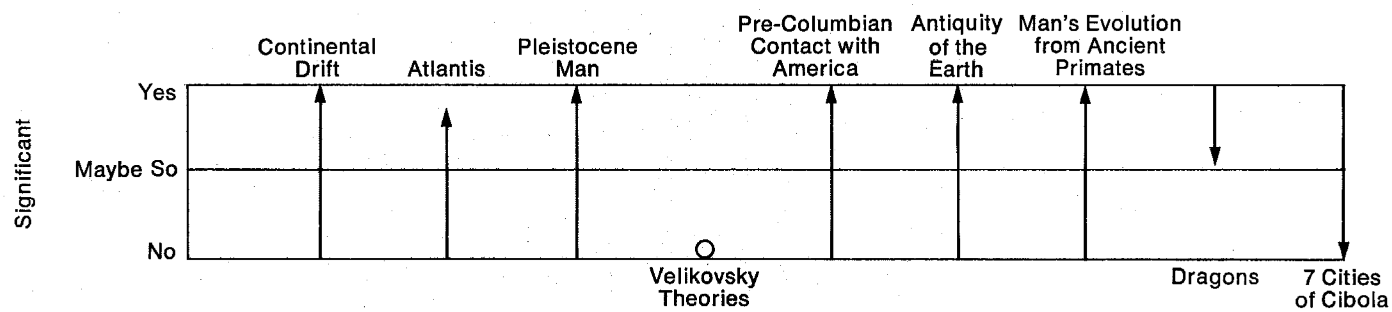
A Classification of Problematical Subjects

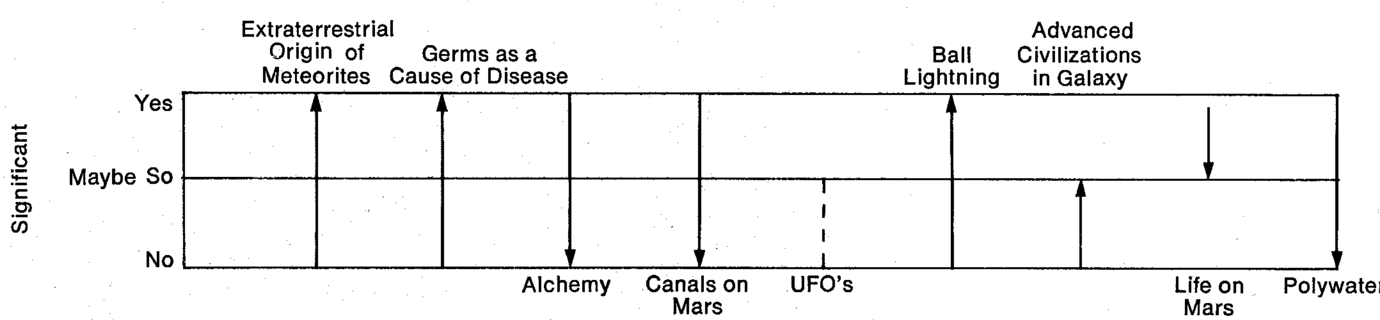
Questionable Living Animals



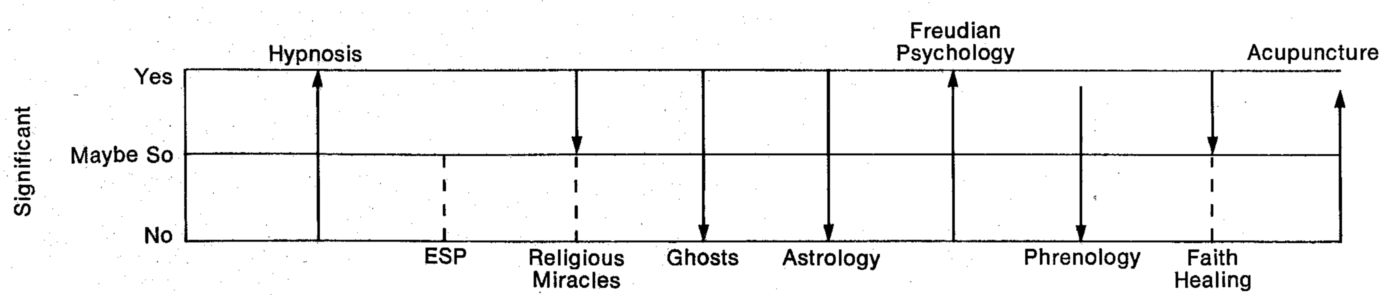
Conjectured Historical Events



Purported Natural Phenomena



Purported Human Phenomena



once not believed to be true and is now accepted.

Fifty years ago, or even less, very few scientists entertained the idea of other civilizations in this galaxy. Now, many do, and people are beginning to wonder how to test this idea observationally.

Although human life on Mars was never widely accepted by scientists, it has been commonly accepted that plant life exists there, and that it is the origin of the seasonal variations. The Mariner program has proven large-scale plant life out of the question. Now Viking is supposed to test for some kind of microbial life or determine whether Mars really is a sterile planet.

Polywater, a supposedly new state of water that was discovered about ten years ago, led to a fast but interesting scientific history in which it was finally shown that the anomalous observation resulted from a subtle contamination of glassware in the laboratory.

To wind up with Purported Human Phenomena, hypnosis was denied as a real thing until medical science was finally able to describe it clinically, and recognize that it is indeed a reproducible state of the human body.

ESP, like UFO's, can mean many things. The idea of psychokinesis—of thought influencing material objects—is pretty hard to swallow, and I do not know of any evidence for this that has stood up in scientific courts. There are other aspects of ESP that have not been excluded as clearly, in an observational sense; in fact, there is some serious scientific research about ESP going on in some institutions.

Religious miracles embrace not only healings, but cases like the one in 1917 when a large crowd in Portugal was reported to have observed the sun stand still in its orbit. This, I believe, did not happen, because the earth would have come apart and destroyed itself if it had stopped its rotation. Certainly, the rest of us would have noticed! But there are other religious miracles, especially those that have to do with healing or with physiological effects on people, that are less easily excluded. I think it would be unwise for science to say flatly that all religious miracles are bunk, because each purported incident needs to be examined on its own merit.

Ghosts were widely believed in Shakespeare's time, but since they have never permitted themselves to be observed for four centuries, I would say there is very little likelihood that they exist.

Astrology not only has no supporting evidence, but we also know where the mythology came from. We know that it was a part of the ancient pagan religions that existed before scientific times. So when we find it recreated in modern guise in the daily newspaper, it is simultaneously tragic and amusing.

Freudian psychology, on the other hand, was greeted very skeptically by the scientific community and only gradually won its place in science as a valid representation of some aspects of the psychological behavior of man.

Phrenology, the reading of bumps on the head, has gone away, and is not even taught in the smallest medical school anymore.

Faith healing, which was also widely believed in early Christian times, and periodically since then, is again one of these situations which should not be dismissed. Parts of it seem absurd, while other parts bear further discussion, and I think acupuncture is a good example. Acupuncture is so implausible to our present understanding of how the body works that one tends to dismiss it out of hand, yet it turns out to have some merit. I think some of the faith healing likewise may warrant investigation later on.

What conclusions can I draw from this little exercise? One very important moral for modern Americans is that we have to live with uncertainty, not just in political, social, and economic affairs, but also in physical affairs. There is always going to be a range of things that are not very clear, and it will be impossible to make them clear because the phenomena that are described are not reproducible in the laboratory, or are not easily reproduced in nature.

Science reduces the miraculous to the ordinary through observation, if the phenomenon is indeed observable. If it cannot be observed, and reobserved, it cannot be a part of science. But sometimes these things take time —decades, even centuries.

My second conclusion is that the irrational approach to modern life—the seeking refuge in beliefs that disregard the facts of science (even condemn them)—is really a step backward toward barbarism. In the fierce competition of the modern world, the cynical materialist, who is not handicapped by irrational beliefs, is always going to win over those who would defy or ignore scientific reality. If we as a people want not only to excel in a materialistic world, but to protect and enlarge the esthetic and subjective side of our legacy to history, we must be very objective about objective things. Otherwise, every time we embrace an emotional or irrational attitude about things that really have physical results and meanings, we will slip a little bit. If we slip enough, we will just disappear from history. And then other groups more limited to strict materialism and less attuned to esthetic, spiritual, and subjective matters will become the dominant forces in this century. It will be their legacy, not ours, that will survive in the minds of the peoples of the next century. □

What Makes Caltech Tick?

NANCY BEAKEL

Whether we want it or not, we are a family involved in intellectual and personal development for all our members

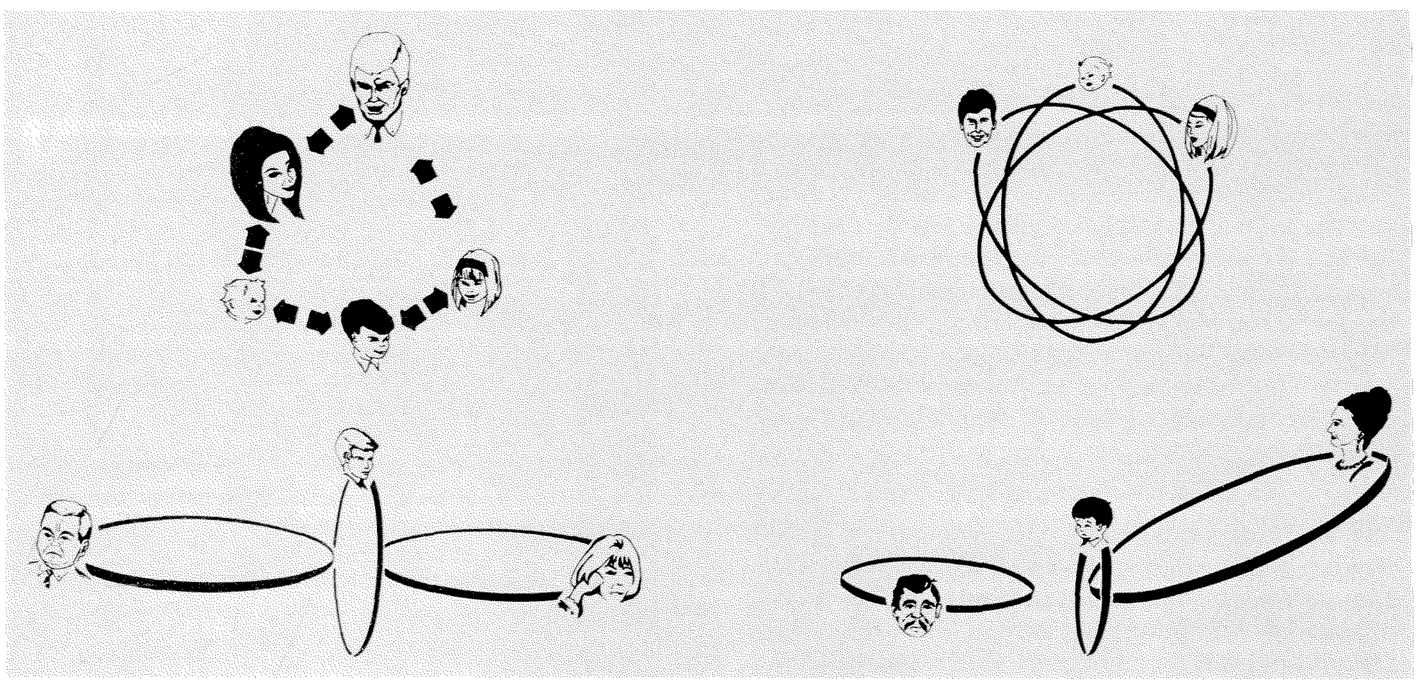
Social psychologists want to know how people interact with other people in a society, and to that end they spend a good deal of time observing people in small groups. People, they say, are shaped and influenced by each other.

The social psychologists express the view that the family, which is the most important social influence on the child, can be considered as a special case of a small group. With this in mind, I would like to attempt to analyze a larger group—our own Caltech family—as if it were a constellation of fond relations like the family groups with which we are all familiar.

First of all, when people come together in small groups, the group begins to evolve a unique personality of its own that is apart from the personalities of its individual members. The group acquires an image, a separate set of traits which are perceived by people outside the group.

The second characteristic of small groups is that they tend spontaneously to develop leadership and a power structure. Leadership is usually divided between a task leader who serves to guide the group toward its goals and a social-emotional leader who facilitates goal attainment by serving the emotional needs of the group.

In normal families, it is believed, father assumes task leadership while mother, as the social-emotional leader, salves wounded feelings and keeps communication lines open. I personally believe that both leadership roles are



In the traditional hierarhical family (top), day-to-day interactions flow down from parents to child and upward from child to parents. Parents also interact with each other, though not always equally. But normal families may often be more accurately represented as the nucleus of an atom, with mother, father, and children as separate entities whose orbits interlock to form the nuclear family (top right). Pathological family systems may be "schismatic" (lower left), in which mother and father endlessly struggle for power, trapping their children on the battlefield between them. Or they may be "skewed" (lower right), with one parent assuming all the power, reducing the other to an impotent satellite, and developing an overwhelming relationship with the children.

increasingly shared by both parents, but whatever the pattern, power structures in normal families are well defined.

In pathological families, this is not the case. Sources and bases of power are ill defined; leadership is either reversed or blurred. Two types of pathological family systems, termed "schism" and "skew," are considered by psychologists Theodore Lidz and Stephen Fleck to be prime examples of families likely to produce a schizophrenic child.

A third characteristic of small groups is that they are dynamic and not static. Relations, roles, power, and leadership are defined, but flexible enough to change at crucial periods in the group's development and as situational pressures demand.

A fourth characteristic of small groups that may be applied to families is that they are constantly interacting and communicating in various ways, both verbal and nonverbal. By communication, groups know each other's perceptions, ideas, feelings, and attitudes; and group members learn of the expectations and sanctions of leaders. Some small groups communicate clearly and effectively, while others do not—and so it is with families.

Fifth, small groups develop rules and norms that govern the members' behavior. Clear communication is crucial here, since for optimal group functioning each member must be aware of rules so that he may then conform (or deviate) with the full knowledge of the consequences of his behavior.

Lastly, groups and healthy families develop cohesiveness. If all other factors operate positively, the normal family creates a kind of emotional glue that holds it together. This affectionate cement is missing in disturbed families. A disturbed family seeking aid usually asks the clinician to "fix" its most overtly troubled member. But the therapist, knowing that the "problem" member of the family is simply the one who is screaming for help, tries to assess the entire family, and with luck and not a little tact may convince the family that the whole system needs an overhaul. Only that will eventually fix the troubled family member.

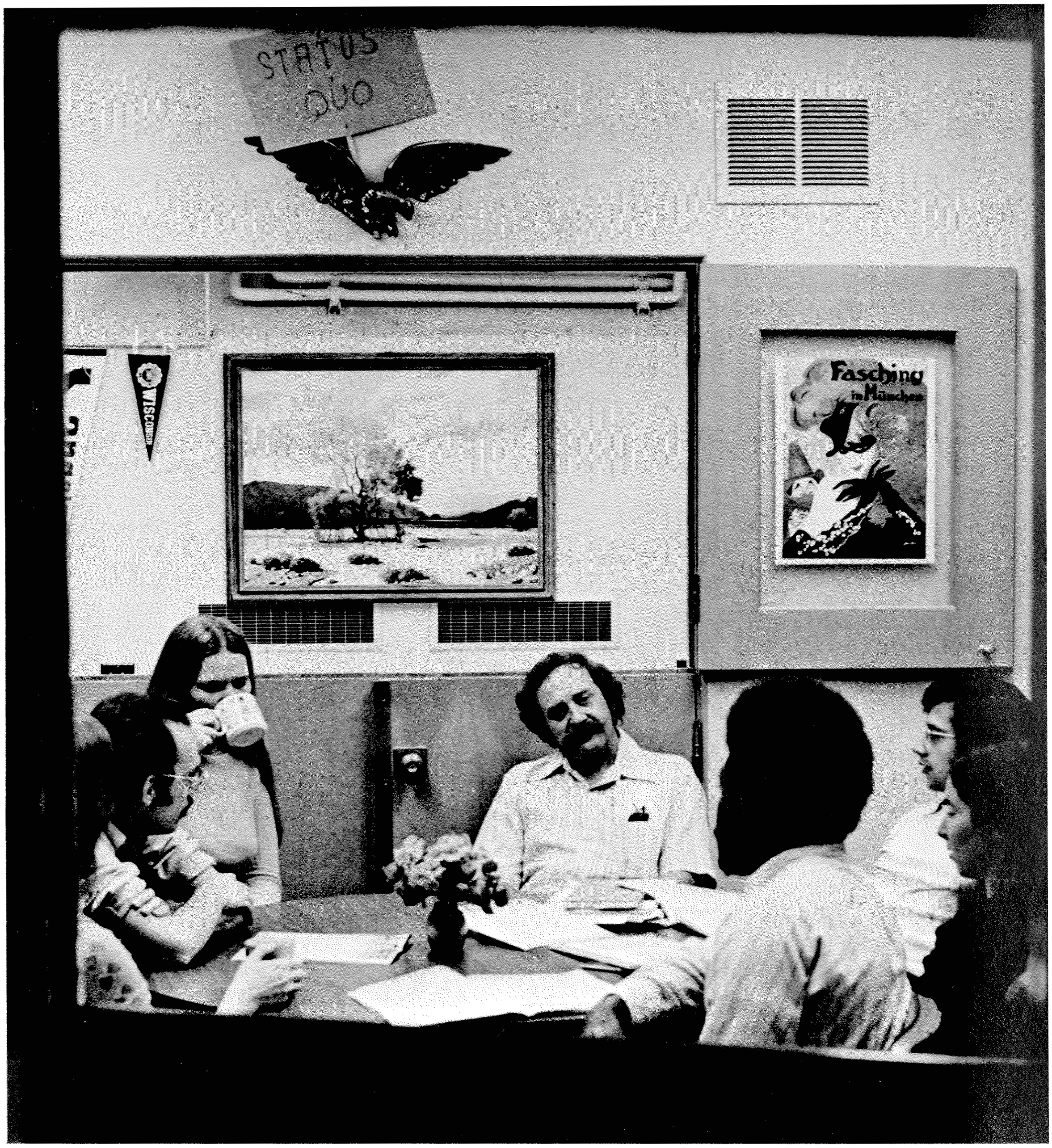
I have not been asked to intervene in the Caltech family, and there is no identified patient in our group. Nevertheless, any system can stand an assessment and minor overhaul, and with a little humor and some objectivity we can expand our view of the family to include an entire scientific community.

I shall assume that the children of our Caltech family are its graduate and undergraduate students—all hard-working siblings in the scientific disciplines. The parents are, of course, the faculty, administration, and staff. Depending on their relative ages, they serve as mothers, fathers, grandparents, aunts, and uncles, but in general as authorities when it comes to the conduct and development of the student/children.

How can we assess the functioning of this family? How can we understand some of its behavior? Is it a healthy family, or does it fit into clinical categories that could be called disturbed? To answer these questions, we return to the six characteristic factors of family functioning.

First, unique personality. The unique personality of the Caltech family is a powerful image indeed to those who perceive it. It is seen as a highly prestigious group of the intellectually elite. To quote from the Caltech catalog: "Caltech . . . in the words of a senior Dutch astrophysicist, may well have become the center for scientific excellence in the entire world." That's quite a reputation, but most students will tell you it's no help in getting a date. In fact, though the Caltech family image may be considered a polar opposite to that of the Jukes and the

Being the most intelligent student group in the United States may be gratifying, but it can also be very lonely.



By communications, groups know each other's perceptions, ideas, feelings, and attitudes; and group members learn of the expectations and sanctions of leaders.

Kallikaks, it is not necessarily any more attractive. To many outsiders, a group of people who appear so far above them intellectually, and therefore so different from the normal, may also appear to be frightening and downright weird. Thus, the children of our Caltech family, the students, find themselves carrying a label which may not fit but is maddeningly difficult to dispel.

Being the most intelligent student group in the United States may be gratifying, but it can also be very lonely. What is more, this status carries with it two potentially damaging demands. First, if one attains the intellectual heights of the upper 1 percent of the nation in math and physics, there is terrific pressure to stay there. If you're that bright, how can you ever take a chance on doing anything dumb? Second, if you are consistently labeled different and possibly weird, you come to believe it. So some Caltech children, either before they join the family or afterward, start to believe their publicity and think of themselves as apart from the human race.

Our faculty/parents are not immune to these effects. They too are embraced by the elite, egghead, weird family image. They share the pressure to constantly display their intellectual prowess without making human errors. And they too are affected by the label that classifies them as something only slightly less than gods.

We have, then, a family trapped in its glorified but potentially damaging public image. As the children of psychotics are expected to be crazy and the offspring of alcoholics are expected to drink to excess, the Caltech family (parents and children) are expected to be weird.

People, we often notice, live out the expectations thrust upon them by society, and because much of human behavior is learned, images tend to perpetuate themselves.

Caltech probably succeeds better than many institutions in its attempt to approximate a model of democratic family functioning.

The children of the Caltech family pull pranks and indulge in extracurricular activities not seen on other campuses because that's tradition and because it fits the image. Some of the more bizarre carryings-on are ways to relieve the pressure of constant academic success and of living up to the Caltech family image.

How does our second factor—leadership and power structure—apply to the Caltech family? Are the bases of parental power in this family clear? Is leadership well defined or do we fit into the fuzzy power muddle of the disturbed family? If the latter is true, are we skewed or schismatic? I take the view that, despite attempts to achieve and maintain a clear-cut democratic power structure, we lean toward skewed family power.
To give credit where it is due, it is true that Caltech probably succeeds better than many other institutions in its attempt to approximate a model of democratic family functioning. Because we are a relatively small academic family, students can be and often are included in decisions that affect the entire family. Student leaders are included in major committees concerned with both academic and administrative policies. Perhaps that accounts for the fact that their behavior does not include phenomena like riots and demonstrations.

But I suggest that there is a skewed relationship between task leadership and social-emotional leadership in our Caltech family—a case of too many fathers and not enough mothers, literally and figuratively.

Task leadership at Caltech is well (if not quite correctly) defined. The leaders are the faculty, and the task is a simple one: Prepare yourself for a brilliant career in science. Win the Nobel Prize. While this task is not by any means delineated by all of the faculty, I think it is initially accepted by the majority of the students.

Social-emotional growth is far less clearly defined and, too often, less stressed than is the task of scientific excellence. Thus, the social-emotional leaders of the community—encompassing many faculty members—are less evident to our student/children and perhaps less sought out by them, except for those faculty members who take pains to be visible.

Third, is Caltech a dynamic, healthy family or a static, disturbed system? How willing and able is the Caltech family to change as the developmental demands of its children change? Here we come to what I call the parent/teacher syndrome. Simply put, it amounts to this: Just as parents resist smart-mouth kids, teachers resist (and resent) the students who appear to be brighter than they. The rule is, "I expect you to advance, but don't go farther than I have gone and, above all, don't depart too far from my methods and my ideas."

The full development of the child requires allowing him increasing amounts of autonomy, and the intellectual and emotional growth of the student requires the same. We can build in such autonomy through Independent Studies programs and the like, and this Caltech has done. But the real contribution to student development must come more subtly and more directly from the parent/professor who must support, even encourage his students to challenge him, to depart from his knowledge into realms of their own. This requires a real involvement with students, a keen interest in novel ideas and approaches, and a concerned devotion to teaching. Above all, it requires flexibility and a willingness to change both the systems and one's self. Like all institutions, we can use more of such flexibility to insure that we remain a healthy, dynamic family system and avoid the resistance to change that produces a withdrawn, noncreative scholar.

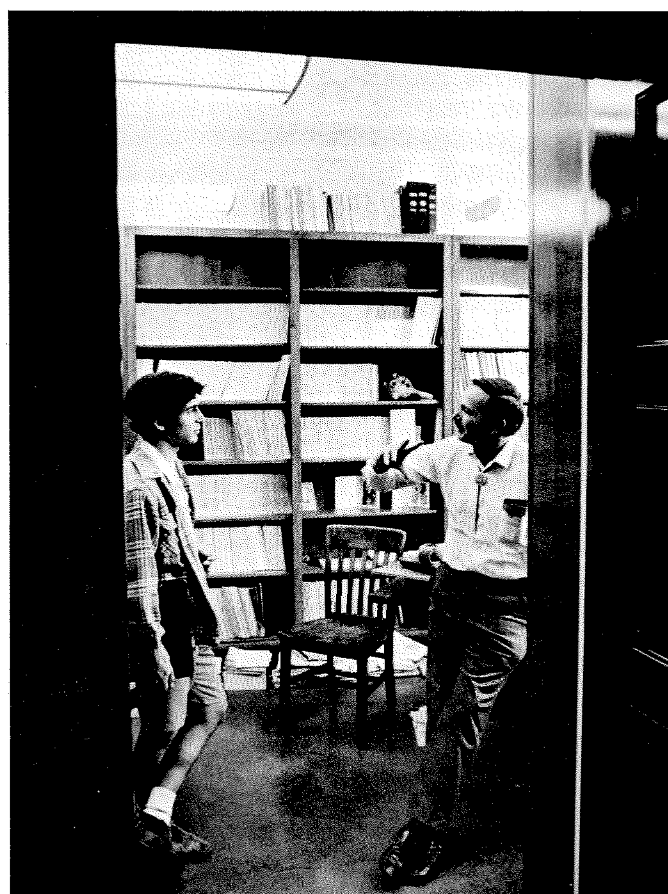
Perhaps this is the appropriate place to insert a plea for parent-understanding. Our society provides classes and degrees and certificates in almost every field of learning. But to my knowledge, no one ever teaches anyone to be a parent. Similarly, the college professor is seldom taught to teach. The PhD must know his discipline thoroughly, but he does not necessarily have to learn any method to impart it to others. Like bewildered parents who stumble on by instinct and the dubious example set by their parents, college professors stumble on in classrooms guided only by their instincts and the example of their own venerated professors. Often the instincts are bad and the example is worse in both cases. Perhaps there should be "professor-effectiveness training." It might even be student funded—a sort of counterattack from students who would provide grants to maintain teaching excellence that would compete with grants that maintain research.

Fourth, what about Caltech's communications as a family? Are all lines open? Can all messages be understood? Theoretically there are no barriers to communication at Caltech, but practically we sometimes suffer the stalemate seen in troubled families where children and parents have stopped talking to each other. And, as in troubled families, this state of affairs results in misperceptions of motivation and feeling, frustration, and even anger.

I hear faculty members comment that students seldom come to see them even though they have advertised widely that their doors are open. Students tell me of working up their courage to approach some of our more renowned faculty members, only to retreat at the professor's doorstep. Or they make it into the office to find the faculty member absent or preoccupied. It seems to me that we ought to be talking more, but the responsibility lies with both parents and children in this community. You know, a great deal of communication is nonverbal—tone of voice, facial expression, and gesture convey a lot of emotional meaning. When a student falls asleep in my class or gets up and walks out, I know I've turned him off. But without more direct, honest communication, I probably don't know how I've done it. Sometimes students act like what clinicians call "passive-aggressive children"—you know, the kid who just forgets to take out the garbage three days in a row because he's hurt and angry about something you said at dinner last Sunday night.

I'd like my students to be more assertive about the things I do wrong in class and elsewhere; I'd like more interest in teaching evaluation; and I know other faculty members who would appreciate this candid approach also. But this must be multiple interaction. Parental figures in the Caltech family have to be openly supportive of open communication. Most of us on the faculty ought perhaps to take more time to track down our passive-aggressive students and say: "Listen, what did I say or do that you're not taking out the garbage?" Or in some cases: "What did I do that you're giving me all that garbage?" Then we might be able to talk to each other in the intimate way healthy families should.

In the area of rules and norms for acceptable behavior, the Caltech family is a behavior therapist's dream. Rules for ethical conduct are clearly defined, and sanctions are openly stated and fairly applied. Caltech's unique honor system operates to protect the rights of all family members and provides peer control of family behavior. Reinforce-



The parent/professor must support, even encourage, his students to challenge him, to depart from his knowledge into realms of their own.

ment for conforming comes from the satisfaction of being an accepted member of the group and contributing to a successfully functioning honor system. Deviation is handled by the student Board of Control, an organization whose members have a formidable responsibility.

But there are implied rules and norms that are linked to the elite image of the Caltech family and that are less overtly defined. There are unwritten rules of diligence, a subtle pressure to work 16 to 20 hours a day. It is not unusual for a Caltech student to stay up three or four days in a row, totally without sleep, to finish assignments. I can't imagine a parent who would allow his children to do that.

There are also implied and sometimes openly stated rules of dedication: "Thou shalt not let thy thoughts stray to the arts or humanities too often, or, God forbid, to social science." The Caltech family norm is devotion to the physical sciences. Like the under-achieving child of college-graduate parents who is made to feel like a failure, Caltech students who opt for an English major or transfer to Berkeley to study psychology are often made to feel that they couldn't make it in science. The Caltech family in this way makes it difficult for its children to make their own choices.

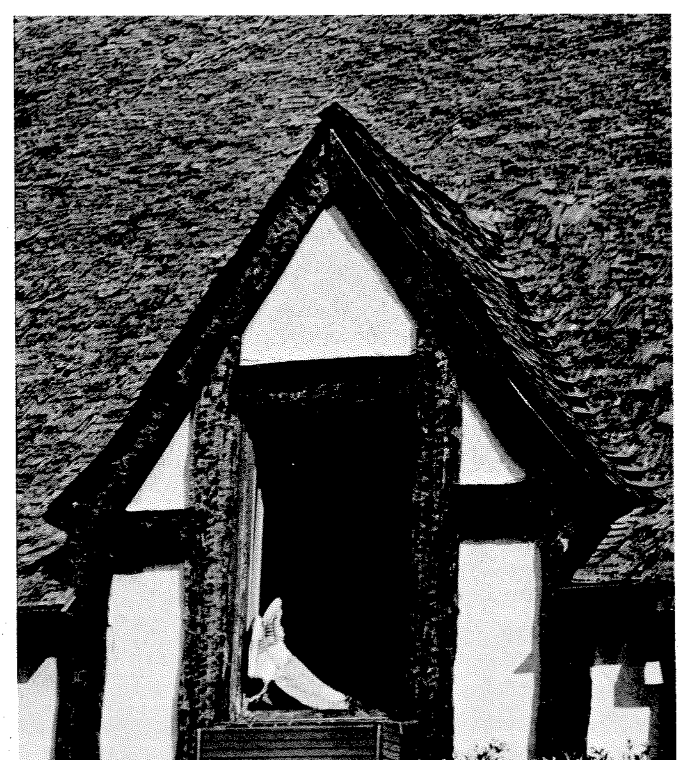
As for cohesiveness—Caltech is a cohesive family. Much of our closeness comes from genuine affection between family members, but some of it is a reaction to the society outside, to the "real world," as students call it. As we have said, Caltech is a family isolated by its excellence from the families outside its own home and yard. Its children often retreat within its boundaries (just as many of them did in their own nuclear families) with a sense of relief that here they can find others like themselves. To the extent that our home becomes one in which to hide from the real world, it inhibits personal explorations in that world, and our cohesiveness inhibits personal growth.

How does it all add up? Are we a schizophrenogenic family—a pathological slice of society driving its members into psychosis? Or are we a healthy family providing our children with optimal opportunity for growth? I think we are somewhere in between—a family with a lot of strengths that is not living up to its potential. A family that is too wedded to its image, too task-oriented, too often rigid, and too often closed in communication between members.

I do not think the comparison between a university and a family is a convenient but empty metaphor. Like most colleges and universities, we say that we do not serve in loco parentis, that we expect students (and faculty) to be functioning adults. But I think we are kidding ourselves. Whether we want it or not, we are a family involved in intellectual and personal development for all our members. You know, we college parents are very lucky. What would happen to us if those eager frosh and first-year graduate students stopped appearing every September? How comfortable would we be if we didn't have students to do the little household chores (like carrying out our research), or how self-satisfied would we feel if we couldn't see them graduate and feel proud of their accomplishments.

It seems to me we owe it to them and to ourselves to be good parents—as all parents strive to be—to work at all areas of family functioning to make the developmental path from freshmen to colleagues as fruitful as possible. To do this we Caltech parental figures must be aware of our rigidities and attempt to be more flexible, we must be human to our students, our colleagues, and the community. We must maintain our excellence while increasing our humanity. We must support, encourage, and reward our children while simultaneously giving them the autonomy and freedom to outthink us and outreach us. We must allow them, even push them, to deviate from our values and to think for themselves even if that means thinking differently from ourselves. We must talk to them and listen to them. And we must extend ourselves and relate to the community around us so that we and they can be seen as real people in the real world.

We must realize that when we have problems with them or when they have problems with us, it is a family problem, and there is no target child whose behavior must be "fixed." We can then continue to be proud of our children and they of us. They might bring the grandchildren to visit. Maybe they will even support us in our old age. We may need it. □



The Emergence of Intelligence in the Universe

SIR FRED HOYLE

The question is – On what fraction of planets in how many millions of cases can we expect not just life, but intelligence, to emerge?

There may be forms of life of which we are totally unaware and of which we can barely conceive. For example, you might speculate on the possibility of life being based on the properties of nuclear matter, life in exceedingly dense space—several hundred million tons of it in a volume the size of a sugar cube. But at our present level of understanding, this would be more a matter for a science fiction story. So let me bypass all the strange things that might possibly exist in the universe and discuss the emergence of life and intelligence in terms of chemical life based on the properties of the carbon atom.

In contrast to the situation only a few decades ago, scientists today believe that they know quite a bit about this kind of life, which is based on complex chemical reactions, with substances called proteins playing a dominant and important role. You know that in ordinary dietary terms we are supposed to have a daily intake of proteins in our food. It is, however, important to realize that we do this not for the sake of the particular proteins that we eat but for the basic substances of which these proteins are made.

What happens is that the proteins we eat are first broken into their constituents, known as amino acids, and these amino acids are then built—within our own bodies—into the proteins required specifically by our kind of creature—the human being. The dog, which operates similarly, uses the same basic amino acids, building them into protein structures peculiar to itself. And so for all living animals. We all use the same basic amino acids, but we arrange them individually according to our own separate needs.

How does each animal build just what is right for itself? Nowadays, biologists even understand the answer to this crucial question. Each of us contains within himself a kind of vast chemical blueprint that is simply copied time and time again as our kinds of proteins are made, in order to serve our separate bodily functions.

But it's not my purpose to develop the chemical basis of life in any detail. I merely want to emphasize that life is now seen to be based on a complex but well-ordered form of chemistry, which is to say, on the relation between various kinds of atoms. The relations between atoms are described by the science of physics—by methods that are well understood. Indeed, no very deep knowledge of physics is required in order to calculate how an atom of sodium and one of chlorine bind themselves to form a molecule of sodium chloride, or common salt.

The relevant basis for this kind of understanding was discovered 50 years ago in the work of Heisenberg and Schrödinger, and that of Wolfgang Pauli. It came at the beginning of that revolution of physical thinking known as quantum mechanics. Yet, although we believe we understand the basic principles on which molecules are constructed from atoms, it's beyond our ability to calculate the details of any but the simplest molecules. It would be possible to calculate the properties of a very simple molecule like sodium chloride with reasonable precision, but it would be quite beyond our powers to calculate the detailed properties of a protein containing a thousand or more amino acids.

Now all this is very odd and very interesting. By restricting ourselves to the study of simple systems we seem to be able to discover rules according to which the world is constructed on a much more complex scale. Could it be that our inability to follow through in understanding this more complex scale is a temporary handicap—one that will eventually be swept aside as science advances? I doubt that this will turn out to be so. I doubt that there is any simpler description of the universe than the universe itself.

The usual concept of the scientist that eventually he'll be able to build a simple model of the universe that will serve to describe with accuracy the behavior of the actual universe is, I believe, a chimera. What we can do, however, is build models that give a satisfactory description of limited aspects of the universe. It's when we come to demand full detail that the trouble arises. We can manage to deal with a molecule of sodium chloride perfectly well, and in doing so we gain insight into the general properties of proteins, and of even larger biochemical structures than the proteins. But we fail in our endeavor to describe detail. In short, our brains, our understanding, permit us a perceptive view of the universe but not a complete view—nor, I believe, will they ever permit us a complete view.

People who'd never dream of strangling a dog don't hesitate to swat a mosquito

It is subject to this inherent limitation that I want to consider what can be said, firstly, about the emergence of life in the universe, and secondly, about the emergence of intelligence. And then, by combining what we find about these two topics, I want to give some thought to what the outcome for life here on Earth may turn out to be in the centuries and millennia that lie ahead of us.

Although I described amino acids as being much less complex in their structure than proteins, and although the proteins themselves are much less complex than the remarkable long-chain molecules that carry our genetic heritage, it's important to realize that even amino acids are complex compared with the substances that life evolved from in the first place. These were molecules such as water, hydrogen cyanide, carbon dioxide, and possibly ammonia; in fact, just the kind of molecules that astronomers have discovered in vast numbers within the gas clouds of the Milky Way.

When we look at galaxies other than our own, we can see evidence of clouds of gas and dust. We have no reason to believe that other galaxies are any different from ours, and when we come inside our own galaxy, we can look at some of the detail of clouds and gas that contain the molecules out of which we believe life was born.

In view of this widespread diffusion of the basic life-forming molecules everywhere in the galaxy—and in other galaxies, as we believe—one would naturally suppose that life is likely to be widespread throughout the universe. The basic physical laws that permit the chemistry of life are the same in other places. Similar structures to ourselves can therefore be expected simply because of the vast profusion of planets and stars.

There are rather more than 100,000 million stars in our galaxy alone. A large fraction of them possess the characteristics that astronomers believe to be associated with the occurrence of planetary systems. In other words, there are strong reasons for thinking that a considerable fraction of the stars in our galaxy—perhaps 50 percent of them—possess planets moving around them. So, in considering the emergence of life on the galactic scale, we have to think of something of the order of 100,000 million planetary sites. Life might also arise in ways other than on planetary surfaces, but let's just keep to the kinds of things we know something about.

Not all planetary systems will be suitable for the emergence of life. Among the planets of our own solar system, only our Earth is likely to possess life. Maybe there are people who would like to challenge this, but when you look at the Earth, you can see why it's possible to have some skepticism as to whether life is likely to exist on the other planets. The Earth is completely different—enormous atmospheric movements and a very different kind of color. The Earth is so manifestly different from the others as to bring home to us the fact that, had the Earth not been present in our system—had the Sun possessed eight planets, instead of nine, without the Earth—then the solar system would, I rather imagine, be sterile.

Among other systems of planets we must suppose that there will be some that will be sterile. What fraction is this likely to be? In one sense the answer to this question is quite uncertain, but in another sense our uncertainty is probably irrelevant to a more important question: Having allowed for all the astronomically and chemically unfavorable cases, do a large number of suitable sites for the emergence of life still remain?

After all, we had 100,000 million possibilities to start with. If only 10 percent of these are astronomically suitable, and if only a further 10 percent possess an appropriate kind of chemistry, as many as 1,000 million favorable sites still remain. It seems, then, rather unlikely that the favored fraction would be less than this—1,000 million favored sites for the origin of life.

The first step toward understanding the origin of life is reasonably well understood. This is the step in which the simple molecules that occur in huge quantities in our galaxy and other galaxies are built into more complex molecules—substances containing a moderate number of atoms (say 30 to 100 atoms) like the amino acids. The essential feature of this first step is that it supplies a store of energy that can then be used to drive more complex systems. The source of the energy must be the light that shines on the planet from the primary central star.

This first step doesn't seem difficult to achieve, and most chemists and biologists seem to have little doubt that it would take place in nearly all cases. So far, so good. Yet, with such an energy store we're still far from the synthesis of the exceedingly complex molecules on which life itself is based. Much work is going on today, seeking to discover how the first biological cell—the first cell able to reproduce itself—came into being.

Until more is known about this second step, it's still too early to make a quantitative estimate of the probability of life emerging in a particular place. There could be barriers requiring highly improbable circumstances that could eat into our 1,000 million cases to a substantial degree. But on the other hand, you can say that it's been the experience so far that estimates of probabilities seem to rise—not to fall—as more becomes known about the problems involved. This has certainly been the case on the astronomical side. The evidence regarding the molecular chemistry of the interstellar clouds shows the same thing on the chemical side, and a reasonable guess is that a similar situation will arise as more becomes known about the biological details.

Given the first living cell, much still remains before life as we know it is forthcoming—particularly before intelligent life can emerge. Even on the Earth, complex life forms, creatures aggregated from very many cells, were a long time in coming. It's only about 500 million years ago that you begin to get the complex life forms that we normally think of as living creatures.

This distribution of life with respect to time on the Earth seems to indicate that until comparatively recently a barrier of some kind existed—a barrier that prevented more complex forms of life than single-cell bacteria and blue-green algae from existing. We can speculate what this barrier might have been, and I find it rather impressive that there is a temperature correlation involved in the very early life forms. Strikingly, they were all forms that survived under high-temperature conditions—bacteria right up to the boiling point of water, the blue-green algae to about 75° C, the various kinds of fungi to about 60° C —suggesting that the Earth in its early history may have been too hot to permit the existence of any but single-celled creatures with highly protective cell walls. If this is true, it has far-reaching astronomical implications.

But let's move on to the emergence of intelligent creatures, which is what we are *really* interested in. The question is, on what fraction of planets in how many of our millions of cases can we expect, not just life, but intelligence to emerge? Indeed, our emotional attitude to life isn't really a chemical matter at all. Although the difference between a well-loved person being alive and being dead may depend on certain subtle chemical processes, this isn't at all the way we feel about it. Most people who'd never dream of strangling a dog don't hesitate to swat a mosquito. Yet the chemistry of the mosquito is basically the same as that of the dog.

The situation is that we distinguish between "higher" and "lower" animals according to the complexities of the nervous systems with which animals are endowed. A nervous system is basically electrical in its operation, with an animal made up of a chemical system together with an electronic one. The more the electronic part of this summation dominates, the higher we judge the animal to be in the zoological evolutionary scale. And the more the electronic system happens to match our own system, the better the animal.

Among humans, the more similar the other person's electronic system is to our own the better regarded, or the better loved, the person is. So you can see that similarity, or otherwise, in the electronic part distinguishes the category of "us" from the category of "them." Furthermore, at a certain level of electronic complexity, we rather arbitrarily introduce the notion of "intelligence"—a level set just a little below our own capacity. So, essentially, as a matter of definition, any creature with an electronic system more complex than our own would be endowed with high "intelligence."

The logic of evolution forces development of the most deadly weapon of all - a thinking brain

Animals aren't regularly able to synthesize the amino acids and sugars that are essential to them, as plants do. Animals must therefore acquire these substances either by eating plants or by eating other animals. Basically, all animals are scroungers, living on the stored chemical potentialities that others have first accumulated. It was precisely to assist in the process of scrounging that the electronic systems possessed by animals developed. And since the better the electronic system the better the scrounger, biological evolution has operated steadily, over millions of years, to increase the level of complexity of animal electronics. And since we judge the level of an animal by the complexity of its electronics, it follows that the higher the animal the greater the scrounger—with man himself sitting at the top of the pyramid.

The electronic system in man has indeed become so subtle that our scrounging for energy, in particular, has now extended well beyond the eating of plants and other animals. We scrounge extensively today on nonliving materials. The discovery of fire made use of the decay products of trees in the form of wood. The burning of coal and oil were further steps along the same path. Now, in the modern nuclear plant, we've attained to the use of entirely nonorganic materials as an energy source. This access to nonanimal sources of energy has developed with increasing rapidity to a point in our modern society where we can clearly see that either some more restrained pattern of behavior must be applied in future years, or the evolution of our species will end itself in a catastrophic social explosion.

It's in these evidently crucial circumstances that we've begun to wonder how things may have fared with other creatures on other planets moving around other stars. We've even begun to wonder about the possibility of communicating with them.

Interstellar communication, as we call it, raises many questions—some technical, some of quite general interest. As far as can be seen at the moment, the only feasible mode of communication between creatures living on different planets moving around different stars would seem to be by a radio link.

We are living today not on the brink of social disaster, but actually within the disaster itself

A vast array of 900 individual radio telescopes, each with a diameter of 100 meters, has been proposed. The idea is that such an array would give the best expression to our present ability to communicate on an interstellar scale. This proposal has been aptly named Project Cyclops ("Hello Out There," *E&S*—March-April 1973; "The Search for Extraterrestrial Intelligence" by Bernard M. Oliver, *E&S*—December 1974-January 1975). It is worth noticing that actual physical travel by men in space, while it may just be possible, doesn't seem really very good. Even if it *were* possible, physical travel would take much more time than an interchange of messages through a system like Project Cyclops.

The difficulties of physical travel to distant stars might seem at first sight to be a decline in romantic possibility, a loss of richness in the scheme of things. But a little thought shows that precisely the opposite is true. If physical travel from one planetary system to another were feasible, then the first creatures to become technologically capable of space travel would be likely to spread themselves throughout the galaxy—just as science fiction writers are always imagining our human species to do. It would be only too likely that the galaxy would come in that way to have only one form of intelligent creature, and this indeed would be a loss of richness.

But if you take the view that space travel is not possible, creatures in one planetary system can't interfere with the physical development of creatures in another system. Many possibilities, with much potential richness, are then permitted.

Are other intelligent creatures really likely to exist? From what I've already said there seems to be little if anything in our own solar system that is due to distant chance. To be sure, if we knew there to be only *one* other planetary system in our galaxy, the odds would be against it containing a planet like the Earth, at an appropriate distance from an appropriate central star, with a similar rotation speed, a similar axial tilt, similar chemistry, and so on. But the chance of a similar situation isn't all that small—perhaps one in ten or one in a hundred, but probably not much less than that. And since we haven't just one planetary system to consider, but some 100,000 million of them, we have no real difficulty, I think, on this score.

But would life in such places become intelligent in the sense that I've been describing intelligence? Well, from our rather brief consideration of the nature of an "animal," it seems that the development of an electronic system would very likely occur for all animals everywhere. In the need to search for food, eyes would be a normal development. Animals with eyes are likely to prey upon each other, since the logic of evolution forces the development of weapon systems, claws, teeth, and ultimately a thinking brain—the most deadly weapon of all. The logical sequence leading to the emergence of a thinking brain appears to me inevitable, and I think we can expect this to have happened quite generally.

I come now to what appears to be the most uncertain question of all. Given a suitable planet, given the origin of life, given the emergence of intelligence to a level at least equal to our own, for how long on the average can one expect such an intelligence to persist? Even if intelligence arises in as many as a million cases in our galaxy, there will still be very few such cases around at the present moment unless high intelligence, once it arises, persists for more than 10,000 years. This is simply because the age of our galaxy, the time span over which intelligence emerges, is very long indeed—about 10,000 million years. So, unless intelligence lasts once it arises, there will be very little overlap in time between its brief emergence on one planet and its emergence on another planet.

The thought that our capacity to execute a project of the technological quality of Project Cyclops might only last for 10,000 years seems, to begin with, to be a rather pessimistic assessment of the future of the human species. But in view of the state of our present-day society, is it not a rather optimistic assessment? When you contemplate the huge human populations that have grown with startling suddenness in only a century, when you contemplate the excessive modern pressure on natural resources, I think it's hard to put much confidence in a future extending more than a few decades. Devastating crises, one feels, must surely overtake the human species in no more than another hundred years. We're living today, not on the brink of social disaster, as we often tend to think, but actually *within* the disaster itself.

We've seen that the phenomenon of "intelligence" is the outcome of aggressive competition. Intelligence and aggressiveness are coupled together inevitably by their biological association. An intelligent animal anywhere in the galaxy must necessarily be an aggressive animal, and must eventually be faced at some time by the same kind of social situation as that which now confronts the human species. Inevitably, then, "intelligence" contains within itself the seeds of its own destruction. This leads to a very critical question: Can any solution be found for this inherent difficulty?

We find it hard to believe that our civilization could ever come to a final end, with no further rise of humanity into the future. A belief in the extended future of our species is almost a religious faith, which I think we all possess. Certainly it was so with me in the past. Although my reason told me that all was far from well, I continued to believe that somehow it would all come out right in the end. Then one day I was suddenly struck with an ominous thought. We all know that nature is exceedingly prolific. There are many millions of galaxies, many millions of stars, perhaps many millions of intelligent kinds of creatures. What nature does not do is to demand success of every trial, every attempt. In fact, it is just the opposite. One could say that nature proceeds by many trials, just because in so few cases is there success. In a manner of speaking, perhaps this is the reason for there being so many planets—so many attempts at an intelligent creature—because, among intelligent creatures, very few of them are ever going to make it.

So, far from us muddling through the future in some way, perhaps the chance of our coming through at all is very small. A nasty, unpleasant thing, you might say, to be putting forward. Well, if what I've just been saying is wrong, it doesn't matter at all. Life will roll on, and events will show that this is a lot of nonsense. But if what I've just said is right, then the very worst thing for us to do is to ignore the dangers ahead. If the danger is really there with high probability, then the most essential step in reducing the probability is to be very clearly aware of the danger. The very worst thing would be to go on without heed of it. So I'm not making apology now for drawing your attention to these issues.

Let me end what I have to say by discussing very briefly how we suppose things will have to go here on the Earth if the human species is to be one of the rare creatures that makes it to some higher, some more stable level of intelligence. Very clearly, a much lower population level will be needed, pressing only gently, if at all, on the resources of the Earth. To achieve such a situation will be a crisis that faces us over the coming decades and centuries. I have now come to believe that this will be a crisis every bit as critical as any of those that have occurred over our long past history. Only after the resolution of this crisis can we look forward to a time span for our species even as long as 10,000 years. Perhaps then we can think in terms of a very much more extended future—millions rather than thousands of years.

So let's turn back to the matter of interstellar communication. For creatures with millions, not thousands, of years ahead of them, a necessary interval of several hundred years between the transmission of a message and the reception of a reply to it wouldn't be a serious impediment. There would be ample time for many messages to be interchanged. No species in this situation would, I think, hesitate, as we do now, to search our galaxy for the other intelligences which must surely have emerged and which may have climbed over the difficulties that confront our human species today. □

Speaking Of . . . Robotics

Two excerpts from talks given at a workshop on Cognitive Robotic Systems, held at Caltech from March 19 to 22.

Around the House

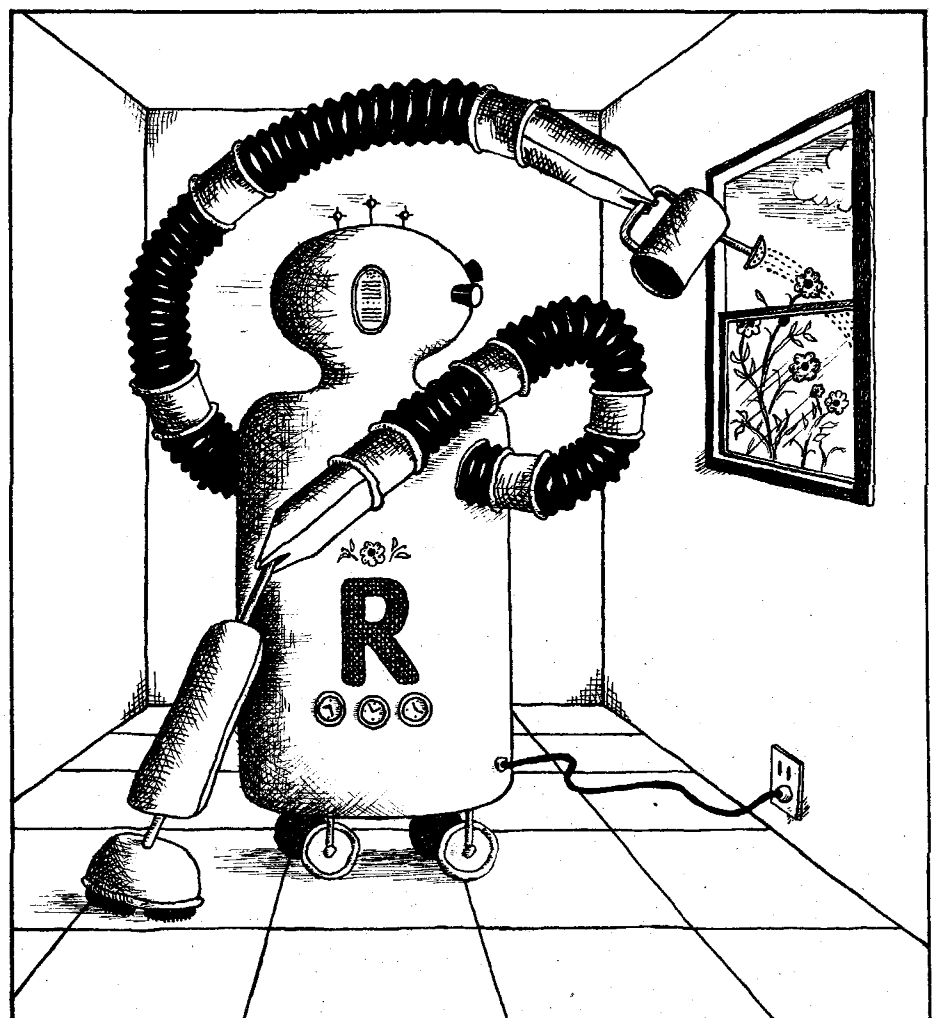
I have a pet area in robotics that I think is worth a lot of attention and that's the so-called household robot. In the next 25 years or so it can have a profound effect on the world. I've thought about it quite a bit, and there are two aspects I like. One is that it has a nice social aspect. If you have a real household robot that works, it doesn't really put anyone out of work, but yet a lot of people would want it because domestics are disappearing rapidly from the whole world. And at the same time (if we get over this recession) people's expectations are rising, and they would like not to do housework.

My own opinion is that a household robot that is useful and economical could be made almost immediately. And its first functions could be what I call surface care—working on the floor and maybe the yard. It can vacuum and wash floors, using standard gadgets it gets out of a special closet, and maybe it can clean up the yard the same way. To program it a housewife just puts a handle on it. Then she goes and vacuums a room, and when no one's around, it tries to do approximately the same thing, avoiding obstacles. When the housewife notices a dirty spot it's missing, she sticks the handle on and says, "No, you forgot this spot over here," and slowly gets it trained. In a while maybe it won't be just doing that, but it will be picking up—like, when it finds a towel or sock on the floor, it will know they should be taken to the laundry room.

There are some other nice things it can do too. It can patrol around the house at night when no one's home and watch for, say, water pipes breaking, or fires, or burglars coming in. For a long time I was in a quandary about what to have it do when it sees a burglar crawling in through a window. It could call the police, of course, but the guy *could* come in and steal something and get away anyway. And I think shooting the burglar has a lot of bad implications. What I finally decided is that it should crouch in a dark corner and bark ferociously.

I hope this will all happen fast, because when we get to the point of automating setting the table and washing the dishes, I want to watch, because that gets to be a little hard. Making beds actually isn't that hard. Rocking the cradle isn't hard either. Imagine someone said to you, "Look, we're going into mass production of this thing, and all it has to do is use its vacuuming attachment to vacuum, its floor-washing attachment to wash floors, and you can wire the house up with a coil, and it learns to navigate by being taken around, and it has access to a big computer downtown when it needs it"—and so on.

I think you could make such a machine for $25,000 if you were planning about a quarter of a million to start. And my own guess is that there's a market for about a million of them at $25,000, because $25,000 is less than a domestic costs, and in a big house one domestic is busy doing these chores, and there are at least a million big houses around. One can imagine the price getting down to maybe $10,000 in time, and at that point if it's a question of whether you get a second car or a household robot, my guess is a household robot will win fairly often. My guess is that over a 30-year span we'll have a market



of over a trillion dollars worth, and I think that's even conservative in some sense.

I think that 20 to 25 years from now there will be robots or autonomous machines doing things beyond our expectations. We ought to get past the idea of machines that move but don't think. I mean, everything that moves ought to have something in it that thinks. Trees don't have to think because they move very slowly, but even insects and worms do a little bit of thinking, and I think that all the machines we build will have in them some autonomous capability partly to control what they're doing and, perhaps more importantly, to worry about their own operation—to know that they need to oil a bearing or they're overheating or they need a replacement part and so on. And the beauty of that from my view is that if the rest of the world, the third world, is ever going to move fast, one of the things they could make use of is machinery. It's very hard for this to happen today, because when you send the machinery, they're not really able to take care of it and use it without growing up in the machine culture. But when you can have a machine, like a tractor, that can pretty much take care of itself, even if someone else drives it, that's a revolutionary thing for the rest of the world.

—Edward Fredkin, professor of computer science and director of Project MAC at MIT; Sherman Fairchild Distinguished Scholar at Caltech from September 1974 to May 1975.

Fourth Revolution

Throughout the history of Western civilization we've had a number of intellectual revolutions that have radically altered man's thinking about himself and the universe and his relationship to it, ranging from Aristotle to Leonardo da Vinci to Newton to Einstein, but I think that it is generally acknowledged that three of these revolutions have been most influential in determining man's image of himself and his role in the universe, and these are the Copernican revolution, the Darwinian revolution, and the Freudian revolution.

The Copernican, of course, shattered the old Ptolemaic model of the earth as the center of that around which all heavenly bodies revolved. Later on the Darwinian revolution, with its theory of natural selection, considerably restructured our thinking of the relationship of men-apes and our common ancestors. Finally the Freudian revolution forced us to abandon myths that we had earlier of the fully conscious rational mind, to admit to the subconscious dimensions of our own minds.

If one wanted to characterize each of these three revolutions along some common theme, one could say that they each in some sense served to diminish man's claim to his uniqueness—as a species compared with other biological species in the Darwinian case, and in other senses too, such as the conception of man endowed by God with strictly rational motivations, responsible for overseeing all other biological species from a vantage point at the center of the universe.

I think that we have, by this time, largely repudiated that concept, although I hear there are some people around who don't believe in Darwin, but nonetheless each of these revolutions in its own time met with considerable resistance and a great deal of controversy, especially by the establishment forces with a strong vested interest in whatever current rationalizations they had about the self-importance of human beings. These rationalizations were probably inspired by intuitively obvious observations that they made but which were ultimately based on false assumptions.

Each revolution was an unsettling one for the establishment and I guess for most of us in those days, until we sort of reknit the fabric of our claim to uniqueness and thus could reassert our collective pride again in being human beings. It required a restructuring of our thinking. At the time when it was not fashionable or respectable to advocate these revolutionary ideas, one took a great risk in doing so. You know the stories of the three people I mentioned; at least the first two took considerable risk in espousing these ideas, and I'd like now to take such a risk regarding a speculation on the fourth such major revolution.

I think it will be an equally profound and comparably important revolution in man's thinking about himself, sort of an assault on one of the last major non-trivial ways in which *Homo sapiens* claims to be unique; that is, our heretofore undisputed position as being conscious and self-aware organisms. I'd like to forecast that the usurper of this traditionally human prerogative will be an artifact of our own making, an intelligent robot of the not-too-distant future.

When I say that an intelligent computer in 50 to 100 years will be able to communicate with humans and to use a respectable subset of natural language, I think that I'm not too far off base. I think there will be a component of the software for these future computers that will be teleological in nature. They'll have their own autonomous internal objectives, depending on how they've been programmed. And they will, linguistically speaking, use the pronoun I, in quotes, properly. What I mean by that is that phonetically, phonologically, syntactically, semantically, and pragmatically they will use the pronoun "I" as a reference for themselves in a way that a human would under similar circumstances, and so it will be very hard to deny this attribute of self-awareness to such intelligent systems.

I'm really going out on a limb when I argue that this is both a necessary and sufficient condition for self-awareness because there may be some other aspects of it that we don't know about, but I suspect that this part of it—the proper use of the pronoun "I" in using English, in carrying out functions and tasks based on internal motivations—will come about, and that this demonstration will be philosophically and socially a very profound one.

—L. Stephen Coles, senior research mathematician, Artificial Intelligence Center, Stanford Research Institute.

Riding Her Hobbyhorse

Ann Clemmens makes the most of handicapping

If you think the word "handicap" refers only to a disability, you haven't met Ann Clemmens. Handicap is what she does before she goes out to the race track.

What's a nice Caltech senior like Ann doing at places like Hollywood Park and Santa Anita? Well, first of all, she's enjoying herself. Second, she's extending her already extensive knowledge of the abilities of thoroughbred horses. And third, she's thinking about going into the racing business.

Ann can't remember a time when she wasn't fascinated by horses, though she's never actually owned one. But she's ridden them, drawn pictures of them, and read and written about them since she was a child. For five years during her teens she was a camper and counselor-trainee at a summer camp, and each year one particular horse was assigned to her. The assignment included not only the privilege of riding the horse but the duty of taking complete care of it. For Ann, the duty was a pleasure too.

She thinks she's read every story about horses ever written, and the "Black Stallion" series by Walter Farley inspired her to try her own hand at writing similar novels. Most of them, she says ruefully, never got past chapter one.

This isn't to say that Ann hasn't ever finished writing a book. A couple of years ago she took a brief leave from Caltech and wrote a 95-page-long manuscript that recaps the major blood lines of American thoroughbreds. She visualized it as a sort of paperback reference work for horse fanciers, but so far she hasn't found a publisher with the same vision. She now has another, much longer, book ready for final typing. It groups winners of races between 1925 and 1975 by the female line, and is really an extension of the racing classic *Matriarchy of the American Turf, 1875-1925*. In the summer of 1974 she worked for the magazine *The Thoroughbred of California*.

It's hard to tell whether the writing, the statistics, or the horses themselves interest Ann most. She enjoys them all. But she didn't actually see a real horse race until five years ago—on July 4, 1970. Watching the races and reading her first *Racing Form* were about equally exciting that day. The mind-boggling thing about the *Racing Form* was how it opened her eyes to the number of tracks there are in the country and how many races are run in addition to the giants that everybody hears about.

The *Racing Form's* performance statistics also started Ann doing her own handicapping—adding in her own judgment and intuition. She's aware that her consuming interest in equine blood lines makes her less than objective when a horse by a good stallion is running. But, she says, "handicapping isn't just a matter of numbers. You have to look at the horse, the company he's been keeping, and the class of race he's been entered in, as well as how he's been performing."

How much blood lines have to do with human performance may be debatable, but the fact that Ann's father and three brothers are engineers may have influenced her choice of colleges. (Proximity to Santa Anita also no doubt enhanced Caltech's charm.) Her BS will be in math, and she hopes to do graduate work in statistics. She's applied to several graduate schools, including the universities of Kentucky and Rochester. Kentucky is in horse country, of course, and Rochester isn't. But the Eastman School of Music is there, and that leads to a consideration of Ann's heritage in the matriarchal line. Her mother is an accomplished musician, and Ann plays both violin and piano and is a member of Caltech's Women's Glee Club. It's a little harder to account for the two letters she's won in fencing, but it all adds up to a girl with a lot more interests than horses.

Incidentally, how's her handicapping performance record? Well, she's not getting rich on her winnings. She's used her own money to bet only twice in her life, and she's down a dime. □

Letters

Scientific Responsibility

Austin, Texas

In his article in the December-January issue of *E&S,* Dr. Albert Hibbs misleads by emphasizing "repugnance" as a collective trait of the theories of Galileo, Freud, Pauling, Shockley, etc. The issue is not whether a forum for "repugnant" theories should exist. It is whether science should pursue areas which have a vast potential to damage human beings. The idea that all topics should be fully investigated derives from the concept of scientists in isolation, searching for "absolute truths." A scientist is first of all a man or woman, and this should imply social consciousness and responsibility.

Examples of repugnant areas of research are manifold. What type of bomb will be lethal to the fewest people while creating the most radiation damage? What nerve gases will turn a man into a vegetable? Debate whether Dr. Shockley's theories approach the same class, not whether a scientist must brush the cobwebs from all corners.

Attempts to prove racial inferiority in any sense attack infinitely deeper than governmental structure, the foundations of which deserve to be periodically tested. Prejudice, men hating each other to counteract their feelings of inadequacy, is rampant. Should the academic community work toward giving it a scientific basis, however improbable the prospect of tangible results seems? The specter of a rational 1933-1945 as a solution to overpopulation hovers.

Science has become a popular god whom few have the knowledge to question and all too many are willing to automatically accept. That god must do its best to be benevolent. Thus, let us investigate as fallible human beings, giving careful thought to researching topics that could work toward putting the de facto injustice of the application of the First Amendment on the sacrificial altar of the god of science.

JOHN F. SANTARIUS
BS '73

Science and Values

Malibu

After reading your article by Sir George Porter on the function of science (*E&S,* December-January 1975) I composed a short essay giving the other side of the question, what is the function of science? I thought it might stimulate a lively dialogue on the crucial question of science and values:

"I've given up God, and religion, but I still believe in man. I believe in values."

In these words, the modern humanist often expresses his world view. The conviction is very widespread nowadays that the gods are all dead or silent, that man has come of age, that the sons of science must now make their way alone, without any help from the outside. Even if it means waiting four billion years for science to discover our purpose!

But can you do this? Can you give up God and metaphysics and still believe in values? Can science by itself establish values? Nietzsche once quipped that the English give up God and then do penance by becoming moral fanatics, which, to him, was a trifle absurd. Does it make any sense to "go completely secular" and still try to hang on to morality, ethics, values?

I agree with Nietzsche: I say it makes no sense. I challenge anyone to establish a single value that man has traditionally prized by using the scientific method!

If you decide to take up my challenge, let me explain what your job will be. To prove a value by the scientific method, you'll need to show that it is objectively public, that it can be perceived by all men. Science knows no private truths; scientific facts must be clear to all. There is no "German math" or "Russian physics," no parochial divisions of truth.

Next, you'll have to establish the particular value, not by revelation, authority, tradition, hunch, or intuition, but by the strict empirical, laboratory method of investigation. In short, the value will have to come only through experience, through the senses. Furthermore, when it comes through the senses, we must be able to see by some clear definition that it is indeed a value.

But that's just the trouble—values can't come through the senses. Value judgments are made *by* the mind, working *upon* data from the senses. Wars, murders, rapes, thefts—all these bad things —are just as natural or empirical as plants, animals, and rocks. They all come through the senses, but none of them comes through with a bright red tag reading, "I am valuable." If they did, we could settle some of those borderline moral issues like abortion and euthanasia.

If you consistently follow the scientific method in all investigations, you'll finally have to conclude that all values are subjective, that values have no basis at all in the objective world.
You can't go from the "is" to the "ought." You can't pass from the descriptive to the normative. You can't prove what people should do merely by studying what they, in fact, do. Else you end up affirming, "Whatever is, is right." G. E. Moore correctly dubbed this "The Naturalistic Fallacy."

"But," you may object, "hasn't science proved that love, the greatest of all moral values, is firmly based on experience?" Careful! What you can prove is that human beings need to love and to be loved in order to survive and live full, happy lives. But what you can never prove in a million experiments is the proposition: "I should love my fellow human being." That is a normative assertion that empirical science doesn't even pretend to establish.

To prove the survival benefits of love isn't remarkable. To survive, my wristwatch needs oil, my car needs gasoline, my lawn needs fertilizer, my neighbor needs love. These are all good, scientific statements, good factual, descriptive propositions. But where do I look for that crucial imperative: *I am obligated* to oil my watch, gas my car, fertilize my lawn, and love my neighbor? What laboratory has proved—scientifically—that I *should* want my neighbor to survive?

That crucial imperative, that should or

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ought, isn't in the scientific method. If a humanist has it in his world view, he smuggled it in from another.

A few years ago someone asked the famous Harvard psychologist B. F. Skinner what he thought was the most basic of all values. Skinner answered, "All values derive from survival value." Yet when asked why anyone should be concerned about the survival of a particular culture, Skinner answered, "There is no good reason why you should be concerned, but if your culture has not convinced you that there is, so much the worse for your culture."

Strange words from a scientific humanist! Is Skinner saying that we must *assume* or *postulate* survival of the race as our basic value? But I thought that all things in the humanistic world view were proved by the best of all methods —the scientific method. Once you start assuming things beyond the bare empirical evidence, you get into trouble. Isn't that what humanists are always saying about prescientific religious world views?

Couldn't another thinker just assume that the survival of the entire race wasn't a value? Is there anything in the scientific method that prevents another Hitler from postulating the value that only a certain fraction of the race should survive? What in the strict scientific method would refute such a postulate? During the Third Reich, the Nazis succeeded in using some "morally neutral" scientists in their program for exterminating the racially unfit. Stephen Spender, who lived through that horror, wrote in *The God That Failed*:

> It is necessary to point out that scientists can derive from science *qua* science no objections to such experiments as exterminating the mentally unfit. If they do object, they are acting upon non-scientific values. Modern science has produced no reason to prevent science from being directed by governments toward purposes of enormous destruction in every country. Science is simply an instrument, for good or for bad. For it to be directed toward good, whoever directs it must have some conception of humanity wider than that of a planned scientific society.

We mustn't forget that Hitler loved to remind people that, according to science, morals are relative and there are no objective standards for right or wrong. Nazi irrationalism denied the unity of the human race and the value of every individual personality, a denial which allowed Nazis to murder six million Jews with a great feeling of righteous justification. The ovens that worked at Auschwitz were manufactured by a very reputable firm in the Ruhr. German science, the best in the world, didn't seem to have the capacity to prevent the moral shame of the "final solution."

"But why are you knocking science so much?" you ask. Please don't misunderstand me; no one is knocking science. The scientific method is the finest thing ever devised to study what science studies—the empirical world. One of the finest things about the scientific method is the rigorous standard of truth it demands in all investigations. But if you apply that standard rigorously to science itself, you can't use it to establish values. I haven't limited science; science has limited itself.

Occasionally a thinker comes along who dramatizes the concrete implications of a line of thought. Such a thinker was Jack London, who embraced with gusto the brutal truth about an amoral universe, about a purely "naturalistic ethic." In his novel, *Sea Wolf*, London has Wolf Larsen say:

> One cannot wrong another man. He can only wrong himself. As I see it, I do wrong always when I consider the interest of others. Don't you see? How can two particles of yeast wrong each other by striving to devour each other? It is their inborn heritage to strive to devour, and to strive not to be devoured. When they depart from this they sin.

If London's beastly view of ethics shocks you, then welcome to the club of those who look for something beyond the scientific method to establish values. As we see it, there is no such thing as duty in a world known only by the scientific method.

ARLIE J. HOOVER
Pepperdine University

Those Were the Days

Los Angeles

In addition to the excellent articles in the December-January issue of *E&S* (I have read them all), this issue had personal interest for me, as I knew Arnold Beckman, Richard Badger, and Al Hibbs. When in 1933 I made my first of numerous trips to Death Valley, I consulted Beckman, who had recently made such a trip. He urged me to see Titus Canyon there, which I did. On all my later trips, except when the canyon was closed because of flooding, I took that in again, always taking along some of my students or friends. Among the students I took was your Robert Leighton, on two trips, while he was still a student—he had been my student here at LACC. Also Charles Wilts.

Richard Badger and I teamed up with Fritz Zwicky and an Austrian physicist, in two small cars, to make an extended camping trip to the Utah and Arizona national parks, Monument Valley, Meteor Crater, various Indian ruins, and so on. This lasted nearly a month. On such a camping trip, especially under the conditions that obtained in 1927, one can really become acquainted with the members of the party.

On one occasion during the war the Registrar, Harry van Buskirk, who was also head of the math department, went away to some convention of Registrars, asked me to take his Honor Section of Freshman Math during his absence, and Al Hibbs was in that section, as I recall. Linus Pauling and I came to Tech the same year, and we were in a math class with "Van B" as he was usually called. When I came back during the war, in 1942, Dr. Millikan drafted me to be the Resident Associate in Dabney House, and Hibbs was in that house, and of course I came to know all the students in that house.

Dr. Millikan and Mrs. M. used to have Open House every Sunday afternoon for the graduate students in physics, and I enjoyed those meetings. I well remember that his Nobel gold medal was on display at the first meeting after he came back from Sweden with it. For me, "those were the days."

RALPH E. WINGER

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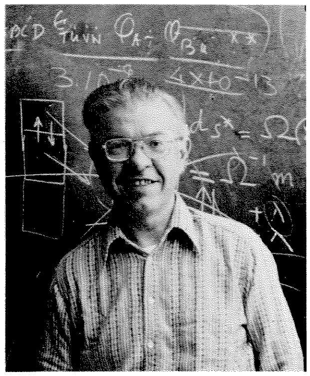

Renaissance Man

When Sir Fred Hoyle gave a Watson Lecture at Beckman Auditorium on February 17, his long-time friend and colleague William A. Fowler, Institute Professor of Physics, introduced him as "a Renaissance man." Fowler backed up this appellation with an impressive—and wry—list of Hoyle's accomplishments, from which we culled the following:

"Hoyle is one of the originators of the steady state cosmology, and he's made many original contributions to the concept of nuclear synthesis in stars and supernovae. He's now constructing a new cosmology that explains everything from the lack of solar neutrinos to the variation in the climate of the earth. Of course, it also explains the red shift, the blackbody background radiation, and how to put out fires.

"Sir Fred has had a long association with the California Institute and the Hale Observatories. It all began in 1952 when he walked into the Kellogg Radiation Lab and announced that his calculations on the structure of red giant stars convinced him that there was an excited state in the carbon^{12} nucleus near the threshhold for formation from 3-helium nuclei. We threatened to throw him out on his ear. But experiments in the lab quickly proved him right, and he's been a visiting member of the faculty ever since. Currently he's a Sherman Fairchild Distinguished Scholar.

"Hoyle's books range from politics and sociology to science fiction. He has written a Christmas pantomime for children and a space serial for television, and he's the author of an opera libretto."

He is also author of *Astronomy and Cosmology* and of *Highlights in Astronomy*, which are just now being published by W. H. Freeman and Company. Hoyle's Beckman talk and his *E&S* article, "The Emergence of Intelligence in the Universe" (page 23), are both adapted from material that appears in those two books.

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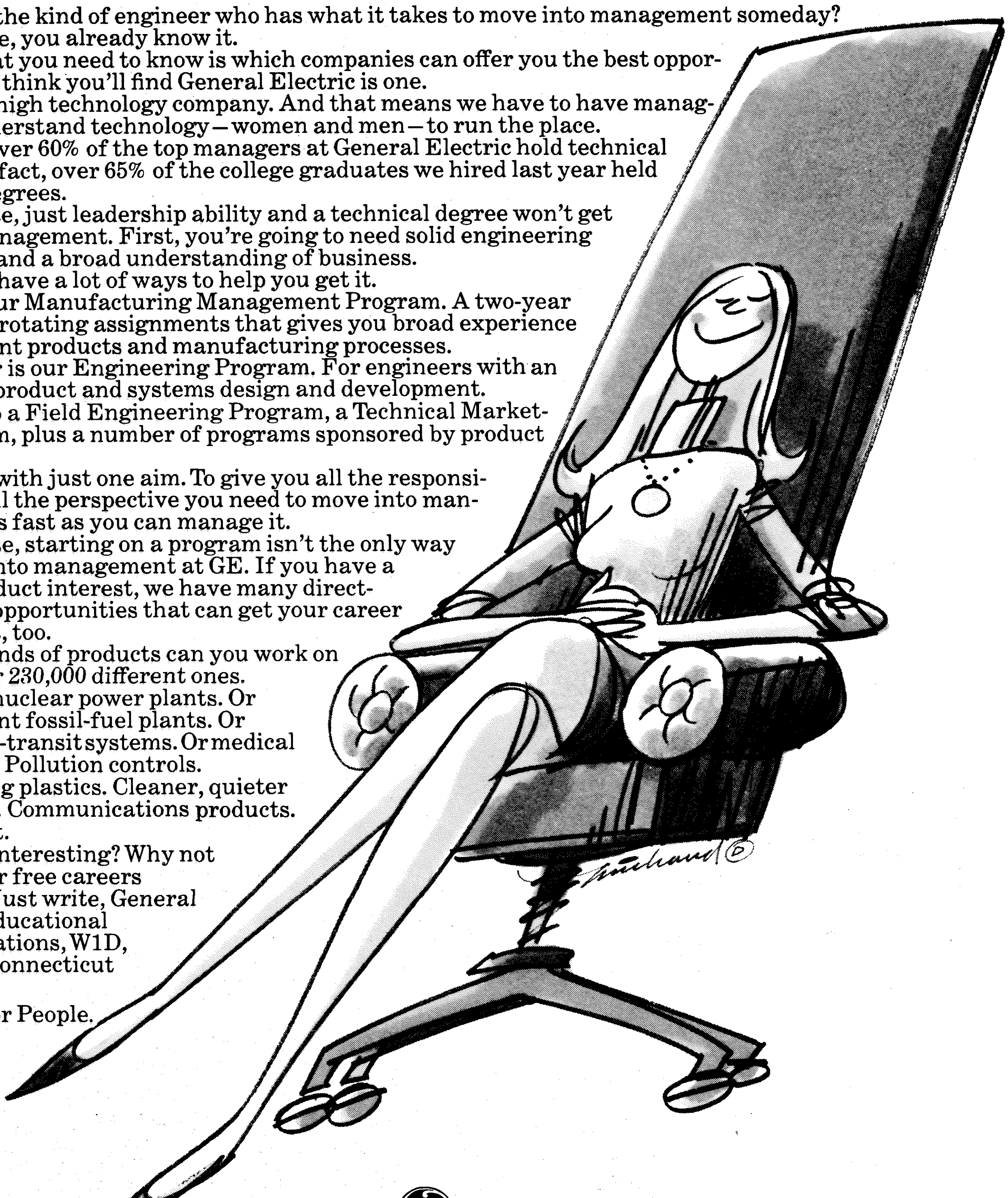

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