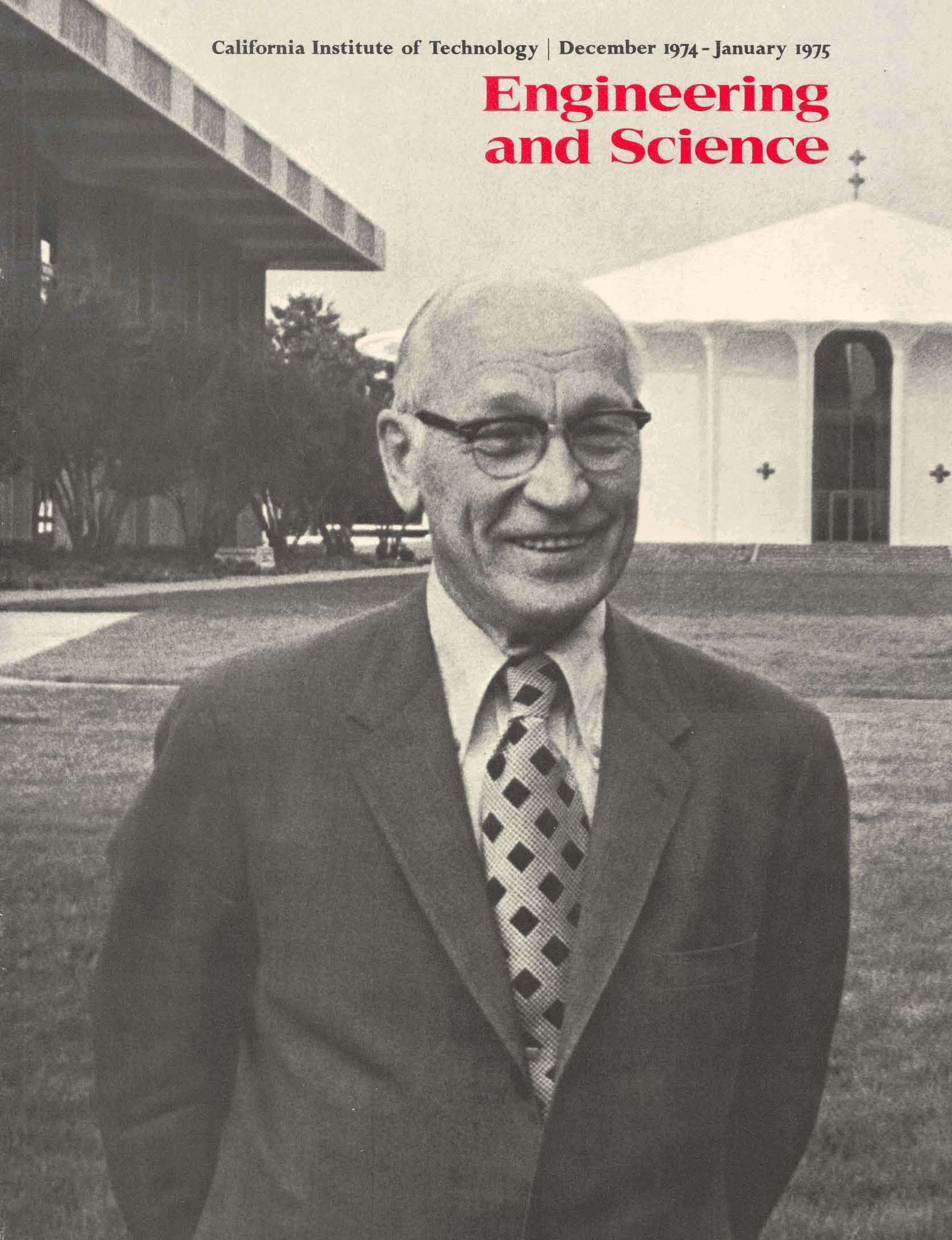
California Institute of Technology | December 1974 - January 1975

Engineering and Science



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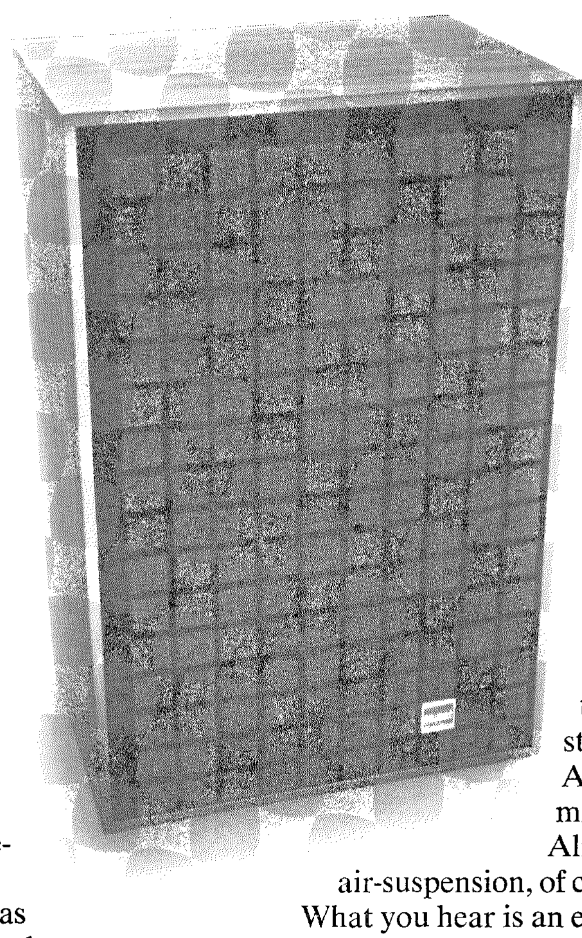

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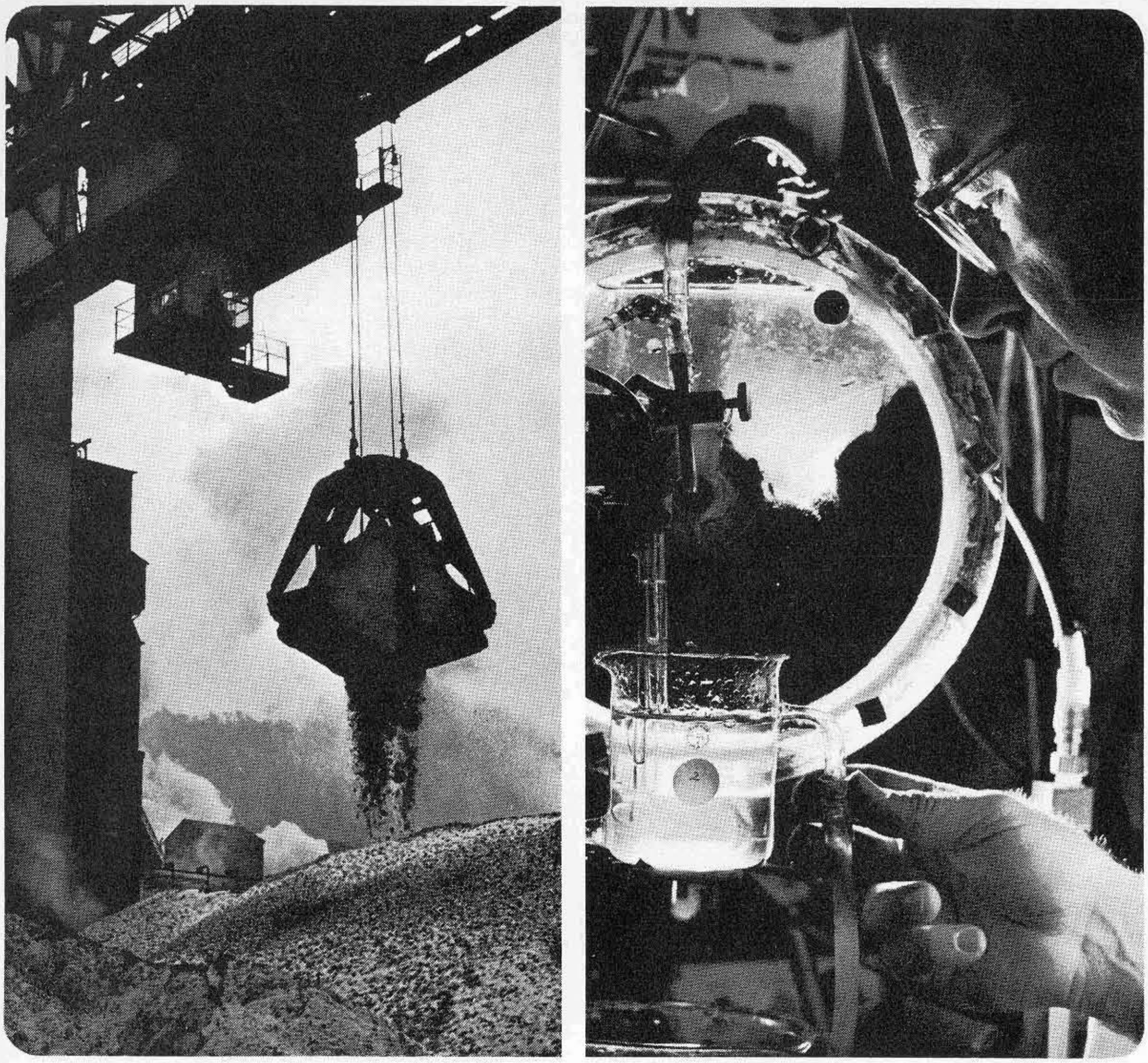
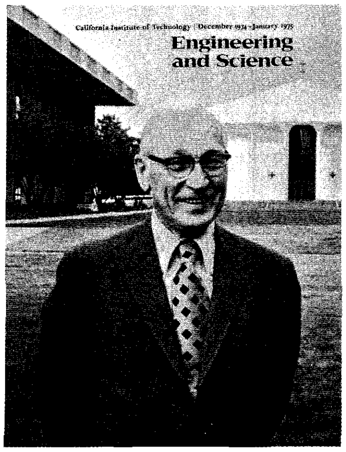
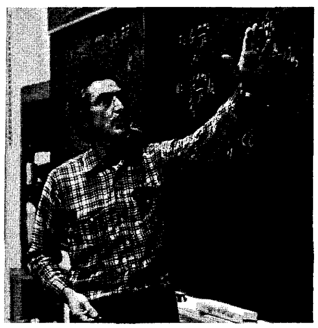


In This Issue



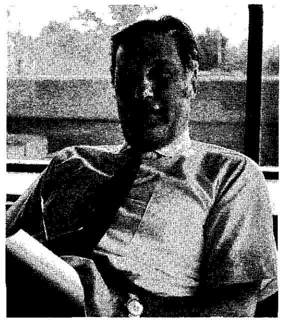
The Chemistry Is Right

On the cover—three Beckmans. From left to right, the Mabel and Arnold Beckman Laboratories of Behavioral Biology, Arnold Beckman, and Beckman Auditorium. Caltech and Beckman have had a lifetime attachment—or a 50-year one, at least. In that time, Arnold has been a Caltech student, alumnus, faculty member, trustee, and donor. On page 18, some highlights from these and other Beckman careers.



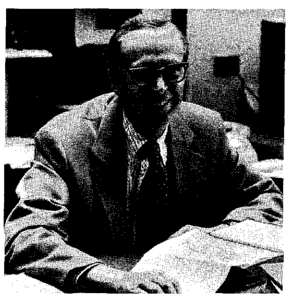
Voice of Reason

Albert R. Hibbs (BS '45, PhD '55) is senior staff scientist in the Caltech-JPL Medical Science Laboratory Planning Office. He is a prolific writer, and is widely known as the voice and/or face of several prize-winning educational radio and television series. Recently he has been the Voice of Mariner, describing and interpreting what the spacecraft are doing on their voyages to the planets. In the past he has lectured in government at Caltech, and he is currently a lecturer in physics. It is as a concerned citizen of the scientific community that he voices the protest and plea of "Inquisition, Repression, and Ridicule," which appears on page 4.



Are You Listening?

When alumnus Bernard Oliver (MS '36, PhD '40) opened the fall Earnest Watson Lecture Series on October 14, not only was Beckman Auditorium full by 7:30, but the lines snaked down the mall all the way to Gates Laboratory. Eventually, with Ramo Auditorium also filled, the lecture had to be piped outside to the overflow. And that was just the beginning. Requests for transcripts poured in for days, and there was no way to respond to the demand. So, it is with special pleasure that (on page 7) *E&S* presents Oliver's own adaptation of his lecture: "The Search for Extraterrestrial Intelligence." Besides being an author and lecturer, Oliver is vice president for research and development at the Hewlett-Packard Company in Palo Alto.



Pioneers' Progress

Rodman W. Paul, who is Edward S. Harkness Professor of History, is an authority on the Far West and Great Plains in the era between the Civil War and World War I, particularly the history of western mining. In the last few years he has become increasingly interested in the saga of the Mormons and the sources of their profound impact on the development of the West. In "The Mormons of Yesterday and Today" on page 12, he analyzes the strengths that have enabled this group to prosper in the last 140 years in spite of enormous hardship and prejudice against them. The article is adapted from Paul's Watson Lecture at Beckman Auditorium on October 28. The historical photographs that illustrate Paul's article are from collections at The Huntington Library, and we are grateful to Carey Bliss of the Library staff for his assistance.

Scholarly Address

Sir George Porter was a Fairchild Scholar at Caltech this fall, coming here from London where he is Fullerian Professor of Chemistry and director of The Royal Institution. He is also a 1967 Nobel prizewinner—and a man who likes to step back from the mainstream of science to question what he does. He did this for Caltech chemists at the Buchman Dinner at the Athenaeum on November 20. "The Relevance of Science" on page 22 is adapted from that talk.

STAFF: *Editor and Business Manager*—Edward Hutchings Jr.
Managing Editor—Jacquelyn Bonner
Photographer—Floyd Clark

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Published four times a year, in October-November, December-January, February-March, and April-May, at the California Institute of Technology, 1201 East California Boulevard, Pasadena, California 91125. Annual subscription $4.50 domestic, $5.50 foreign, single copies $1.25. Second class postage paid at Pasadena, California, under the Act of August 24, 1912. Published by the California Institute of Technology and the Alumni Association.

Engineering and Science

December 1974 - January 1975/Volume XXXVIII/Number 2

Inquisition, Repression, and Ridicule

ALBERT R. HIBBS

Does the scholarly community have an obligation to extend a respectable forum for the open discussion of repugnant theories?

In the spring of the year 1498, Moro, the Duke of Sforza, held a gathering of scholars in the large hall of the Sforza Palace in Milan. The affair was called "The Duel of Learning."

There were arguments among the learned men concerning the immaculate conception of the Virgin Mary and then an intense medical discussion on the questions:

1. Are handsome women more prolific than homely ones?
2. Was the healing of Tobit with fish-gall natural?
3. Is a woman an imperfect creation of nature?
4. In which inner part did the water originate which flowed out of the Lord's wound when he had been pierced by a spear?
5. Is woman more voluptuous than man?

The dispute on all the questions was heated, for these were matters which learned men of the time found of great importance both to their contemplation and to their professional advancement within the society of their peers.

At some point in the course of the debate the Countess Cecelia of the House of Sforza persuaded the Duke to challenge his guest to enter the debate of the scholars. His guest was Leonardo da Vinci.

Leonardo was extremely hesitant. He felt most uncomfortable speaking in front of large groups. In fact, he had an absolute fear of such a challenge. Nevertheless, the Duke and his Lady insisted that he speak.

He was totally unknown to the scholars assembled. He was not a member of any faculty, nor had he written learned documents on the burning issues of the day. He was known only as an artist who was working on a painting called "The Last Supper." For this reason, most people were pleased at the idea that he would speak, since it was well accepted that artists were comical.

He told them about petrified marine animals and the imprints of seaweed and corals which he had found in caves and on mountains a great distance from the sea. He stated that this was a demonstration of how, over the long period of its history, the face of the earth had changed. He stated that where there are now dry lands and mountains there had once been the bottom of the ocean. He suggested that eventually even the Nile River would fall into the Atlantic beyond the Straits of Gilbraltar.

He is quoted as having said: "I am positive that the study of petrified animals and plants, which has hitherto been despised by men of science, will give a beginning of a new science of the earth, of her past and her future."

The scholars around him were baffled. How were they to act? Should they say praiseworthy things because the Duke had asked him to speak, or should they laugh because what he had said was so patently absurd, and obviously intended as a joke? It was finally decided that laughter was the proper behavior, but after the audience had quieted, one of the more noteworthy scholars pointed out that all of this was simply the result of the flood as it had been written.

Leonardo replied by noting that the level of the flood according to the Scripture was ten cubits higher than the highest mountains. Therefore shells swirled by the waves would have fallen on the tops of mountains but not on the sides, nor the bottoms, nor inside of caverns. Furthermore, they should have fallen in wild disorder and not in carefully placed layers. Furthermore, how could they be imbedded in the rocks by a flood which lasted only a number of weeks?

An astrologer had the answer to all of this, saying that the sea animals and all the other things found by Leonardo had been created by the magical action of stars.

Leonardo asked if all mysteries were simply explained as a magical action of stars, how could science advance? Before too long, one of the more learned scholastics caught Leonardo on a question of theology. As he put it: "Can it be that all our knowledge of the soul, of God, of life beyond the grave, all of which knowledge is not susceptible of experimentation is, according to what you say, sir, not open to proof, as you yourself were pleased to express it? Are you saying, sir, that even though such knowledge is confirmed by the unfailing testimony of the Holy Scriptures that it is still not proven?"

Leonardo attempted to beat a hasty retreat from the trap of heresy that had been opened in front of him, and was fortunately saved from any further difficulties by a loud shouting match among the assembled scholars.

This was Leonardo da Vinci's first and last attendance at a symposium of learned men. For all of his understanding, and for all of his ability, he was nevertheless a somewhat simple man in dealings with the rest of humanity. He was disappointed, baffled, and perhaps even disgusted by the ridicule he had been subjected to. From that point on, and through the rest of his career, his scientific theories remained in his notebooks, written backward with his left hand and in fact quite often in a special code—not a terribly complex code, but at least difficult enough to frustrate anyone who might glance at his notebook.

But if Leonardo was subjected to the ridicule of the philosophers in this particular symposium, the general flavor of his life was quite different. He was both honored and sought after. In fact, for a couple of years, Pope Leo X was his patron.

As is well known, the situation was quite different a century later, in the case of his countryman Galileo Galilei. For Galileo was indeed served with an injunction, haled before the Holy Office, and sentenced to prison for what amounted to the remainder of his life. Even though he was allowed to serve his sentence in his own house on a small farm that he owned, we should not believe that this sentence was purely symbolic. The house was indeed small, and (for those days) a long distance from any center of civilization. During one of the more painful illnesses of his old age, his friends begged the Pope for permission to take him to Florence for medical treatment —but that permission was flatly refused.

Although many of us are familiar, at least in general terms, with the unhappy history of Galileo, there may be only a few who have looked into the real details of the matter. Many of us are inclined to view Galileo's trouble as a conflict between religious dogma and scientific freedom. With this belief firmly in our minds, we feel justified in considering ourselves far beyond such sordid mistakes. But was this really the conflict, and are we indeed so far beyond the mistakes we ascribe to the Inquisition of 1633?

Galileo was not charged with, nor sentenced for, heresy. The charge was rather that he failed to obey an injunction which had been laid upon him 17 years earlier—an injunction concerning his support of the theories of Copernicus that the sun is the center of the solar system, and the earth moves around it. But a careful study of the records indicates that this injunction was a fake. It had apparently been forged into the church records, and with the deliberate intent of laying a trap years ahead of time which might at some future date be useful in bringing the great man to heel. In other words, Galileo was framed. But by whom and for what purpose?

The story began years before. Some of the early writing and letters of Galileo had caused considerable anguish and embarrassment to a learned society of Dominicans, a group who considered themselves to be the center of philosophy in Italy.

At this same period of time an ancient antagonism was brewing again between the Jesuits and the Dominicans. The Jesuits' traditional role was running the educational system, and they were just as upset with Galileo as the Dominicans were. Galileo's published works were usually written in Italian, rather than the scholarly Latin. This meant that anybody could read them. And indeed, many noblemen and their offspring were reading them, and were asking their Jesuit teachers some embarrassing questions about natural philosophy. The Dominicans and Jesuits were frequent, and sometimes bitter, rivals for Vatican favor, but they found a common enemy in Galileo.

Actually, Galileo had many friends in the highest echelons of both Jesuits and Dominicans. (You can almost hear him saying at the time he was summoned before the Inquisition, "Why, some of my best friends are cardinals!" —and it was true.) But to have close acquaintances and supporters among individual, even leading, members of a group doesn't necessarily mean that you are on good terms with the bureaucracy. Yet the fact that Galileo had such powerful friends forestalled any direct attack. The rule, then as now, was—"Don't make waves!"

The crisis finally arose in 1614 when a Dominican monk of small wit, but great ambition, decided to make a name for himself by attacking Galileo from the pulpit, something that had not yet been done. He announced that mathematics was of the devil; mathematicians should be banished from Christian states; and these ideas about a moving earth were very close to heresy.

In the workings of the church, in the early 17th century, individuals, whether clerical or laity, could write letters and publish papers about almost anything they pleased,

We must recognize that bureaucracies have not changed much since the time of Galileo

even the theories of Copernicus, so long as they were very careful to word them in such a way that obvious heresy was avoided. But when a monk preached a sermon with references to heresy, and thus "stirred up the multitudes," the bureaucracy of the Vatican became concerned.

The Jesuits capitalized on the situation and persuaded the Vatican that embarrassment was a distinct possibility. Point one, it had been triggered by a Dominican; but, point two, Galileo was the basic problem.

Although the theories of Copernicus did indeed seem to be against official church doctrine, the highest authorities had studiously avoided making any official pronouncement on the subject. They wanted to keep their options open. Suppose further study should tend to show that Copernicus was right? The best move was to take no stand at all, but now the hand was forced.

The action was an official examination of the theories of Copernicus by a group of scholars and philosophers called "qualifiers." The result of the examination was that the Copernican theory on the solar system was held to be absurd, false, against theology, and in part heretical. No one was to hold or to teach this theory. Galileo was notified of that decision and agreed that he would not "hold or teach" that the sun stands still and the earth moves. He then tried out, very delicately and very carefully, writing and teaching about the theory in a discussive manner, being careful never to claim it as absolute truth.

This approach was quite acceptable to all concerned. The Vatican authorities heaved sighs of relief. The Pope encouraged him to publish. It seemed that a serious flap had been avoided. No individual was actually indicted for heresy and no one, including Galileo, complained about the formal restriction on the wording of scientific papers. Yet the Jesuit and Dominican monks remained frustrated. The enemy still lived and prospered.

Now we come to the plot. After Galileo had been told of the judgment concerning the theories of Copernicus, a curious note was entered into the official files of the Holy Office. It is curious in many ways. It was on the back of a sheet of paper where few notes were put, and certainly nothing with great official value. It was unsigned. The date when it was entered is not stated. It appears to be a minute of a meeting. It states that Galileo was enjoined as follows (and in those days the word enjoined had a specific and somewhat frightening legal meaning): " . . . nor further to hold, teach or defend it in any way whatsoever, verbally or in writing."

The crucial phrase in this document is ". . . or defend it in any way whatsoever, verbally or in writing."

This was the injunction on which Galileo was tried and convicted. Throughout his trial and in the years after his sentencing, Galileo claimed it was this specific injunction that had never been laid upon him. And apparently he was right.

Galileo threatened the status quo of education, and the self-respect of the philosophical hierarchy. They wanted him out of their hair. It took many years and seemingly forged documents to get him, but they finally did. It had to be carefully done. If they made too much trouble too soon, the blow could easily have fallen upon them.

Perhaps it is an interesting comment on the personality of Galileo that he steadfastly believed that the matter really did concern the theories of the solar system. He repeatedly tried to have somebody in authority actually read his *Dialogues*. The book had already received the official seal of approval from the Vatican censors, but higher authorities found it either too difficult or, perhaps, too boring.

I have dwelt a long time on the story of Galileo because I believe it has some special meaning for us. I believe we must recognize that times and bureaucracies have really not changed so much, whether the bureaucracies are governmental, religious, educational, or scientific.

continued on page 28

The Search for Extraterrestrial Intelligence

BERNARD M. OLIVER

During the last four decades a quiet revolution has swept through the scientific community. Scientists who only a quarter of a century ago would have rejected the idea that the universe may be filled with intelligent life have come to accept this belief. Indeed, many now feel that it may be man's destiny—you might say his first step toward maturity—to contact that life, to learn about it, and to share in its goals.

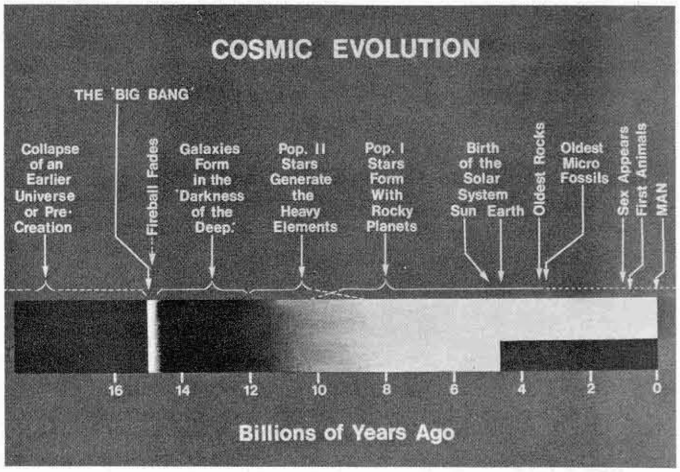
This change in belief is a result of many discoveries in many different fields—in astronomy, in nuclear physics, in atmospheric chemistry, in geophysics, paleontology, biology, and others—and many of these discoveries have been made at Caltech. Out of all of these discoveries has emerged a new and grander picture of the world, one that may ultimately reshape man's entire philosophy. The picture we now behold is one of *cosmic evolution*: a universe that was born and that has evolved into galaxies of stars and finally into living things. It is a universe that will continue to evolve for aeons to come before it either vanishes into oblivion, collapses toward rebirth, or comes to some end that we cannot yet foresee.

The universe as we see it today is expanding. The galaxies of stars are flying apart at a speed proportional to distance (that is, the farther apart they are, the faster they are receding from each other). This expansion suggests an explosive beginning, and indeed if we run the film backward through the projector and apply the known laws of classical and nuclear physics, we can reconstruct what things must have been like about 15 billion years ago when it all began.

We see the universe beginning as an awesome fireball, inconceivably hot and dense. The theories of nuclear physics suggest that only *one second* after the very instant of birth, all the particle annihilation had stopped, the hadron era was over, the lepton era was over, and all of the primordial matter of the universe (only hydrogen and helium) was left as a sort of a faint precipitate in this very early inferno of the fireball.

The "interior" of that fireball was and is the whole universe as we know it. We are inside the expanded fireball, and so far as we are concerned, there is no outside. In a sense, we may consider the universe to be an immense black hole.

For the next million years or so, as the expansion continued, the primordial matter was trapped by the intense blaze of radiation, and could not condense. One



In 15 billion years the universe has evolved from the blazing inferno of the primordial fireball into galaxies of stars surrounded by planets, many of which may support intelligent life. Out of chaos the wonderful laws of nuclear physics and chemistry have produced the complexity of the brain. Only the expansion of the universe prevents this evolution from being a violation of the second law of thermodynamics.

million years after birth, the universe was a pure blaze of light, as bright as the surface of the sun.

By the end of another 100 million years the continuing expansion had cooled the radiation to the point where all the light had disappeared. The entire universe was then about at room temperature, and the matter was of nearly uniform density everywhere. Imagine all space filled with gas at about room temperature, and no light anywhere. The hydrogen and helium were now free to begin their contraction into huge clouds that were to become galaxies of stars. But as yet there were no stars, and "Darkness was everywhere on the face of the deep."

Then each galactic gas cloud fragmented into billions of globules, each of which contracted until the heat generated in their centers kindled the fires of hydrogen fusion. Once again there was light—no longer a blaze of light in all directions, but billions of pinpoints of light: the early stars. Since these early stars were formed only out of hydrogen and helium, the only matter left over from the original fireball, none of them had rocky earth-like planets around them. They may have had planets, but they were gaseous ones. Calcium, aluminum, silicon, oxygen—none of these elements existed yet.

Stars, then and now, are the furnaces in which all the chemical elements heavier than helium seem to have been formed. Stars spend most of their lives on what is known as the main sequence, quietly burning hydrogen into helium in order to supply the light and heat that they radiate into space. During this phase, the luminosity, or total power output, of a star is proportional to the 3.5 power of the star's mass. The result is that although massive stars have a lot more fuel to burn, they squander it at a prodigious rate and live only a few million years, while very small stars, which may have very little fuel, burn it so slowly that they live for tens or hundreds of billions of years. (No star much smaller than our sun has yet left the main sequence.) When the hydrogen in the core of the star is exhausted, the star blows up into a red giant. Then helium burning begins in the core, and the production of heavier elements commences.

In their red-giant phase, stars go through very complex cycles that are not fully understood yet. But we do know that when a massive star—one that's several times more massive than our sun—completes its fusion stages, it does not shrink to become a white dwarf as our sun will do some seven billion years from today; instead, it ends its life as a supernova.

For a few weeks after this huge explosion, these massive stars shine with such supernal brilliance that they outshine the whole galaxy and can be seen in the daytime sky. These events happen only once or twice a century in a single galaxy, but there have been many recorded instances of supernovae appearing both in our galaxy and in nearby ones. The Chinese observed such a star in our galaxy in the year 1054 A.D.; they called it a "guest" star. It appeared from nowhere and was visible in the daytime sky. It's very interesting to note that no record of the appearance of this star exists in Western Europe, where church dogma at the time declared the heavens to be eternal and unchanging. Apparently it was far easier not to see this brilliant object than to have one's fingernails pulled out by the roots for heresy. Now, 920 years later, we know the object as the Crab Nebula, and it's the subject of much interesting research today.

Most of the matter of this star is seen flying out into space, there to enrich the interstellar medium with the heavy elements that were formed by nuclear fusion, neutron capture, and beta decay. Someday, somewhere, out of this enriched gas and dust a new good earth may be born. The calcium in our very bones came from similar explosions billions of years ago. We are quite literally little bits of stardust.

Apparently, in the very early stages of the Galaxy—the first few billion years—hundreds of generations of short-lived massive stars exploded as supernovae. After billions of these had flashed throughout the Galaxy, enough heavy elements were added to permit Population I stars to form.* These are the stars that can have rocky planets about them.

Stars are still being born even today in our own Milky Way and in other galaxies. The present theory is that the spiral arms of a galaxy are not regions of heavy star concentrations but rather that they are regions of high gas and dust concentration: the maternity wards of the galaxy where new stars are being born at a rapid rate. It's the very brilliant high-luminosity O and B** stars that don't live long enough to get very far from their birthplaces that give the arms their extra brightness. So the process of interstellar gas enrichment is still going on.

Our sun is a fairly young star. It's only five billion years old. Over 100 billion Population I stars in our galaxy are older than the sun. How many of these have earth-like planets and how many of these good earths support intelligent life? Before we try to answer that question, we should look briefly at what did happen on earth.

After the sun had condensed, leaving a disk of whirling, turbulent matter behind, this matter began to coalesce into planets. We find that the outer planets—Jupiter,

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*In 1944, Walter Baade of the Mt. Wilson Observatory divided stars into groups according to their ages and habitats. Population I includes younger stars associated with gas and dust; for example, those found in galactic clusters or the spiral arms of galaxies. Population II stars are older and are found in regions essentially devoid of gas and dust.

**Almost all stars fall into one of seven spectral classes: O, B, A, F, G, K, or M. This system of classification, based on the relative intensity of selected absorption lines in the stellar spectra, furnishes a continuous sequence of spectra related to colors (blue through red) and therefore the stars' surface temperatures (45,000°F. through 2,400°F. or less). The types are further subdivided by numbers representing a tenth of a spectral class; for example, an F_5 star is halfway between an F- and a G-type star.

Saturn, Uranus, and Neptune—have about the same relative abundance of chemical elements as the sun. They are typical of the material out of which the sun condensed. If you were to strip Jupiter of its atmosphere, it would be only about 5 or 6 times heavier than Earth, whereas with its atmosphere it's about 318 times heavier. The outer planets are mostly hydrogen and helium, with only about 2 percent heavy elements. The inner planets, by contrast, are almost all heavy elements, with very little hydrogen and helium.

When the sun was young, the solar wind was a real gale. Apparently, the young sun blasted most of the hydrogen and helium out of the inner part of the solar nebula, leaving behind only the dust—or perhaps the already accreted planets. It is out of this dust that you and I were made.

Mercury, Venus, Mars, Earth, and the moon were probably formed without atmospheres and had to generate them from gases produced by volcanoes. This only happened to an appreciable extent on Earth and Venus. The moon and Mercury are too small to have had any appreciable amount of vulcanism. Mars is a borderline case. We can see extinct volcanoes there, and indeed Mars has some atmosphere, but only about 1 percent as much as Earth. Apparently the ratio of surface to volume in the smaller planets was great enough to radiate the internal heat fast enough to prevent a large amount of vulcanism. On Earth the steam from volcanoes condensed into seas. There has been enough vulcanism on Earth to account for all the seas and many times the amount of atmosphere that we have today.

The primitive atmosphere was thus composed of volcanic gases, gases like methane, ammonia, hydrogen sulphide, carbon dioxide, and sulphur dioxide. A great turning point in scientific belief came when Stanley Miller (professor of chemistry at the University of California) demonstrated that a mixture of such gases, when exposed to ultraviolet light, produces amino acids, simple sugars, porphyrins, and other compounds that are the building blocks of proteins and of DNA. Apparently the atmospheric chemistry was such as to *fertilize* the early earth.

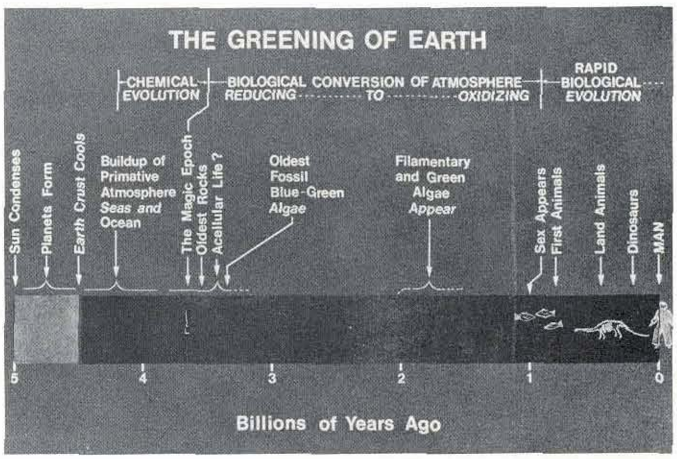
Some of these organic compounds have also been detected in the interstellar medium by radio astronomers, so we know that they are not peculiar to the surfaces of planets. Nevertheless they probably were produced on Earth in very great amounts, perhaps several pounds for each square inch of Earth's surface. They fell out of the early atmosphere into the early seas, turning these seas into a consommé or chicken soup. Literally. It was out of this broth that life began.

We don't know when or how the first self-replicating molecules formed. We don't know how the first DNA began. We don't know, either, when the first cell was formed to isolate that DNA in an environment of its own making. These things remain to be discovered. But we do know that on a cosmic time scale it didn't take very long. Deep in some of the oldest sedimentary deposits on Earth microfossil remains of blue-green algae have been discovered that date back 3.35 billion years. Considering that blue-green algae was certainly not the first self-replicating organism formed, that it must have been preceded by simpler forms of life—perhaps bare nuclei—and that a long period of evolution must have taken place to produce as complicated a thing as the blue-green algae, it's quite evident that life on Earth began almost as soon as atmospheric evolution had rendered it fertile.

Now we come to quite an epoch. The primitive atmosphere was a reducing atmosphere, full of noxious gases that would kill all animal life. What seems to have happened is that for about two and a half billion years the blue-green algae and its descendants patiently removed the carbon dioxide and released oxygen. All during this time the volcanoes were still pouring more carbon dioxide into the atmosphere, and the algae thrived on it. Most of Earth's carbon that was once in this carbon dioxide is now locked away in limestone produced in the early oceans.

On Venus, the temperature was just high enough that seas did not form and life did not begin. The volcanoes continued to belch forth carbon dioxide, which began to trap the sun's heat. We now know from our space program that the surface of Venus is hot enough to melt lead. It suffocates under a blanket of carbon dioxide about a hundred times heavier than Earth's atmosphere. Blue-green algae saved Earth from this fate.

Less than a billion years ago a major advance occurred in the stream of life. Life invented sex. This is of



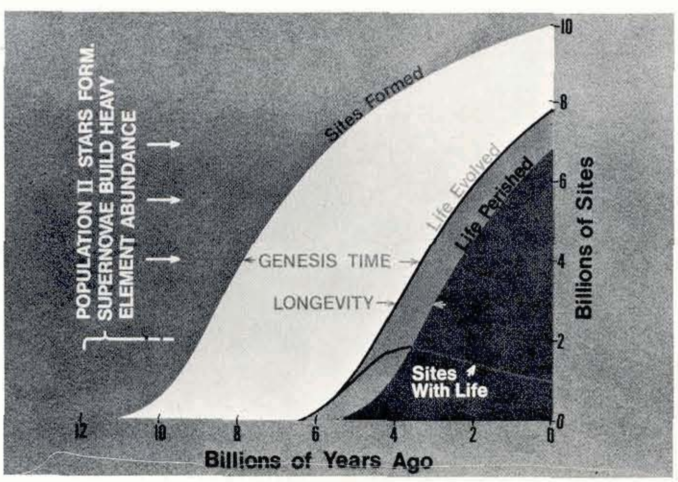
Three and a half billion years of vulcanism, chemical evolution, and atmospheric evolution produced the green hills of Earth and set the stage for animal life. A similar development seems likely on any planet of earth-like composition, temperature, and size.

enormous genetic importance, because prior to the invention of sex a favorable mutation that occurred in one member of the species had to be succeeded by another favorable mutation in that same member or its descendants in order for the combination to occur in a single individual. With the advent of sex there was intermixing, and as a result, favorable mutations that had occurred in separate individuals of the species combined much more readily. (And that's really all you need to know about sex.)

The geological record shows that it was right after the invention of sex that evolution really took off. Marine animals appeared, followed by land plants, land animals, the reptiles, birds, and trees. Angiosperms (flowering plants) appeared. Their rich seeds changed the whole food balance of the world so that much more animal life was possible than ever before. Finally—very late in the scene—man appeared. All of this came about in the relatively short span of 800 million years.

What I find so impressive is that the steps from fireball to life, from chaos at the beginning to the indescribable complexity of, say, the human brain, all happened through natural law. Surely this must be the greatest miracle of all —that the universe, out of the fire in its beginning, has evolved not only into stars and planets, but into living things that now have eyes and minds that can contemplate the universe that begat them. What greater miracle does man need?

The crucial point to this story is that there doesn't seem to be anything in this whole pageant of evolution that is in any way peculiar to Earth. There is no special quality that Earth alone possesses, and if this is true, then the Copernican revolution is indeed complete.



Evolution of Life Sites—After supernovae explosions had enriched the interstellar gas with heavy elements, stars with rocky planets began to form. There are now on the order of ten billion life sites in our Galaxy. On some life has not yet evolved, on others it has perished. The number of advanced cultures at this time is roughly equal to the average longevity of advanced cultures in years; i.e., $N \approx L$.

Of course, not every star is a good sun, so we don't expect to find life around every star. To begin with, stars larger than F_5 stars have a total main-sequence lifetime that's less than the time it took life to evolve on Earth. Unless our evolution was unusually slow, there aren't evolved civilizations around such stars. Stars smaller than about K_5 have such a low light and heat output that a planet, to be warm enough, would have to be in such a tight orbit that the tidal coupling would stop its rotation. It's rather unlikely that on such a planet there would be benign enough conditions for life to evolve. So we think that only middle-class stars within the size range from about F_5 down to possibly K_5 can be good suns. Fortunately, there are a lot of these; about 20 to 25 percent of all the stars fall into this spectral class range.

But not every good sun will have a good earth around it. We think that almost all suns have planets, but in some systems the distribution of the planets may be wrong. There may be none at the right radius from the star to be at the proper temperature. Or the favorably situated planet may be too small to have volcanoes, so it just goes around forever and never generates life. Or it may have too much vulcanism, so that the entire planet is covered with ocean, in which case life could start, and might even evolve into intelligent counterparts of our Cetaciae (members of the order that includes aquatic mammals such as the dolphin and the whale). But it's doubtful they'd ever build radio telescopes in their marine environment.

When we take these factors into account, we conclude that out of the few hundred billion stars in the Galaxy, there are perhaps ten billion life sites. That is to say, there are about ten billion places where life has either evolved and perished, or exists now, or will someday evolve—sites that are destined to, or have already, fulfilled their task of supporting life. But if *we* want to contact any other life in the Galaxy, it must exist during this epoch, not billions of years in the past, or billions of years in the future. What can galactic evolution tells us about this?

Population I stars began to form about ten billion years ago. The rate was very rapid from about nine billion to about six billion years ago, but has slowed down since then, as the interstellar gas and dust has become somewhat depleted. Among the stars that developed during this early period were many F, G, and K stars with planets that were destined to support life. If our own genesis time is typical, then after about four or five billion years intelligent life evolved on a fair fraction of these sites, so there was probably intelligent life in the Milky Way before our sun was born. Unless the longevity of civilizations is typically billions of years, there were more of them in the past than there are now.

When one includes the best estimates for all the astronomical and biological selectivity factors, it turns out that

Man's first step toward maturity may be to contact life beyond the solar system

the number of intelligent races in this one Galaxy at the present time is about equal to the average number of years that such civilizations exist. The significance of this is pretty clear. It says that if civilizations usually solve their societal, ecological, population, and resource problems—and therefore live a billion or more years—then the Galaxy is teeming with intelligent life. If, on the other hand, they kill themselves off after only a hundred years in nuclear wars or some equally stupid way, then the Galaxy is practically devoid of intelligent life.

So the question of whether there is intelligent life out there depends, in the last analysis, upon how intelligent that life is. How can we find out? How can we be sure? How can we determine if other intelligent life indeed exists? For at least a decade it's been obvious that interstellar travel by spaceship is not only impractical for us at this time, but a virtual economic impossibility with any technology we can foresee. Chemical rockets are far too slow to do the job. It would take a chemically powered rocket about ten times as long as all recorded human history to get to the nearest star. It would be very difficult to recruit astronauts for that kind of a journey. If we could make the journey at something like seven-tenths the speed of light, then because of relativistic time-dilation, the flight time for the crew would be numerically equal to the distance in light years.

Let us consider the ultimate capabilities of nuclear space travel. Let's ignore any limitations imposed by modern technology and assume the best rocket permitted by natural law—one that annihilates matter with anti-matter. (Don't ask me how I'm going to build an anti-matter fuel tank. That's one of the problems I'm ignoring.) The pure radiation from the annihilation would constitute the rocket's exhaust.

Let's assume that we'll need about a thousand-ton payload in order to house a crew of ten for a decade. We'll need four stages, one to start the thing off, one to stop it when it gets there, one to start it back, and one to stop it when it gets home again. The relativisic rocket equations show that about 33,000 tons of matter and anti-matter would have to be annihilated to make a trip at seven-tenths the velocity of light. The total energy released would be enough to supply the entire present electrical power needs of the U.S. for half a million years. The takeoff power even from orbit would be about 10^{18} watts. This is ten times the solar power falling on the earth. But this wouldn't be sunlight. It would be hard gamma rays, and would present quite a shielding problem, especially for the ship itself. If only one part in a million of the rocket power leaked to the ship, the ship would have to get rid of a million megawatts of heat, and that requires a thousand square miles of radiating surface. That's hard to achieve with a total weight budget of a thousand tons.

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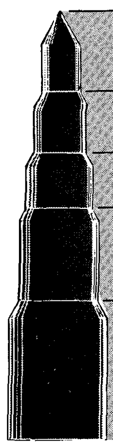
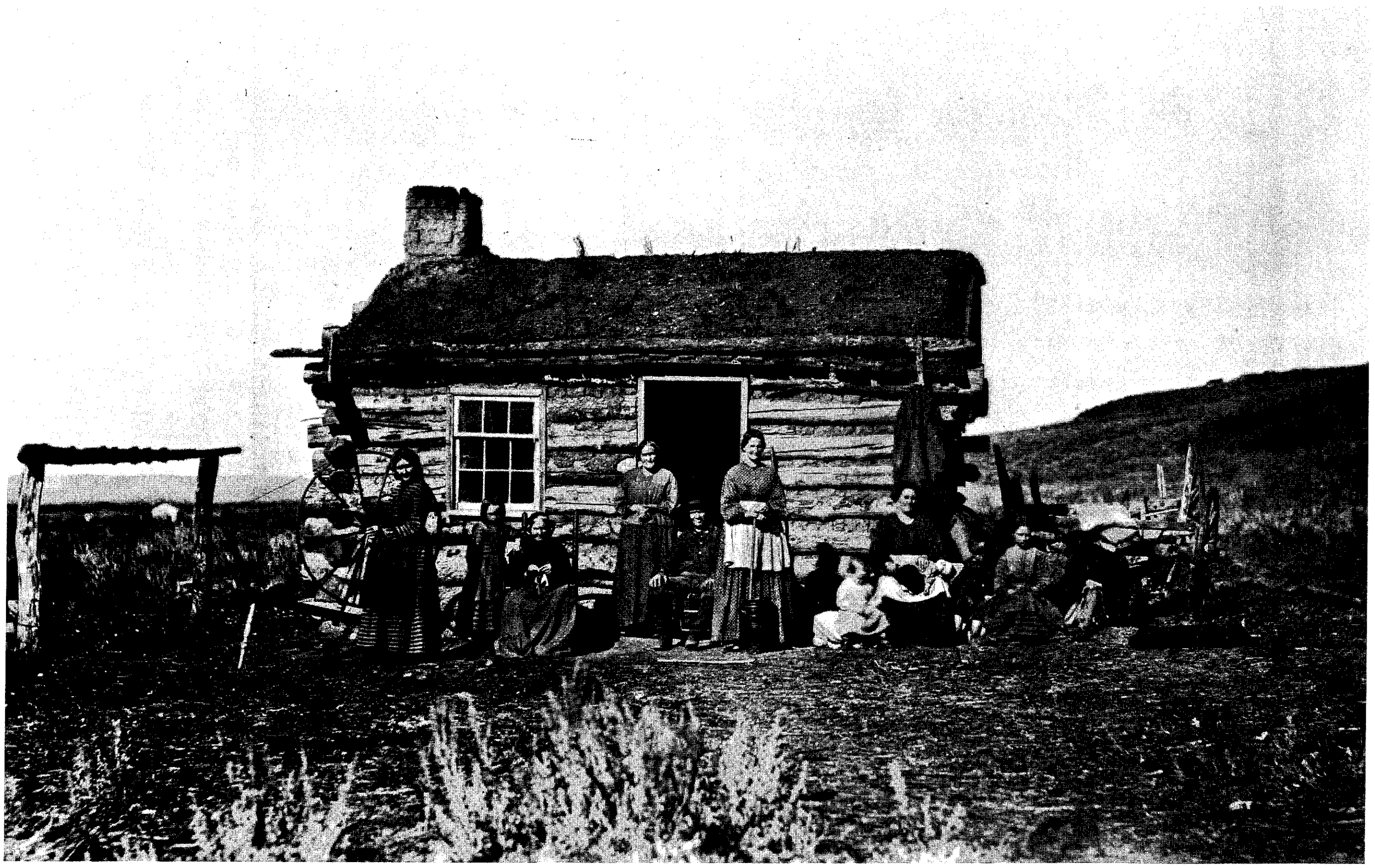
DESTINATION	BILLIONS OF MILES	LIGHT TIME	FLIGHT TIME
MARS	.15	13 MINUTES	~ 6 MONTHS
JUPITER	.50	45 MINUTES	~1.5 YEARS
PLUTO	3.5	5 HOURS	~10 YEARS
NEAREST STAR	25,000	4 YEARS	~ 40,000 YEARS

Interstellar Travel—Chemical rockets are far too slow (above) to take us to the stars or to let others visit us. Even ignoring technological limitations, relativistic nuclear rockets require prodigious energy expenditures (below).



	TONS	ENERGY IN YEARS OF U.S. ELECTRICAL CONSUMPTION
PAYLOAD	1000	
FOURTH STAGE	1400	51000
THIRD STAGE	3400	21000
SECOND STAGE	8200	123000
FIRST STAGE	20000	305000
TOTAL	34000	500000



A Mormon family gathered outside their sod-roofed log cabin somewhere in the Great Salt Lake Valley about 1868. The barren land, the small, primitive dwelling, and the proportion of women and children to one adult male were typical of the time and place.

The Mormons of Yesterday and Today

RODMAN W. PAUL

The Mormons as you see them today present a striking contrast to the Mormons as they were 127 years ago when they were about to start moving their people across the Great Plains to the arid lands of Utah, then virtually unoccupied by white men. There were 16,000 Mormons in that original folk migration to Utah. Today there are more than 2,500,000 Mormons in the United States, plus another million in foreign countries, bringing the total to 3,500,000.

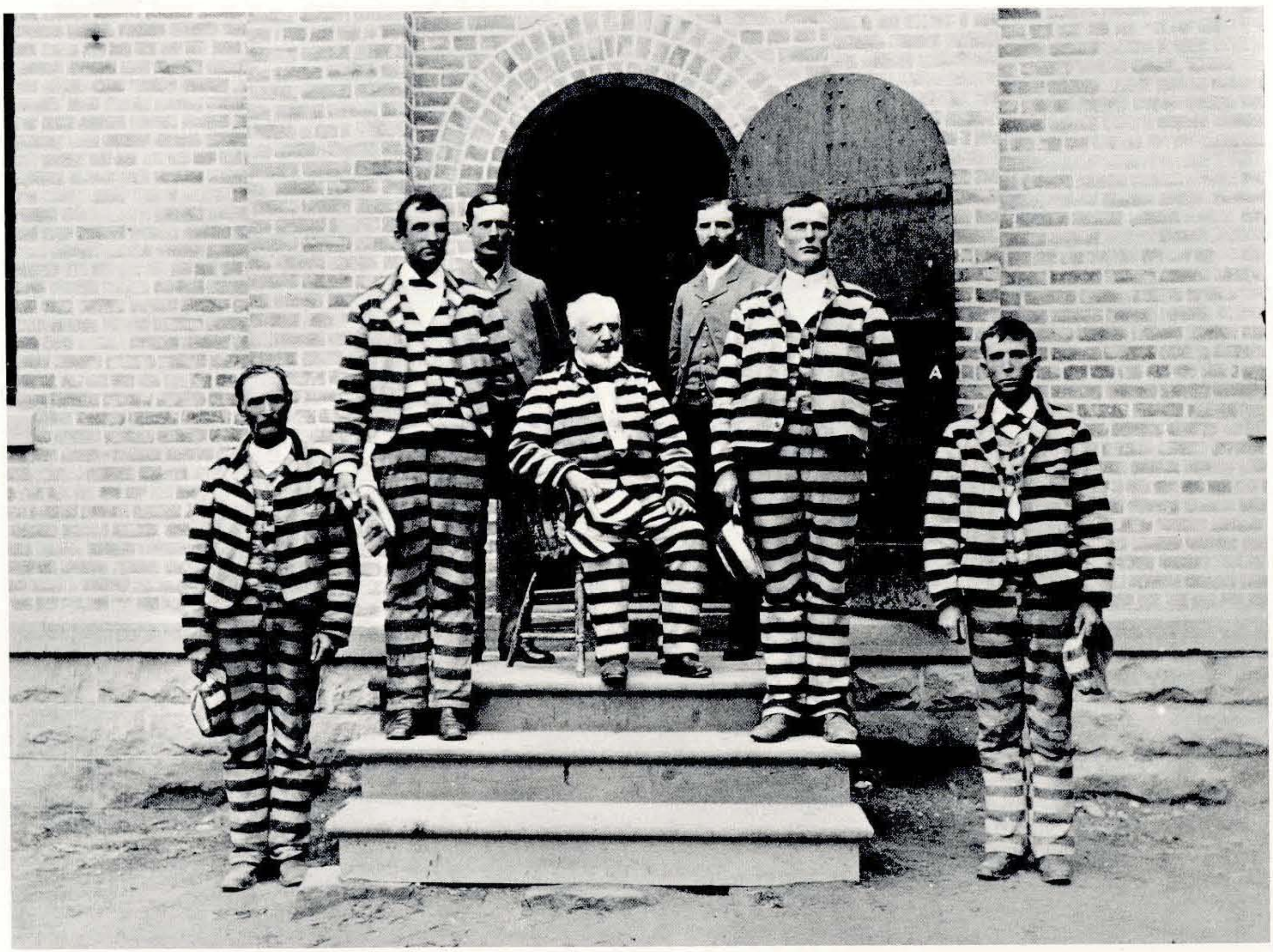
If you live in a prosperous suburb, especially out here in the West, you probably have Mormons for neighbors, for most Mormons today are middle-class business and professional people who have long since moved away from rural Utah to cities and suburbs throughout the West, and also to some big eastern centers like New York and Washington. Metropolitan Los Angeles has become one of the largest Mormon centers in the world. Pasadena has a large colony.

You will probably find that your Mormon neighbors are at least comfortably situated economically and that some of them are well-to-do. If you are invited into their homes, as I have been when I've been asked to talk with them about their history, you will almost certainly find that in a Mormon home there is an all-pervading sense of an old-fashioned, wholesome, comfortable family life. If the talk turns to politics, you will find your hosts are conservative politically: they don't believe in new social experiments; they are suspicious of Democrats. They are devoutly patriotic: Their sons go into the Boy Scouts when they are kids and serve their turn in the armed forces later. The dinner their wives will serve will be so substantial and so certain to end with homemade ice cream and cake that you'll find yourself drowsy just at the moment when you are expected to start talking. There will be no smoking, drinking, or hot beverages. There will be no profanity—that is, there will be no expletives to omit. You will be impressed by how well the other guests know one another, by the strong feeling of group solidarity. Clearly they share in common more experiences and attitudes than you will find among a number of non-Mormons.

Contrast this with the condition of those 16,000 Mormons 127 years ago, as they huddled about campfires in Nebraska and Iowa, waiting to be told by Brigham Young when to start for Utah. Their new religion had come into being 17 years earlier, in 1830, and had won for itself persecution and scorn from the non-Mormon or "Gentile" majority. Their founder and prophet, Joseph Smith, had been murdered in 1844 by a lynching mob of Illinois militiamen. The Mormons had been hounded out of three successive midwestern states in which they had tried to establish large group settlements.

Most of the Mormons of that day were poor and had had little formal education. Their American-born members were simple farmers or craftsmen, their English and European converts were former factory workers or artisans. They were already notorious for their social experiments and cooperative enterprises, which had revealed a remarkable ability to live together and work together. It was rumored that they had begun to experiment with that most sacred of American institutions, marriage, by trying polygamy—one man, more than one wife. By 1847 they had developed such a strong and distinctive group identity that they thought of themselves as almost a separate nationality. Indeed, ten years later, when the United States government had sent troops against them, they began to talk outright secession.

Beginning in the 1860's, Congress passed a series of laws to eliminate polygamy, and the result was the arrest and imprisonment of many Mormon leaders. These hierarchs of the church (with two of their guards) were in the Utah State Penitentiary in the 1870's.



How did these 16,000 forlorn separatist outcasts of 1847 become the 3,500,000 prosperous, patriotic, middle-class Mormons of today? Why did the 19th-century Mormons, who were among the most striking innovators this nation has ever produced, become the 20th-century Mormons, who are dedicated supporters of traditional values?

To give a clear answer, it will be necessary to take the question in two steps. The first is to explain how the Mormons managed to survive at all during the 19th century—what held them together when they were persecuted, isolated, and ultimately attacked by the full force of the United States government? Why didn't the Mormons disintegrate into futile little splinter groups, as most nonconformist Protestant sects tended to do when fortune turned against them?

There were, I think, three principal factors that molded the Mormons into a unity capable of surviving and, what is more, capable of growing. The first of these was the unity of sharing an unusual faith, a faith that automatically set its believers apart from the general population. Most Protestant splinter groups merely reinterpreted the accepted King James Bible and rearranged some existing patterns of church government, but Mormonism went far beyond that, for it asserted that there had been modern revelations from God to an actual, known 19th-century human being, Joseph Smith of upper New York State. To accept Mormonism one had to believe *literally* that an angel revealed to Joseph Smith the existence of a hitherto unknown sacred book written on gold tablets, the Book of Mormon, comparable to the Bible, and that thereafter God repeatedly communicated with Joseph Smith. Those who were capable of taking this immense step of literal belief inevitably set themselves apart from the skeptical or derisive majority and thus became what the Mormons themselves called a "peculiar people."

Becoming a "peculiar people" led to persecution and to the martyrdom of their prophet, Joseph Smith. This had a unifying effect; nothing so unites a group as the sense of standing together against a hostile world.

But their ability to hold together was facilitated by something that was as unique as the modern revelation upon which the Mormon faith was founded. I refer to the theocracy that Joseph Smith created. The dictionary defines theocracy as a "system of government by priests claiming a divine commission." In the Mormon Church there are no professional priests. Instead, every adult male of good character is a priest, and by hard work can rise to sucessively higher rank and responsibility in the church's very definite hierarchy.

The individual male earns his living in a regular secular job, even as you and I, and must manage to do his own work while meeting the church's very heavy demands upon his time. The only exceptions are at the very top of the Mormon hierarchy, where the sheer weight of responsibilities makes it necessary for the individual to give up his secular job in order to devote full time to the church's demands. Save at the very top, no one gets paid for doing the church's work; on the contrary, all Mormons are expected to support this elaborate organization by paying a genuine tithe—a real 10 percent of their income.

Women and Negroes may not become priests. The women are expected to work hard as a kind of ladies' auxiliary, and this they do, all the time, but they must achieve glorification and satisfaction in the church through their husbands' contributions to the church and through bearing children. Negroes are encouraged to join the church, but they must not expect to be allowed to enter even the lowest order of priesthood. Their dark color means that they bear a lifelong curse as the descendants of one of the sons of Adam and Eve, Cain, who in a fit of jealousy slew his brother Abel. Cain thus won a curse that has caused a black skin to be imposed on his descendants.

The Mormon Church is thus a huge organization that is staffed by unpaid nonprofessionals and is supported by remarkably generous giving by all loyal Mormons. The church is organized into successively higher levels of authority, beginning at the level of the local congregation, which is called a "ward" and is presided over by a layman called a "bishop," and rising up through a larger geographical entity called a "stake," until finally you come to the central authorities of the church, who have operated out of Salt Lake City ever since the Mormons have been in Utah. Twice a year there is a huge meeting in Salt Lake City to which the faithful are earnestly urged to come. It is at those semiannual meetings that the faithful are told what their leaders have decided.

You might ask how officials are chosen for these different levels. Joseph Smith declared that his church was to be not a theocracy but rather what he termed a "theodemocracy." In practice this has meant that the leaders of the church select some promising, up-and-coming Mormon for a post, and then ask the people of the particular group he will lead to ratify the choice by show of hands in meeting. The approval so given is known as the "sustaining vote." Usually it is forthcoming.

From Joseph Smith's time to the present this elaborate church structure has provided a definite place, a definite role for every active Mormon. The energies, the enthusiasms, and money of each member are enlisted. The church has dominated not only the religious life of its members but also their social life, frequently their political life, and at times their economic activities.

After the Mormons moved to Utah, the church created

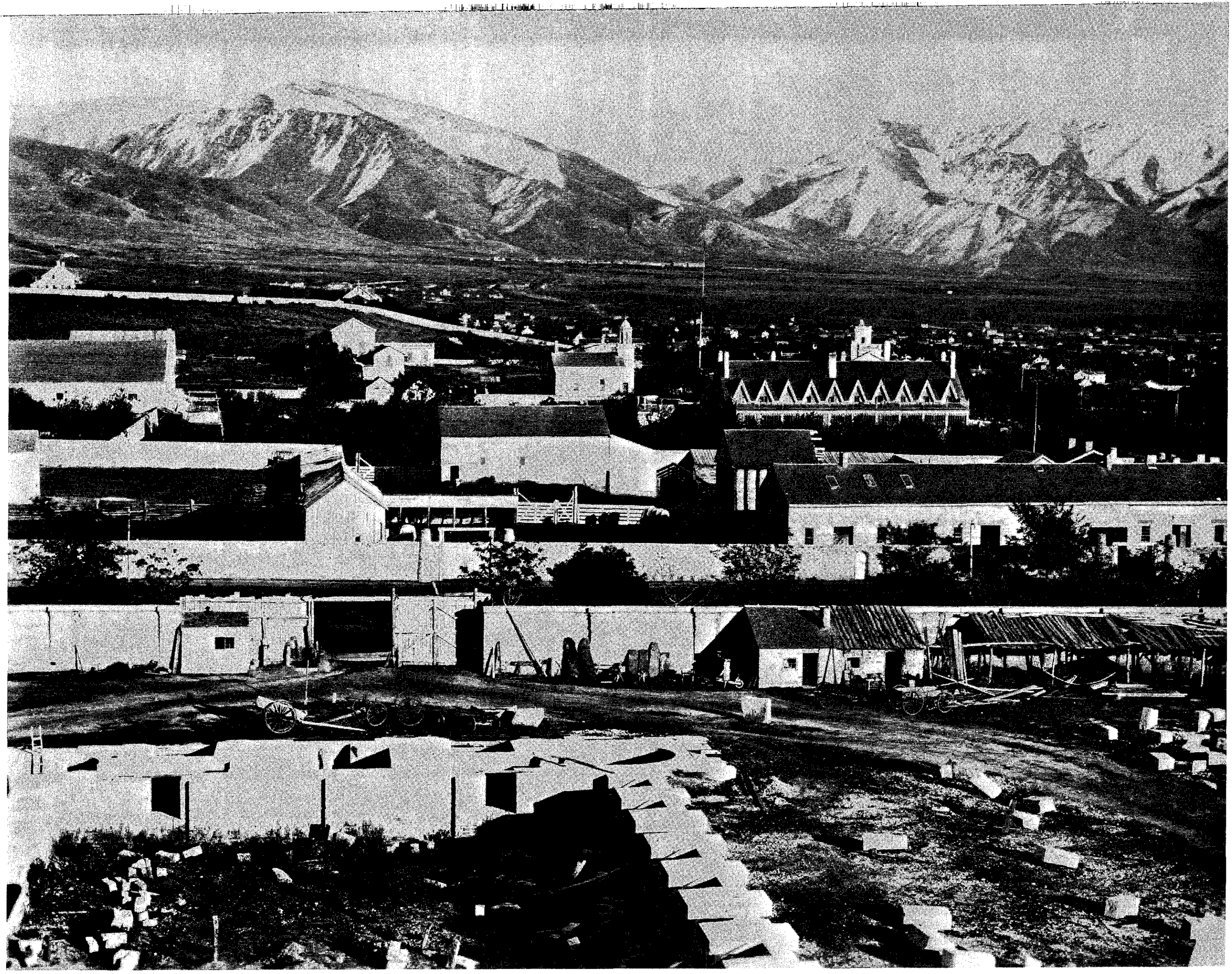
This 1852 lithograph shows Salt Lake City in about the year 1849, when it was obviously much more village than city.

and controlled the only government Utah had until 1851. When Congress established a territorial form of government in that year, Brigham Young became the first governor, and the church remained a de facto force in government at all levels, despite Congress. Nor did the church's influence in government cease after the national government in Washington displaced Brigham Young as territorial governor in 1857.

This theocracy could operate the more easily because from the very beginning of their denomination the Mormons had shown a remarkable spirit of communitarian cooperation. Those early Mormons were too poor, too limited in education and experience to undertake big projects as individuals. Instead, they learned to work together under the leadership of their church. By pooling their labor under church direction, and with only the simplest of equipment, they planned and built towns, irrigation canals, roads, factories. They founded cooperative stores and cooperative enterprises of all kinds.

Joseph Smith initiated these arrangements and developed a cadre of effective leaders who served as his immediate subordinates. For his administrative accomplishments he deserves more credit than he has usually received. At his death he was succeeded by one of the outstanding organizers of the 19th century, Brigham Young. If the circumstances of his life had worked out differently, Brigham Young might have become a captain of industry—an Andrew Carnegie or John D. Rockefeller or a railroad builder. Instead, this able, energetic, earthy man became the absolute ruler and the revered, genuinely loved father figure of all Mormons everywhere. He used the church hierarchy as the instrument through which he ruled, and from among the church leaders he selected the captains and lieutenants that he needed to carry out his purposes. But Young himself was a master of detail who kept in touch with everything. Whenever he traveled, which he did frequently, he always knew a great deal about not only each town he visited but also about many of the individuals who lived there. To a hard-working rural Mormon, it meant everything that the ruler of the church knew that Sister Eliza had had an unusually hard time after the birth of her sixth child, or that Brother Isaiah had been the principal carpenter in rebuilding the local church after it had suffered storm damage.

Young could be ruthless and earthy, as he frequently was, but he had many qualities more notable than his most publicized achievement, which was the admittedly impressive catalog of his wives. His most recent and most dubious biographer alleges that he had "at least 70 wives" and 65 children. More reliable statisticians credit Young with only 56 children by 16 wives. Even this somewhat reduced total seems to me an impressive achievement.



By the 1850's the Mormons had begun construction of their Temple in Salt Lake City. Its foundations appear in the foreground of this photograph taken from the top of the Tabernacle. The Temple was finally completed in 1893. At the right center, the building with many gables is Brigham Young's famous Beehive House, in which he lived for a time with a number of wives and children.

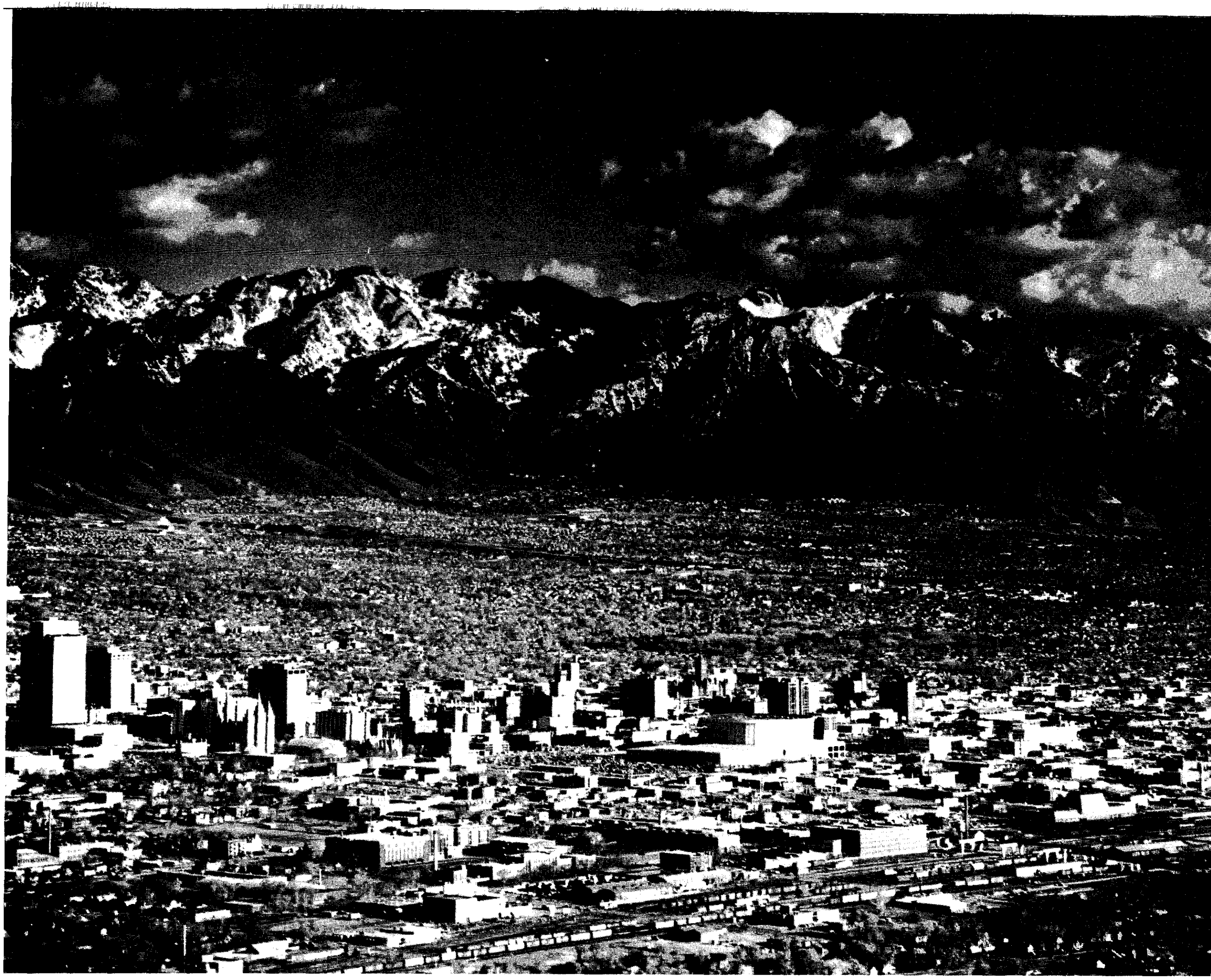
Young's ability to keep so many wives from quarreling and so many children from overwhelming him would in itself prove that Young must have been a remarkable, not to say a master, diplomat.

Brigham Young ruled the Mormon community from shortly after Joseph Smith's death in 1844 until his own death in 1877. During the 30 years between the Mormons' arrival in Utah in 1847 and 1877, Young directed the founding of 350 towns in the Southwest. Thereby the Mormons became the most important single agency in colonizing that vast arid West between the Rockies and the Sierra Nevada. A modern historian has remarked that the two most important forces in settling the intermontane West were the Union Pacific Railroad and the Mormon Church—in other words, two large, well-organized, and centrally directed institutions. In such a harsh geographic setting, the job could not possibly have been done by exclusive reliance upon the efforts of unorganized individuals.

Most of the towns that Young caused to be founded were in arid regions that required irrigation systems and a careful use of the limited supply of water, timber, and good land. For the United States as a whole this was the age of unrestrained laissez faire, which means that the primary standard of judgment was personal profit and the devil take the community's needs.

Yet under Young's leadership, and in accordance with the Mormons' well-established pattern of communitarian living, social values were placed ahead of individual desires. Towns were planned according to the old New England pattern, where the residences and their attendant kitchen gardens were clustered in the middle of the town, so that the people could have nearby neighbors, schools, and churches, while the irrigable crop lands were out in the more open country beyond the settlement, and the pasture lands were still further away. Water, which is crucial in an arid region, was declared by Brigham Young to be the property of *all* the people rather than private property, and was to be distributed through an irrigation system built under church leadership and by the labor of the people who would be using it. Use of the water was tied to the land that needed it and was regulated by the local people, so that water monopoly was impossible.

When disputes arose, the local "bishop" of the church ward usually intervened to settle the controversy quietly, without recourse to expensive and time-consuming law-



Salt Lake City today is filled with the structures that house approximately 176,000 people and their activities. The building at the extreme left contains the offices of the Church of Jesus Christ of Latter Day Saints, which is the official name of the Mormon organization. The tallest building in Utah, it towers over the nearby Temple, which in turn overshadows the round-roofed Tabernacle.

suits. These direct, logical arrangements deprived the lawyers of the water litigation that was a principal source of income to the legal profession in most western states.

In declaring water to be the property of the whole community, and in working out this simple pattern for use, Young and the Mormons were calmly, if perhaps unconsciously, discarding several centuries of Anglo-American precedents developed under the common law, but developed for use in a humid climate. Elsewhere in the West a great deal of expensive litigation could have been avoided if lawyers and legislators had been more willing to throw away Blackstone's *Commentaries* in favor of copying the example set by these unsophisticated Mormons.

In Brigham Young's eyes, building towns and irrigation systems was not enough. The Mormons had always wanted to make themselves economically self-sufficient, so that they would not be at the mercy of the non-Mormon majority of the nation when they needed supplies. Once they were relatively isolated in Utah and had survived the difficult first years, they began a remarkable if unsuccessful drive to create all kinds of industries and services that the church could control. Factories, mills, an iron foundry, express and teamster services, local railroads, cooperative stores, woolen mills, cotton growing, and a sugar beet industry were examples of ventures that Young persuaded the faithful to finance through drafts upon the local congregations to supply money, labor, draft animals, and the simple supplies and raw materials that the Mormon community was capable of producing. At best these subsidized ventures were high-cost enterprises producing for a limited market, and after the transcontinental railroad was complete in 1869, cheaper, more sophisticated goods from the Middle West and East wiped out most of them. The losses sustained were absorbed by Young's loyal followers.

By now I think you can begin to see how and why the Mormons were able to hold together and indeed to grow steadily in numbers and resources through the difficult years of the 1850's, 1860's, and 1870's. They were united by accepting an unusual faith; they were led by a remarkable man who headed a theocracy that penetrated every aspect of daily life; and they were addicted to cooperative, communitarian ways of meeting all challenges. But in addition to these forces from within, they were strengthened in their loyalty to their church by the

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The Chemistry Is Right

Arnold O. Beckman and Caltech have been working together for more than 50 years. Some highlights from those years – and from Beckman's other careers

Arnold Beckman has worn just about all the hats there are at Caltech—student, alumnus, faculty, trustee, and donor. Now, having served as chairman of the board of trustees since 1964, he has been named a life trustee and chairman emeritus. And don't bet he's going to stop there either.

There wasn't any Caltech when Arnold O. (for Orville) Beckman was born on April 10, 1900, in the small town of Cullom, Illinois, where his father was the blacksmith. By the time he was nine years old, there were already indications that Arnold might become a chemist. Rummaging in the family attic, he came upon a copy of *Steele's Fourteen Weeks in Chemistry* that had belonged to his aunt, and got so interested in performing the experiments in the book that, for his tenth birthday, his father built him an eight-by-ten-foot shed that served as a laboratory, and his older brother supplied him with chemicals from Chicago.

When Arnold got to high school, he was ready to take the senior-year chemistry course as a sophomore, and in his junior and senior years he took regular university courses in the subject.

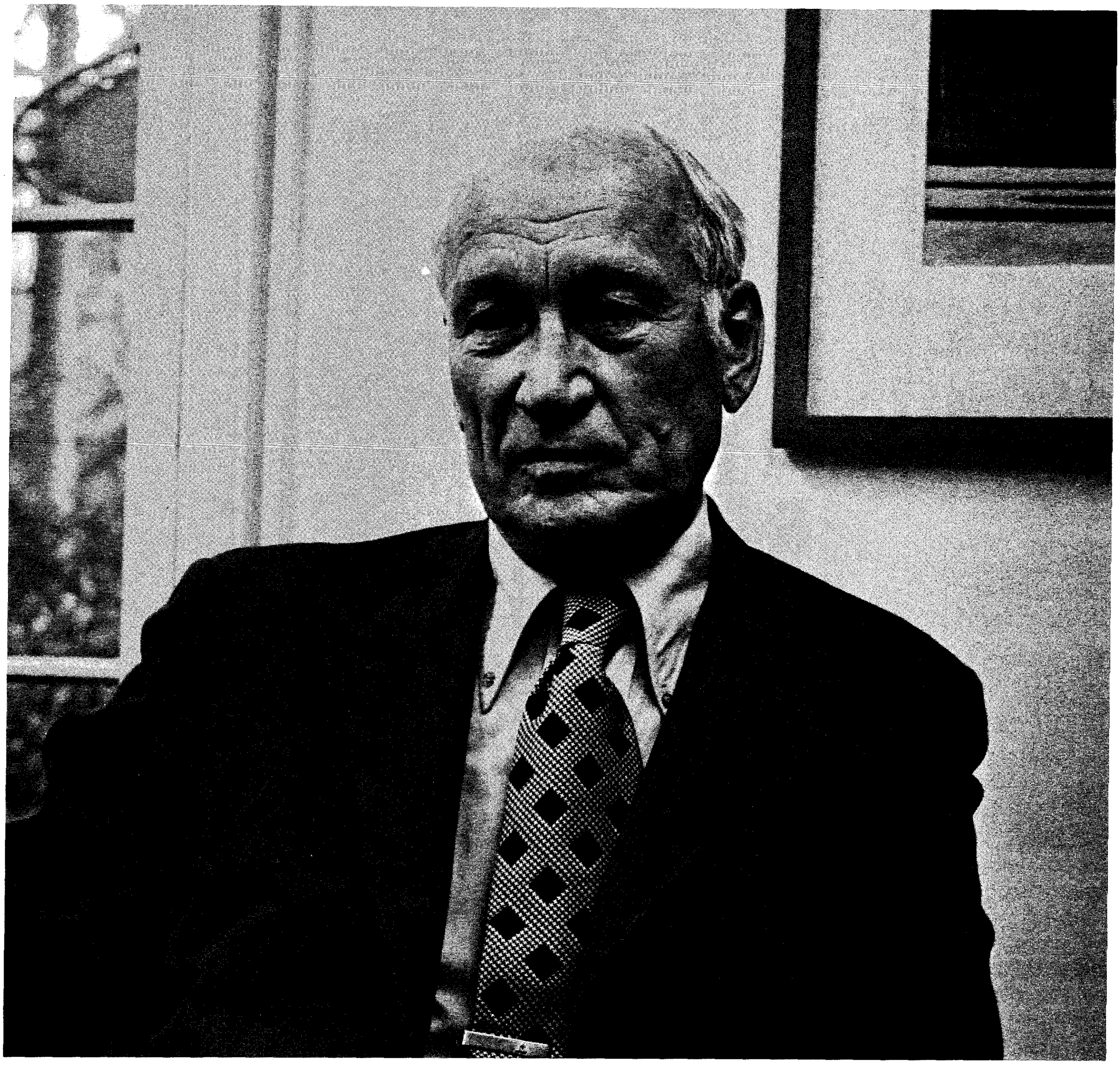
Not that chemistry was his only interest. All through high school, for one thing, Arnold had a steady job playing piano at the local movie house—which meant six evenings a week plus matinees on Saturdays. In his spare time he played with a dance band.

Arnold was top man in his high school class, and in 1918 he was allowed to leave school three months before graduation to take a war job as a chemist at the Keystone Steel and Wire Company in Pekin, Illinois. After a few months there he enlisted in the Marines, went through boot camp at Parris Island, and then was sent to the Brooklyn Navy Yard.

"I've always been lucky," Beckman says. "There I was—about to be shipped out. But the quota was filled just before they got to my name. I think the squad got sent to some place like Vladivostok. I stayed in Brooklyn.

"I was still in Brooklyn on Thanksgiving Day. We had just put away a great big turkey dinner when an invitation came in for a group of us to have dinner at the Greenpoint YMCA. So we were ordered to get out there and eat a second meal. Well, it was another stroke of luck that one of the volunteers who waited on our table was a girl named Mabel Meinzer. She's been my wife for almost 50 years now.

"The war ended before I was ever shipped out. I was lucky there too because, when we heard the war was over, there was an announcement that anyone who wanted to go back to school as a civilian should sign up on a particular list. So I signed up. That was in the morning. After lunch they announced that they wouldn't take any more names on that list, but the men who had signed in the morning would be mustered out—and everybody else would stay at the Navy Yard, or be sent somewhere for guard duty for another year or more."



It was too late in the year to enter college, so Beckman decided to work his way out to the West Coast. He was heading for Yellowstone Park when he stopped off in the town of Ashton, Idaho, and his trip came to a halt.

The manager of the Ashton movie house needed a new piano player, so Beckman agreed to do a trial show for him. Before he had even worked his way through the *Poet and Peasant* Overture, Arnold not only had a steady job, but room and board at the manager's house. He settled down to an idyllic existence in Ashton, working at the movie house every night (playing through the entire summer, incidentally, without a single sheet of music), and spending every weekend camping and fishing for trout with the projectionist and his brother.

Beckman entered the University of Illinois in the fall of 1919. There he got to know Richard Tolman, who came to Caltech in 1921, and helped to shape the Institute of today. When the time came for him to go to graduate school, Beckman decided to come to Caltech too. In a Model T, he and a classmate spent six weeks crossing the country, and he entered Caltech as a graduate student in chemistry in 1923.

A year later, Beckman was almost out of money, so he took a boat back through the Panama Canal to New York and got a job in the Western Electric engineering division (which later became the Bell Telephone Laboratories). Of course, Mabel Meinzer was another reason for his going to New York. They were married in June 1925.

In 1926 the Beckmans, in another Model T, moved to Pasadena so Arnold could finish his graduate work at Caltech.

Graduate students got simple quarters in those days—"a couple of 60-watt bulbs and a counter," as Beckman remembers it. Still, there was occasional excitement in his lab in the basement of Gates—like the day Arnold had to stop working because test tubes kept crashing outside his window. Climbing the stairs to investigate, Beckman discovered an undergraduate student tossing loaded test tubes, at regular intervals, out the window of the frosh lab. The student had a simple explanation for his behavior. He was trying to make nitroglycerin. But he was hard of hearing. So he was dropping his trial results out the window, figuring that when he really got nitroglycerin, he would really hear it. Fortunately, says Beckman, the man wasn't much of a chemist.

As a graduate student, Beckman was a regular visitor to the Corona del Mar beach house of A. A. Noyes, chairman of Caltech's chemistry division. Noyes often invited graduate students there—usually to help him with revisions of his chemistry textbooks. The journey from Pasadena was made in Noyes's Cadillac touring car, known as Brown Betty. On one trip, Beckman made himself indispensable when Brown Betty refused to climb a hill outside Santa Ana. Noyes, who was helpless in the face of mechanical failure, watched Beckman wield the only tools available—a five-pound hammer and an extra-long screwdriver—to adjust the distributor points and save the day. Beckman thus became one of the few students who was allowed to drive Brown Betty, and, on occasion, he still entertains the deflating thought that perhaps that was how he managed to get his doctor's degree at Caltech.

He got that degree in 1928, and stayed on at Caltech as an instructor in chemistry. He was an assistant professor in 1934 when Robert A. Millikan encouraged him to take a consulting job with the National Postage Meter Company, which was having ink problems. Beckman was able to solve them so successfully that they set up a National Inking Appliance Company to make devices for inking metered mail.

In the spring of 1935 an old classmate from the University of Illinois, Glen Joseph, came to Beckman for advice. Joseph was working on some by-products of lemon juice for the Sunkist Fruit Growers, and was trying to measure the acidity of these materials, using a galvanometer and a glass electrode. Both were so delicate and fragile they kept breaking.

Beckman's solution to the problem was to get rid of the galvanometer in the measuring instrument Joseph was using and substitute an electronic amplifier. He sketched a circuit, and a radio ham put it together. The resulting instrument was a dud. So Beckman worked out the circuit himself and delivered the instrument to Joseph. It performed so well that, in three months, Joseph was back for another one.

This enthusiastic reaction encouraged Beckman to go into the business of manufacturing the instrument. It was not exactly a major operation. The firm bore the impressive name of National Technical Laboratories, but the staff consisted of two graduate students, working part-time. The plant was a nine-foot roped-off area in the garage behind the shop of Fred Henson, who had been the chemistry department's talented instrument maker. In time, the company moved into more prepossessing quarters—an empty store at 3330 E. Colorado Boulevard, recently vacated by a dry-cleaner, and owned by Ernest Swift, Caltech professor of chemistry.

In September 1935 Beckman took one of his instruments to an American Chemical Society meeting in San Francisco, to ask some of his former chemistry professors whether they thought there was a market for such a thing.

National Technical Laboratories had produced a total of six pH meters by that time, and Beckman was not at all sure how many more people would be willing to pay $195 for an instrument that would do the same job as a five-cent piece of litmus paper.

Graduate students
got simple quarters in those days
– a couple of 60-watt bulbs and a counter

The experts gave Beckman their most optimistic estimates – that he might sell 600 pH meters in 10 years

The experts gave Beckman their most optimistic estimates —that he might be able to sell about 600 pH meters in about ten years. The year was 1935, so that sounded like good news to Arnold. He and Mabel set out by train to call on chemical supply houses all over the country.

It soon became clear that the pH meter filled a wide commercial need. The 600 instruments were sold in a couple of years (and, to date, the Beckman organization has produced more than a quarter of a million pH meters). Beckman left Caltech in 1940 to devote all his effort to the development of scientific instruments.

To put it plainly, he has been spectacularly successful. In 1940 he produced his second instrument, the spectrophotometer, which makes a chemical analysis of a sample by light absorption, determining what substances are present and in what amounts.

The Beckman spectrophotometer was so much faster and more accurate than other instruments and methods that it became the workhorse of the chemical laboratory. For example, World War II had cut off the supply of fish liver oil from Scandinavia, which was used in making vitamin A and vitamin D. At that time the biological assay for vitamin content involved feeding the material to be analyzed to starved rats for a period of about three weeks, then chopping off the rats' tails and measuring the amount of bone growth that had taken place. The spectrophotometer was able to make the assay in a couple of minutes.

The ultraviolet spectrophotometer was followed by an infrared spectrophotometer, which proved invaluable during the war for the chemical analysis in the production of synthetic rubber and aviation gasoline.

Over the years the Beckman organization has produced new precision instruments until today the company makes a total of about 4,000 of them. A $200,000,000 business, Beckman Instruments derives about 40 percent of its sales from medical research and clinical medicine, 38 percent from industry, 16 percent from scientific research, and 6 percent from defense.

But scientific instruments are no more Beckman's whole life today than chemistry was in his high school years. A founder of the Instrument Society of America, in 1971 Beckman was named California Industrialist of the Year by the California Museum of Science and Industry for his "profound and lasting contributions to industry, education, and public service."

He is a member of the National Academy of Engineering, the American Chemical Society, and the Newcomen Society. He is an honorary member of the American Institute of Chemists, a fellow of the American Association for the Advancement of Science, and a Benjamin Franklin fellow of Great Britain's Royal Society of Arts. He is past president (1956) of the Los Angeles Chamber of Commerce, a former director of the National Association of Manufacturers and of the Security Pacific National Bank, the Southern California Symphony Association, and Mills College. He has played a leading role in the campaign against air pollution and has served on a number of state and national organizations in this effort.

The first alumnus to be elected to Caltech's board of trustees, Beckman has been a member of that board for 21 years. As chairman (1964-74), he was also chairman of the executive committee and ex officio member of five other elected committees, which of course involved endless meetings—all of which he attended regularly.

The Caltech campus today is graced by two Beckman buildings—the Auditorium, which has not only given the Institute great architectural distinction and provided a gathering place for the campus, but has proved to be a binding force for Caltech and the surrounding community; and the new Mabel and Arnold Beckman Laboratories of Behaviorial Biology. Characteristically, Beckman thinks the buildings are "the best investment I ever made."

The Beckmans live in Corona del Mar, where Arnold finds time occasionally to sail his 41-foot sloop. They have two grown children—Arnold S. and Patty.

If it begins to appear that Arnold Beckman has all too many accomplishments, it might be noted that he has at least one talent that is just plain going to waste: He can still play a complete silent-movie score on the piano without a scrap of sheet music—from *Poet and Peasant*, through *Hearts and Flowers*, right on down to the Triumphal March from *Aida*. □

The Relevance of Science

SIR GEORGE PORTER

The ultimate relevance of science is to try to discover man's purpose by every means in our power

When Michael Faraday was asked the question, so tiresome to a scientist, "What is the relevance of your work?" he could give his well-known reply, "Madam, what use is a newborn baby?" Or, when asked the question by the Prime Minister, Robert Peel, about his magnetic induction, he could reply, "I know not, Sir, but I'll wager one day you'll tax it." And in the golden age of Victorian progress, the point was taken and later proved to be correct.

It is not so easy to satisfy the questioner today. The baby is grown up into a man of great achievement and power. It has almost won its battle against disease and the miseries of hard labour; Michael Faraday and James Watt released more men from slavery than did Abraham Lincoln. "Yes," says the man of relevance to the man of science, "I accept this, and I really am grateful. But now I've had enough. I need time to adjust to what I've got already. So will you please find a cure for cancer and then stop."

In some ways the man has a point. I should like to mention one of his anxieties because I share it and because it is urgent. It is nuclear power—not weapons, which are another problem, but reactors. When that first baby reactor was born in Chicago in 1942, scientists saw it growing into a benefactor of mankind. It was also good for science, and billions of dollars have flowed into research of all kinds because of this hope. Today, I don't think I am using emotional terms when I say the baby has grown into a monster. The world is as near to anarchy as it has ever been, and yet we are about to put nuclear reactors all over the earth—in Northern Ireland and Southern Ireland, in India and Pakistan, in Israel and Egypt, in Turkey and Cyprus, in Vietnam and in Chile. We haven't the remotest idea how to destroy the radioactive wastes, but soon everybody will know how to use them for war, sabotage, or blackmail. If we are making a mistake, then it is—unlike other mistakes we must make from time to time—irrevocable and irreversible because the radioactive products will be with our children and theirs for more generations than have passed since the beginning of civilization. What chance is there of man surviving in a plutonium economy, even as long as one half-life of plutonium, 24,000 years? Yet the momentum, the investment in nuclear power, is now so great that it seems already too late to stop the proliferation.

What do we say now to our man of relevance? I would say the following: Man, being what he is, will demand his megawatts today even if he dies tomorrow. We have made a terrible mistake in offering nuclear power as a solution too soon. We admit it. Now our only way out is to find an alternative which is cheaper; nothing else will be accepted. What is more, we believe we can do this—by using solar energy, for example. But this means more research, more science, more knowledge, not less.

So our man of relevance will probably agree to add energy, and a few other things, to cancer in his list of things still to be done. But he will maintain that we are bound, soon, to reach a limit where we have everything we want. "Then," he will say, "you scientists will just be doing it for your own amusement. I have no objection to this as long as it's safe, and I understand that it's fun and compulsive, like playing chess, but why should I pay for your game?"

I believe that there is a very good reason, though I don't expect it to appeal to every man. So far, we have answered the man of relevance entirely in material terms. This has less and less appeal as material needs are satisfied and spiritual needs assume greater importance. Science has increased our health and wealth; now what about our happiness?

To answer this question we have to ask deeper ones which are at the basis of our philosophy, our religion, and our ethics. What is it that we want of ourselves, of man, of our earth, of the universe? In the past, these questions have been answered by the theologians, and the answer—being rather pleasant—was readily accepted. But man's reason does not permit him to think happy thoughts which are irrational, and many have had to discard the old religions on these grounds. Our great dilemma is that science has not yet helped man to find a new religion which in any way replaces the old ones. There are philosophies of life, such as humanism, which provide a modus vivendi but do little to solve the basic questions answered so confidently by the old religions.

Most of our anxieties, problems, and unhappiness today stem from a lack of purpose which was rare a century ago and which can fairly be blamed on the consequences of scientific enquiry. It is well known how the leaders of the established religions resisted the Age of Reason, sometimes literally to the death. By the middle of the 19th century, when it became clear that the establishment had lost the argument, a truce was called. The matter was resolved by the proposition that religion and science were quite separate activities, so there could be no conflict. Religion was concerned with the spirit of man whilst science dealt with the material and physical world.

This compromise and division of territory never rang true and probably deceived nobody. Things had already gone too far, and it was already clear not only that religions had always interpreted the physical world, as Judeo-Christianity does from the first verse of Genesis, but also that the greater understanding provided by science had a profound effect on man's philosophy, ethics, and spiritual beliefs.

The discoveries of Copernicus, Darwin, and the molecular biologists have irrevocably changed our beliefs about our place in the world, but the new understanding has been negative in the sense of destroying old conceptions and religious views and much that goes with them without providing a new positive philosophy and purpose.

If, then, we have changed our traditional faiths through increased knowledge of ourselves and our universe, is it not possible that our way to a new faith, a new purpose for life, is through further knowledge and understanding of nature?

This is the true relevance of science.

It is, of course, quite possible that we can never understand, never discover a purpose, but we shall not succeed if we do not try. Time and time again in science some artificial barrier has been proposed beyond which science could not pass, and many of those barriers are now behind us. There is absolutely no evidence that the great reasoning power with which mankind is endowed has *any* limitations, and until evidence to the contrary is discovered, we shall be wise not to give up the search. We have nothing to lose and everything to gain.

Once this "ethic of knowledge," as Monod calls it, is accepted, life becomes more meaningful again. The fatalistic mood is tempered with hope. Survival of the species once again becomes important because our search is likely to span many generations, and if we destroy ourselves by some self-inflicted catastrophe, man will never know what his destiny might have been.

It might be argued that it is impossible for us to imagine any conceivable purpose in the universe and therefore what we pursue is a mirage. But not many years ago, it was impossible to imagine any solution to the chicken and egg problem of the origin of life; yet a simple solution, understandable to all, has been found. When the earth was thought to be flat, it was impossible to imagine any solution to the problem: Where does the earth end? But a spherical earth is now so obvious that we hardly need to employ our imagination at all. Could it be that man's purpose will one day be as obvious as the spherical earth?

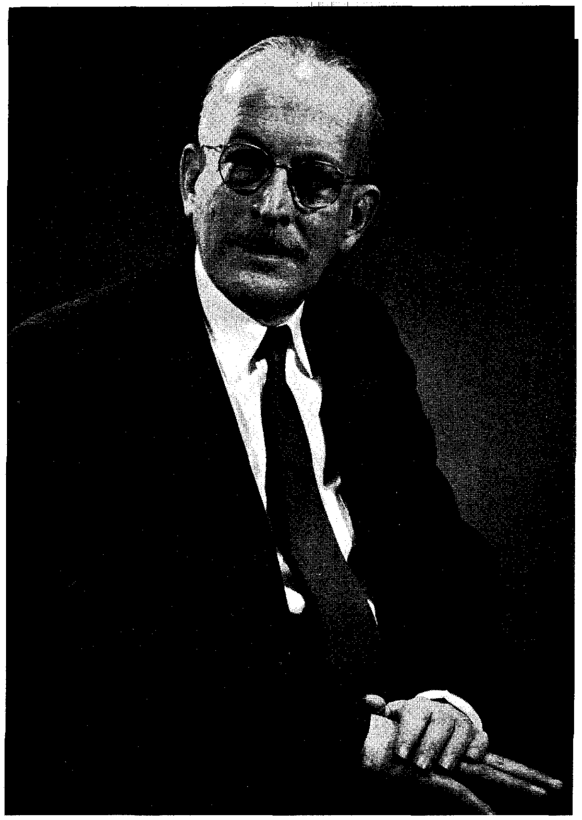
What areas of science are likely to be most fruitful in this quest? Until the glimmer of an idea appears, a hypothesis to be pursued, it is imposible to know; and it is probably wise to pursue most actively those areas where progress seems to be possible at the time. So-called relevant research does not always lead to relevant discovery, and—if the proper study of mankind is man—it may be equally true that the proper study of man at this time is through physics, chemistry, and biology.

If the problem seems insuperable, we should continue to remind ourselves that modern science started only about 400 years ago and has already transformed our lives and our understanding. What may we not achieve in the four billion years which remain before the earth becomes uninhabitable?

What is it that we want man to achieve? Is it merely the greatest happiness of the greatest number? How many men should there be on earth anyway, and how many birds? How important is an individual compared with the survival and progress of the species? Until we have a better understanding, all our ambitions for a better world are at best short term and, at worst, may be quite wrongly conceived. Our ethics and morals must ultimately be derived from this better understanding.

There is, then, one great purpose for man and for us today, and that is to try to *discover* man's purpose by every means in our power. That is the ultimate relevance of science, and not only of science but of every branch of learning which can improve our understanding.

In the words of Tolstoy, "The highest wisdom has but one science, the science of the whole, the science explaining the Creation and man's place in it." □



Richard M. Badger
1896-1974

Richard M. Badger, professor of chemistry emeritus, died on November 26 at the age of 78. He had been a member of the Caltech community— as a student, teacher, and researcher— for more than 50 years.

Badger was a native of Elgin, Illinois, but his family moved to Brisbane, Australia, when he was a child. He returned to Elgin for part of his secondary education and continued through the Junior College of the Elgin Academy. He then enrolled at Northwestern University, but his college career was interrupted by World War I, in which he served in France in the Army's 311th Field Signal Battalion. After the war he came to Caltech, where he received his BS in 1921 and his PhD in 1924. He was a research fellow at the Institute from 1924 to 1928 and then spent a year in Germany doing postgraduate study as an International Fellow in chemistry at the Universities of Göttingen and Bonn. He returned to Pasadena as assistant professor of chemistry in 1929, was appointed associate professor in 1938, and became full professor in 1945. He became professor emeritus in 1966.

Though he worked in several fields of physical chemistry, Badger's predominant scientific interest was the application of spectroscopy to the solution of chemical problems, including the structures of polyatomic molecules, the problem of hydrogen bonding, and the relation of potential constants to internuclear distances. Through the systematization of experimental data, he formulated Badger's rule, which expresses the relationship between the forces acting between two atoms and the distance separating them. The rule has been useful in chemical thermodynamics as well as in determining the structure of molecules.

During World War II Badger remained at Caltech working on fundamental physical problems for the Manhattan District and investigating the properties of smokeless powder for the Navy Bureau of Ordnance. He also was engaged on projects for the Office of Scientific Research and Development and the Army Air Corps. Important advances in technology and instrumentation during these years facilitated his distinguished work in infrared spectroscopy.

In 1952 Badger was elected to the National Academy of Sciences in recognition of his important spectroscopic studies of complex molecules. He was also a member of the American Physical Society and the American Academy of Arts and Sciences.

For almost 40 years Badger taught undergraduates at Caltech, and in 1961 his dedication was recognized by the Manufacturing Chemists' Association award for college chemistry teaching. This award, consisting of a medal, citation, and honorarium, is presented to teachers of undergraduates who have been "personally responsible over a period of years for awakening in students a genuine interest in chemistry, for inspiring them to serious intellectual effort in studying that field, and for developing that interest into a continuing dedication."

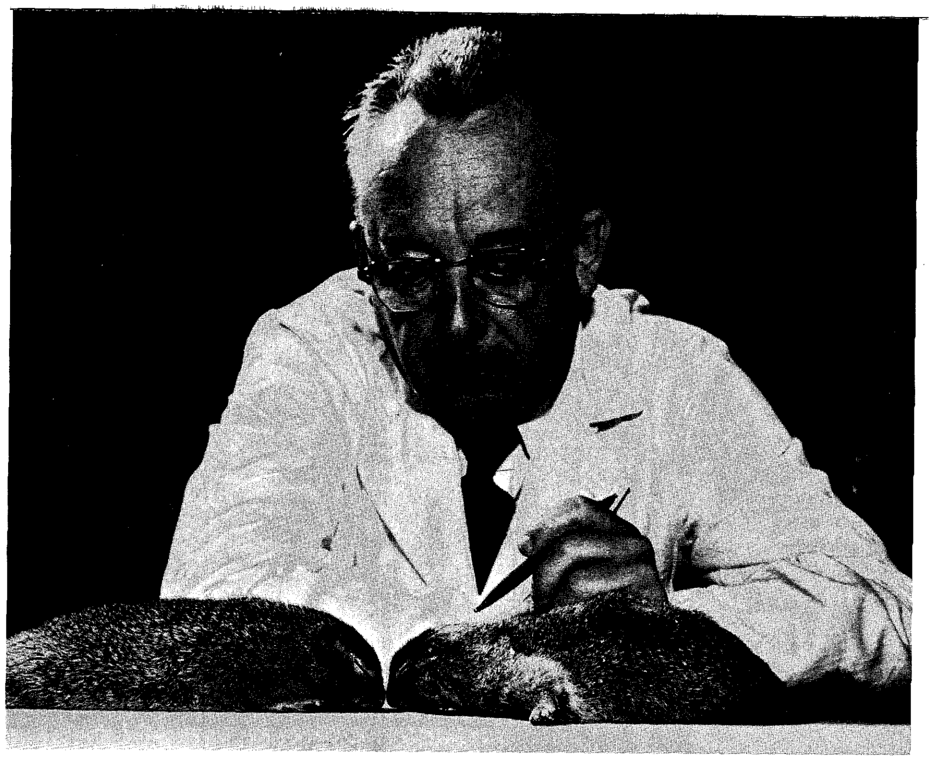
Badger was the author or co-author of more than 85 research articles, and he was also a conscientious citizen of the Caltech community. From 1961 to 1963 he was chairman of the faculty, and he served on the faculty Committee on Academic Policies and on the chemistry division's graduate committee.

Badger's hobbies employed his talent for precision; he did instrument making and fine metal- and wood-working. He also made jewelry and painted in watercolor, particularly desert scenes, which reflected an appreciation of the beauties of the California desert that he acquired in the course of many camping trips.

These expeditions appealed to the adventurous side of Badger's nature as well as the artistic, and he was always eager to explore beyond the beaten track.

Services for Dr. Badger were private. He is survived by his wife, Virginia; a son, Anthony S. Badger; a daughter, Jennifer B. Sultan; and three granddaughters. □

Dan H. Campbell
1907-1974



Dan H. Campbell, 67, professor of immunochemistry, died in Pasadena on September 16. He had been a Caltech faculty member for 32 years.

Dr. Campbell was a pioneer in the field of immunochemistry, which is the study of antigen-antibody reactions. These reactions occur when the body produces specific proteins (antibodies) in response to invasion by foreign substances (antigens). The antibodies may combat the harmful effects of the antigens, but the reactions may also produce diseases and side effects ranging from sneezes to fatal shock.

Campbell and his research group were leaders in the development of techniques for isolating and standardizing allergens and for growing in the laboratory antibodies that attack them. He was particularly interested in the mechanism of hibernation, and made extensive studies of the physiology and blood chemistry of arctic animals in both the active and the hibernating states. During World War II he developed a widely used substitute for blood plasma and was a consultant to the Manhattan Project.

A native of Fremont, Ohio, Campbell did his undergraduate work at Wabash College in Indiana, receiving an AB in 1930. In 1960 his alma mater awarded him an honorary ScD degree, and the citation noted among his distinctions that he had never fulfilled the English requirement for graduation. In fact, though his academic record was otherwise outstanding, he failed his English courses for four years in a row.

Campbell's difficulty stemmed from his inability to spell, a handicap that he dealt with by writing words phonetically (cliché, for example, was "cleesha" to him) and leaving to a succession of devoted and competent associates the job of putting things right. For 44 years the chief decoder of his written communications was the girl he met in junior high school and married in 1930—Margaret Dorr.

For graduate work Campbell initially went to Washington University in St. Louis, receiving an MS in 1932. The University of Chicago awarded him a PhD in 1935, and he was a faculty member there until 1942, first as instructor in bacteriology and immunology and then as assistant professor of immunology. At the invitation of Linus Pauling, he accepted a position in 1942 as assistant professor of immunochemistry at Caltech. He became associate professor in 1945 and full professor in 1950.

Originally, immunochemistry at Caltech consisted mostly of Campbell himself, but his research group grew rapidly both in numbers and in output. By 1955 it was large enough to take over most of the third floor of the newly constructed Church Laboratory of Chemical Biology. For some years approximately 20 postdoctoral fellows, graduate students, and staff members worked with Campbell, and together they issued a stream of research papers. Campbell himself was the author or co-author of almost 200 of them, and of several books. He was also on the editorial boards of four journals on immunology.

Campbell received many awards, citations, and honorary fellowships for his work, was chairman of several national and international conferences on immunochemistry, and was a member of numerous professional societies. He was president of the American Association of Immunologists in 1972-73.

In 1968, 75 of his colleagues and former students feted him at the 52nd annual meeting of the Federation of American Societies for Experimental Biology—presenting him with a four-inch-thick bound volume of personal greetings and published scientific papers. The prefatory letter read in part: "This volume is a collection of papers . . . that spans over a quarter century of time. It is a record not only of your own consummate skill and farsightedness in science but also your faith in those whom you taught, for they, in their own way, have hammered on the anvil of intellectual toughness."

Until the last few years, when ill health forced him to limit his activities, Campbell was an ardent and skilled hunter and fisherman. The walls of his office were hung with photographs of his prize trophies. Gardening was also a hobby, and he took great pride in the fruit from his home orchard.

Memorial services for Dr. Campbell were held in Pasadena on September 18, and a forthcoming issue of *Immunochemistry, An International Journal of Molecular Immunology* will be filled with papers in his honor by former students, friends, and colleagues. In addition to his wife, he is survived by his son, John, two grandchildren, and a sister. □

periodic attacks made upon them by the United States government, which in turn was responding to the pressures in American public opinion as interpreted by influential office holders, reformers, and editors in many parts of the country. In 1857-58 President James Buchanan sent the United States Army into Utah under the command of the future Confederate general, Albert Sidney Johnson. In the 1860's and 1870's Congress passed laws to eliminate polygamy and to take trial of cases of alleged plural marriage out of the hands of Mormon judges and juries, which invariably failed to convict. With the Edmunds Act of 1882 and the Edmunds-Tucker Act of 1887, Congress began a far-reaching attack on the Morman Church and polygamy. Arrest and imprisonment of polygamous Mormon leaders, confiscation of church property, federal control of voting, and invasion by a swarm of United States marshals gradually reduced the Mormons' physical ability to resist the imposition upon them of standards of behavior that would be in harmony with the practices of the majority of the United States. When in 1890 the United States Supreme Court upheld the drastic statutes under which these actions were taken, the Mormons were beaten, although their loyalty to their faith was probably strengthened rather than diminished by these assaults.

Intense pressure upon the leaders of the church finally caused the then president of the church to announce in 1890 that there would be no more polygamous marriages. With polygamy out of the way, Congress permitted Utah to draft a constitution and become a state in 1896 — in other words, a self-governing entity that would be much freer from control by Congress and the president of the United States.

What has happened since the 1890's is extraordinarily interesting. Having once decided to surrender on the key issue of polygamy, the Mormon leadership decided to go all the way in many other aspects of life. They would eliminate distrust and dislike by deliberately conforming to the rest of the United States. This meant accepting the patterns of thought of Victorian middle-class America, including the prevailing stress on laissez faire economics and hostility to anything that suggested socialism, despite the decades of Mormon church socialism. The Mormons' economic cooperatives were allowed to pass into private ownership, to be operated as profit-seeking enterprises.

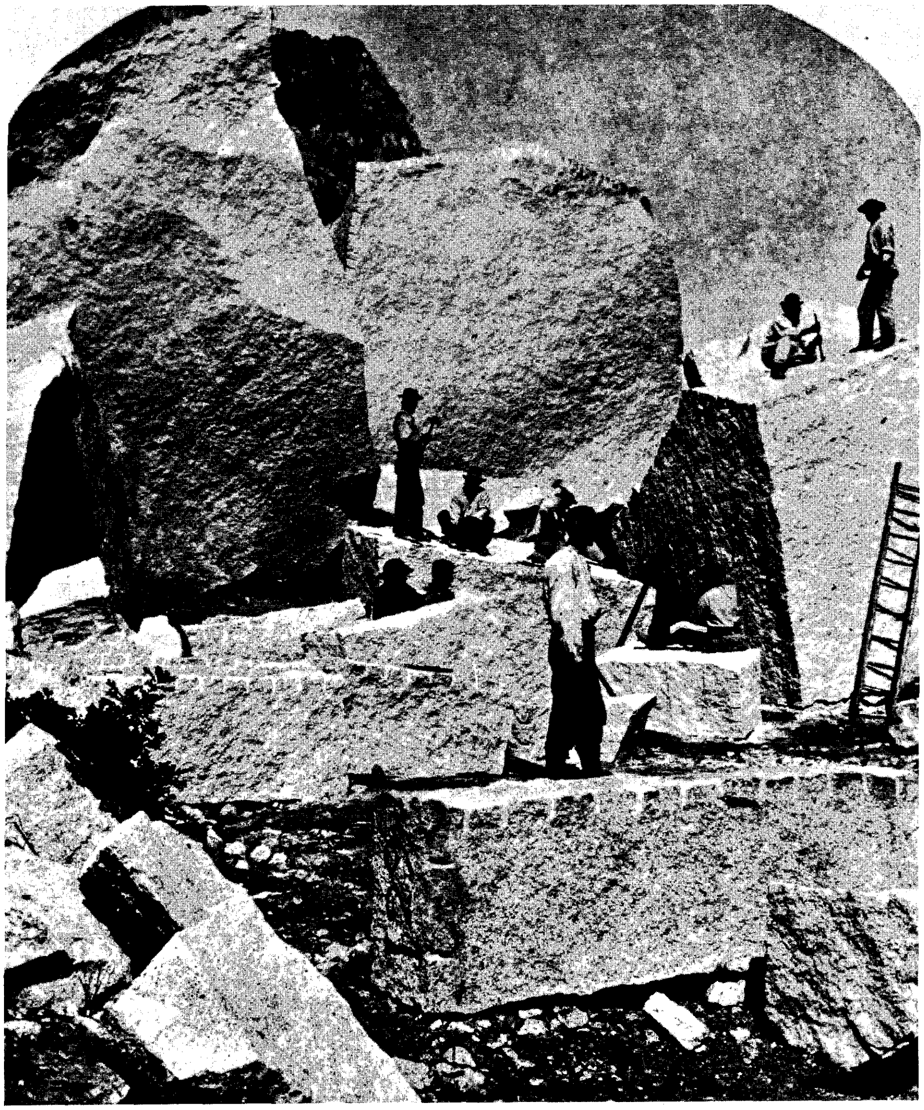
In some cases this meant that the former cooperatives became the private property of some of the local and general leaders of the church. But note that while the private profit motive grew at the expense of the old zeal for communitarian enterprises, nevertheless Mormons of all levels of income continued to tithe and to devote extraordinary amounts of time to the work of the church. The church continued to be the center of their emotional and social lives. And since the church was so central to the thinking of all practicing Mormons, and since it had always given political leadership in the past, so did it continue to exercise a heavy influence in politics in the new era.

Politically the Mormons had been organized in a party of their own, the so-called Peoples' Party, prior to making peace with the national government. But now the leaders decided that the Mormons would have more influence in Washington if they joined the national parties, and since you couldn't be sure which party would be in power at any given time, they decided to have their followers divide up between the Republican and Democratic parties, so that the Mormons would have a solid bloc of votes in both camps. On a given day the faithful were solemnly instructed so to do. In practice the leadership of the church has tended to find the atmosphere of the Republican party more congenial than that of the Democrats.

The reason is that by the time of making their peace with the nation, an important group of well-to-do, successful men had emerged at the head of the Mormon Church. Such men found little difficulty in conforming to the general attitudes of Victorian America once the divisive issue of polygamy was removed. In politics the natural allies of these men were the Old Guard Republicans in Washington and in the individual states. When the Congressional Republicans stopped persecuting the Mormons, an alliance followed easily. The same kind of affiliation with well-to-do middle-class America occurred also in labor relations. Many more of the Mormon leaders of that day belonged to the owner or manager class than to the ranks of the workers. Understandably, they joined middle western and eastern employers in denouncing labor's attempts to organize.

This tendency to affiliate with the conservative, ruling, entrepreneurial elements of American society was probably strengthened by at least two factors. One was the relatively provincial setting of most Mormon communities at the turn of the century, even after the railroads had reached them. The present-day dispersion of Mormons to big cities in non-Mormon regions is a recent phenomenon that has developed only since the Great Depression and the Second World War. Most Mormons of 70 or 80 years ago still lived in small towns and modest-sized cities that had little communication with the big national and regional centers where, in the age of Theodore Roosevelt and Robert La Follette, liberals and progressives were arguing fiercely over new ideas about social justice and using the power of the state to curb monopoly and economic abuse.

The other factor was a practice established by Brigham Young, who preferred that at his death his successors should be chosen on the basis of seniority. By following this practice, the Mormons have acquired the most aged ruling class of any organization known to modern man. The Mormons have had presidents who were in their 90's and who were assisted by men in their late 60's or their 70's or 80's. No matter how great the goodwill of such men, it is asking too much to expect them to comprehend the points of view of the great majority of an American population that is young enough to be the children, grandchildren, or even great-grandchildren of these dignified elderly



The ancient Egyptians building the pyramids probably looked somewhat like these Mormons quarrying granite in the 1860's to build their Temple. The huge blocks were hauled to the construction site by ox teams.

leaders of the Mormon church.

It is almost unnecessary to add that in this general drive to make peace with middle-class America, the old tendency to Mormon separatism has dwindled and has been replaced by an earnest patriotism. Does this mean that the modern Mormons have been fully absorbed into American society? That basic question has deeply concerned a new group of Mormon intellectuals that has become increasingly significant during the past decade. In 1966 this group decided to found a serious journal in which they could thrash out the difficult problems that they faced when they tried to discover a harmony between the faith, the teachings, and the church organization that Joseph Smith had revealed to their forefathers in the 1830's and 1840's, and the harshly insistent conditions of the 1960's and 1970's. The very first issue of this new journal started with an admirable editorial preface that said:

> Today . . . most Mormons live outside Utah . . . Today it is not unusual to see Mormon Congressmen in Washington, Mormon business executives in Chicago, Mormon professors at Harvard, or Mormon space scientists at Houston. Mormons are participating freely in the social, economic, and cultural currents of change sweeping twentieth century America.

Then, with no transition, the editorial suddenly added this assertion:

> But Mormons do remain apart from greater American society. Their experience, heritage, and tradition of years in isolation remain an integral part of Mormon belief; Mormon doctrine reinforces individual withdrawal and defiance of conformity in the face of modern convention. This new era of life in the secular world, far from the cloisters of a Rocky Mountain Zion, has created a host of dilemmas for the individual who seeks to reconcile faith and reason.

All of us face in some degree this problem of reconciling ancestral faith with contemporary thought and practice. But for the Mormons the reconcilement is the more difficult because Mormonism is such a complete way of life. Even though Mormons participate vigorously in the PTA, the Chamber of Commerce, local politics, business, and the professions, nevertheless they are still spending a high percentage of their lives in self-contained Mormon groups. From childhood until old age they meet, talk, play, and pray in their own groups. They have their own charities, projects, entertainments. I suspect that they feel more comfortable among their own kind. They have elaborate youth programs at high schools and colleges, in order to hold their young people in the church during the years when most denominations lose a high percentage of their young men and women.

Where most of us must find our individual and often lonely ways through this confusing modern era, the Mormons can live in a warmly supportive group atmosphere, if they wish. To break with so all-embracing a pattern is a wrenching, distorting experience. For just that reason independent thinking and modern doubts have come only slowly to most Mormons. It is far easier to conform to the church's omnipresent guidance than to challenge it. Meantime change is of course coming to the world with extraordinary speed. Will our Mormon neighbors be able to work out adjustments to contemporary pressures, without sacrificing the essence of their distinctive and close-knit culture? In this year 1974, the answer must be in doubt, but in view of the Mormons' remarkable record of meeting challenges in the past, I am by no means convinced that they will fail this time. □

Still today, when an individual disturbs the establishment, or deviates too loudly and too effectively from the accepted wisdom of a large and bureaucratically organized group, we find ways to silence him—sometimes by ridicule (although this has often proved a very weak weapon, and one which frequently turns against its user), sometimes by repression, and, if all else seems to fail, by legal action.

We're all familiar with the famous 1925 Scopes trial in Tennessee. The theories of Charles Darwin had been ridiculed for 60 years, but they still lived and were apparently growing steadily more healthy. Although certain religious forces attempted to repress them, religion, at least in the United States, was too weak to make the repression effective. So it was left to the law. And even here, only a very few states could be persuaded to make the teaching of evolution illegal. Nevertheless, it was done, and the result was that curious carnival in Dayton, Tennessee. As you may recall, the law won, just as it did in the case of Galileo. Mr. Scopes was found guilty. But it was, as we know, a futile victory. He was fined $100, and of course he lost his job. Not too bad compared to Galileo.

It might be interesting to review the 1954 security hearing of Dr. Robert Oppenheimer. Unfortunately, it is not likely that we have all of the important documents available to us. We do have enough to feel that this whole business was not quite right. There is a distinct impression that Dr. Oppenheimer was being tossed out of the official halls not because he was an actual security risk, but rather because his political opinions, particularly as they applied to matters of national defense, were a troublesome embarrassment for the establishment. But it is very difficult to know whether in any sense Oppenheimer was framed as Galileo had been. Such records as are available seem to indicate that the government had a pretty good case. Of course, they had the same pretty good case several years before they used it. So here again, the suspicion exists that Oppenheimer's questionable security status, if any, was more a matter of legal convenience than an actual threat to national security.

Perhaps you remember the curious case of Immanuel Velikovsky and his book, *Worlds in Collision.* Velikovsky was subjected to scientific ridicule for his opinions, and perhaps he deserved the ridicule. But did he deserve the repression that the organized scientific community attempted to place upon him?

This situation is well documented. Harlow Shapley, the director of one of the nation's foremost astronomical observatories, informed his favorite publisher that if the company dared

When an individual disturbs the establishment, we find ways to silence him

to publish the work of Velikovsky, Shapley would never submit another manuscript to it. The publisher, Macmillan, had the book reviewed by independent critics, and following a favorable reply, printed it. But only a few months later, the pressure of many scientists, previous and potential authors and customers, forced Macmillan to ask Velikovsky for permission to transfer rights to Doubleday—even though the book was on the best-seller list.

One of the astronomers who denounced the work as "nothing but lies" in a letter to Macmillan concluded by saying he had not and never would read the book.

I should add to this story that early in 1974 a debate was arranged by the American Association for the Advancement of Science, meeting in San Francisco. Velikovsky met his critics on stage in front of an open audience. It would appear that nobody's mind was changed. The devotees of Velikovsky remained devoted, and the critics remained critical. But the criticism was honest and scientific, and Velikovsky's replies were scholarly. There was no attempt at repression—and obviously no need for it.

One last example, and in this case I will ask you to consider your own reaction. I'll quote a few excerpts from a 1973 column in the *New York Times* by Associate Editor Tom Wicker. The question that Wicker wishes to pose about an individual and his theory (which the writer calls "repugnant") is given by this paragraph:

"His particular case not only raises the usual First Amendment question about offensive ideas, but a corollary: to what extent is a free society obligated to create opportunities for expression of such ideas?"

And further: "But do universities and publications have an obligation to extend him a respectable forum for his . . . theories?"

One of the objections this columnist raises against the individual is that even though he is a reputable scientist in one field, he is now talking about another, and as the writer states: "It can reasonably be argued that—on this subject, rather than in his field of expertise—he is not professionally entitled to serious attention or academic credit."

It is interesting that one of the charges raised against Galileo in the long process of bringing him before the Inquisition was that he was discussing matters of theology and natural philosophy, whereas he should stick to his own field; namely, mathematics. Centuries later, Oppenheimer was accused of using his scientific stature to make pronouncements in politics, where obviously he had no competence, and Freud was accused of dipping his hands too far into matters of morality instead of sticking to his own field.

Whatever attempts were made to repress Freud's theories, they were obviously not successful. Even the "repugnant" theory of infant sexuality has seen the light of day. Is that particular theory right or wrong? Who knows? The issue is still in doubt. Even the expert psychoanalyst has difficulty gathering data from the unconscious mind of a human being.

Was this repugnant theory important? Apparently yes. It was the basis of the

Freudian heresy, and the basis for making us take a new look at the whole problem of mental disorder. We now recognize that mental illness is to some degree treatable, and the degree is improving year by year. We are moving away from the old tradition of locking the victims of mental illness into insane asylums and trying to forget they exist. Of course we have only come a short distance along this road, but would we have progressed even this far had Freud been successfully repressed?

To relieve the mystery about my modern example, I will quote from its first paragraph: "Dr. William Shockley is a noted physicist of dubious qualifications for his views on genetics."

I use the example of Professor Shockley with obvious intent. In a number of discussions with my friends and colleagues, I have found that the majority find the genetic theories of Dr. Shockley as personally abhorrent as does the editorial writer whom I have quoted. One of my friends, an eminent medical researcher and a man of liberal view, responded, "Oh I know about his stuff. He's just a racist!" Well, maybe he is. And of course "racist" is a highly pejorative word these days. But even if we question his motives, does that disprove his concepts?

The dogma of racial equality is very important in our present governmental structure

Right now Dr. Shockley seems to be going through the ridicule phase. He is being shouted down at public lectures, insulted by newspaper writers, and occasionally a university cancels his lectures. But as we have seen in past cases, this seldom works. Will the next step be repression? What form will it take? Will the scientific and educational establishments that you and I represent take part in it? And if that fails, will the law be used next? The philosophy behind our current laws on this matter is clear: There are no racial differences in mental capability. Differences in capability appearing between the races are due to environmental factors only. This is the official position of the federal government—Administration, Congress, and the Courts. It is just as official as the position of the Holy Office in 1633 that the earth stands still and the sun moves around it.

In fact, the situation now may be even more rigid. The dogma of the church regarding the solar system in the 17th century was really not a central issue in the structure of the bureaucracy. However, the dogma of racial equality is of enormous importance in our present governmental structure.

Judging from experience, that famous expensive teacher, we might conclude that, if Dr. Shockley persists with his "repugnant" theories, there is at least a slight possibility that he may be subjected to some sort of legal action. Of course, if experience is as good a teacher as it is expensive, such action will not be against the theories themselves, but on some other charge.

But it is likely that even the law would not succeed in silencing Shockley. He might have difficulty getting his papers published, although in principle any member of the National Academy of Sciences has the right to publish anything he pleases in the Proceedings. It is rather curious that this traditional right has fairly recently come into question in a manner many consider to be unprecedented. In 1973 a Nobel Laureate chemist, Linus Pauling, had difficulty with the Academy's editorial board over one of his papers on megavitamin therapy. It was, in fact, rejected, and subsequently published in another journal.

I do not intend to place Oppenheimer, Pauling, Shockley, or Velikovsky on the same level as Galileo—although perhaps Freud belongs there and history may have more to say about the others. The comparison I intend is rather between the educated society of the 20th century—ourselves—and the educated society of the 17th. I cannot avoid the impression that we have not improved as much as we would like to believe.

Some of my scholarly friends have argued that Shockley's ideas ought to be repressed. They cause more social mischief than they are worth. And after all, at the present time, there are insufficient data to prove them right or wrong.

This argument has a familiar ring. It has been sounding through the halls of science for almost four centuries—and through the temples of philosophy and religion for considerably longer—"Don't make waves!" Surely by now we have learned that inquisition, repression, and ridicule are not the shields and bulwarks of society, but quite the opposite. They are damaging to progress, damaging to education, and, in fact, damaging to all mankind.

This argument has been sounding through the halls of science for almost four centuries

Did the astronomical community really have anything to fear from the publications of Velikovsky? What a ridiculous notion! Are we to fear that the racial theories of Dr. Shockley will take over society? There is no need for it. He has all the critics he needs.

Columnist Wicker raised the question: "Do universities and publications have an obligation to extend Shockley a respectable forum for his theories?"

I believe that question is slanted the wrong way. It implies some sort of obligation to Shockley. But the obligation is to ourselves. The central question is: Does the scholarly community have an obligation to extend a respectable forum for the open discussion of repugnant theories? To that question, the answer is clearly, "Yes!" □

The Search for Extraterrestrial Intelligence

. . . continued from page 11

I think you can see why some of us feel that interstellar travel may never be accomplished economically. It's true that smaller, lighter-weight probes, and such things as interstellar ramjets (that no one knows how to build) have been proposed. But since over 10,000 stars might have to be sampled before we found the life we're seeking, then even with substantial reductions the costs are still prohibitive.

This is both a disappointment and a comfort. It's a disappointment because it would be very exciting to visit other worlds. But it's a comfort because *they* can't get *here*. I don't think we're ever going to end up as a gourmet delicacy on some alien's breakfast table.

It's my sincere belief that both UFO's and interstellar invasion are matters that we don't have to worry about. I feel the only practical approach to interstellar contact is to search for radiation transmitted by other civilizations either for their own purposes or in a deliberate attempt to communicate.

Three years ago I had the pleasure of conducting at the NASA Ames Research Center a summer study session called Project Cyclops. The goal was to assess whether present technology is up to the task of making a realistic search for this kind of radiation and what the cost might be in both money and time. I want to stress that this was a summer study that lasted three months, involved 20 people, and had a budget of $100,000—so I don't expect that the answers are definitive. But we did make some progress, and our major conclusions were these:

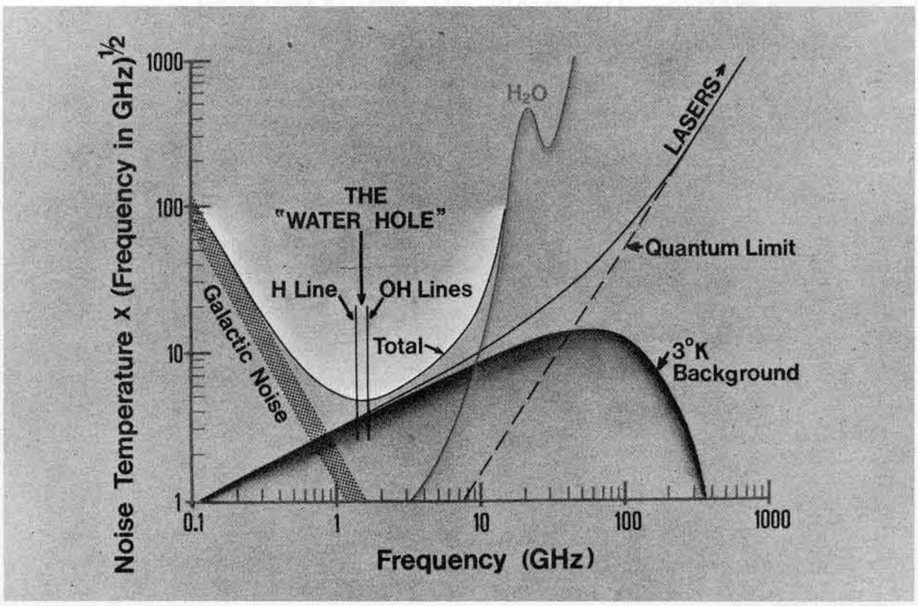
First, we feel very confident that the best region of the electromagnetic spectrum for the search—the place to tune our receivers—is in the microwave region, the wavelengths from 3 to about 30 centimeters. This is the quietest part of the spectrum; it has the least background noise associated with it. The narrower we make our receiver band, the less noise we'll admit and the weaker the detected signal can be. But there's a limit to how narrow we can make the bandwidth because, as a result of Doppler shifts, the signals are not absolutely steady in frequency. If the receiver is too narrow, the signal will drift clear through the passband before the receiver can respond. It turns out that the receiver bandwidth must be proportional to the square root of the operating frequency and, when this factor is included, the best part of the spectrum is from 1 to 2 gigahertz. One gigahertz (GHz) is a billion cycles per second. We'd like to narrow our window further so we wouldn't have to search so much of the spectrum, but we can't find any *technical* reasons to do so.

The Cyclops team felt that it found an appealing reason to favor a rather narrow region at the very optimum part of the spectrum. At 1.42 GHz there's a strong spectral line caused by interstellar hydrogen. Just a little bit higher in frequency, at 1.66 GHz, is another spectral line caused by hydroxyl ions in space. We think that this may be the interstellar communication band, defined for all of us by nature herself. Water separates into hydrogen and hydroxyl ions, both of which are important in all life processes. So is water.

Thus the band lying between the spectral lines of the two dissociation products of water is a poetically symbolic place for water-based life to search for its kind. Where shall we find other intelligent species? Why, at the age-old meeting place of all species—the waterhole.

The second conclusion of the Cyclops team was that it is now possible to build a receiver able to search the entire waterhole at one time instead of having slowly to tune a receiver through the billions of channels it contains and listen to each channel in sequence. In effect, this receiver is a kind of high-resolution spectroscope; it spreads out the waterhole into a very high dispersion spectrum and looks for a signal at each point in the spectrum simultaneously. In a thousand seconds it could spot any signal, even a drifting signal, if the received power were only one-billionth of the noise power in the waterhole band.

The third conclusion was that, even with this detector, and even using the best part of the spectrum, we are going to need a very large antenna system indeed, one perhaps several miles in diameter. Single, steerable antennas that big can't be built on Earth, and are probably prohibitively expensive to build in space. But what we can do is



The Waterhole—Frequency instabilities force us to wide receiver bandwidths the higher we go in frequency. This, together with the spectra of certain cosmic noise sources, makes the region from 1 to 2 gigahertz the ideal part of the entire electromagnetic spectrum. There we find the emission lines of the dissociation products of water standing like the Om and the Um on either side of what may be our gateway to the stars.

to plant an orchard of smaller antennas and add their outputs together. This is called a phased array.

With an array of a thousand or more antennas and with low-noise receivers, Cyclops could detect any signal in the waterhole in 1,000 seconds, if the flux from that signal was only five photons per second per square mile. We could eavesdrop on signals that might be radiated from planets out to a distance of about 100 light years, and we would be able to detect beacons of reasonable power from any of the million or more good suns within 1,000 light years.

The cost of this system is obviously large—on the order of $6 to $10 billion, depending on how big it has to be before we succeed. This expenditure might occur over a 10- or 20-year period as antennas were added to the array year after year. If we were to achieve contact soon, we would not need to build the full array. The rate of expenditure would be a little over half a billion dollars per year. That's less than Americans spend on cigarettes; it's almost in the noise level of the federal budget. Nevertheless, it's a lot of money, and to justify spending it, we have to expect some substantial benefits out of finding other intelligent life.

IS THERE INTELLIGENT LIFE ON EARTH ?

PROGRAM	$ BILLIONS PER YEAR	YEARS	POSSIBLE OUTCOME	
			WORST	BEST
NATIONAL DEFENSE	>200 (US ≈ 80)	?	CIVILIZATION ANNIHILATED	EFFORT IS WASTED
CYCLOPS	0.6	15	GREAT ADVANCES IN COSMOLOGY	SUPERHUMANITY BEGINS

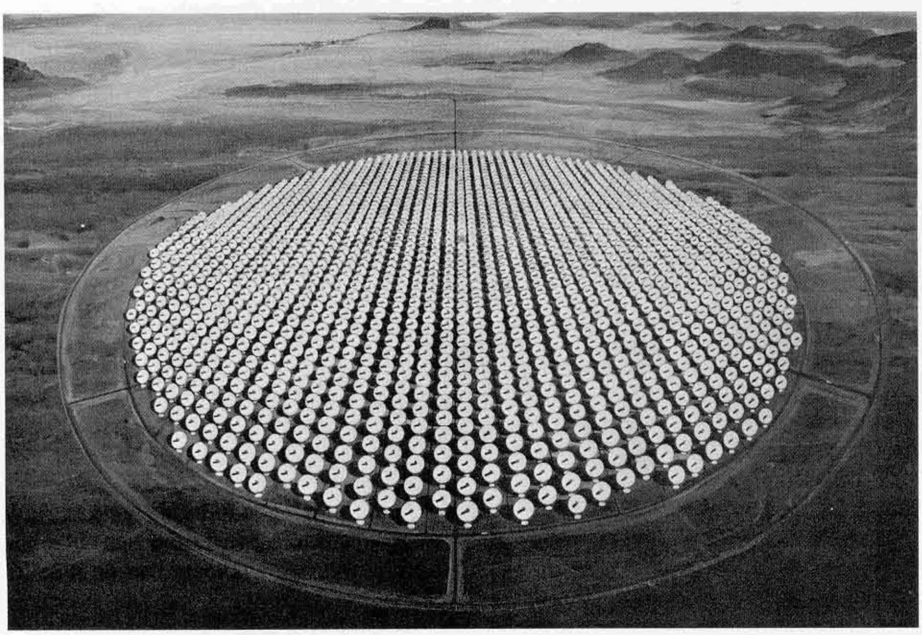
A Comparison of Two Societal Programs—The search for extraterrestrial intelligence is a gamble. So is national defense. We will never detect other civilizations unless we are mature enough ourselves to spend out of intellectual curiosity only a small part of what we now spend out of fear.

If our reasoning is correct, intelligent cultures have existed in the Galaxy for a few billion years, and if we find interstellar communication possible, they too certainly will have by now. Out of the billions of races that have attempted it, many must have been successful. Those that were successful probably have pooled their knowledge over the millennia and passed it on to younger races that joined their community. In fact, one of the requirements imposed on junior members might be to establish beacons to attract still younger races and thereby facilitate their first contact.

If all this is true, the task we face may be easier than we think. If this sort of a communicating community has been going on for this length of time, then a vast body of knowledge will have accumulated over the aeons, and this knowledge is accessible to any race whose technological prowess qualifies it.

I have termed this body of knowledge our galactic heritage, and I believe that access to it would truly be the most important event in the recorded history of man. The galactic heritage could include a large body of science that we have yet to discover—answers to questions that we haven't even thought of. It would include such things as pictures of the Galaxy taken several billion years ago by long-dead astronomers; it would include the natural histories of all the myriads of life forms that must exist in the planets of the member races. The whole story of cosmic evolution would be spread before us, illuminating not only the future but our past as well.

We might be able to tell if the expansion of the universe is going to slow down, and also whether the universe is going to recycle itself or not. We could see the unimaginably diverse kinds of life that evolution has produced in other worlds and learn their biochemistries, their variety of sense organs, and their psychologies. Culturally, we might learn new art forms and



Cyclops from the Air—The huge Cyclops array would be the most powerful radio telescope ever built and would permit real-time images of the radio sky. When the full power was not needed for any one task, the array could be subdivided to serve many astronomers simultaneously. Cyclops would be radio astronomy's Palomar.

aesthetic endeavors that would enrich our lives.

But more significant, I think, would be the societal benefits. We will be in touch with races that have achieved longevity. The galactic community would already have distilled out of its member cultures the political systems, the social forms, and the morality most conducive to survival, not for just a few generations, but for billions of years. We might learn how other races solved their pollution problems, their ecological problems, and how they have shouldered the responsibility for genetic evolution in a compassionate society.

If Cyclops could provide even a few of these answers, it seems to me that its cost would be justified. But finally, and perhaps even more important, participation in such a community would, in Neil Armstrong's words, "enhance the spirit of man." It would lift our horizons out of the sphere of our own rivalries, and involve us in the common cause of life throughout the Galaxy. What this cause may be, of course, no man can say. Perhaps someday life may save the whole universe from oblivion as life has already saved Earth from the heat death of Venus.

Since 1958, when NASA began, its total expenditure on all its space and aeronautical programs has been about $50 billion—about five times the estimated cost of Cyclops. Over this same 15-year period we have spent one *trillion* dollars out of fear—one thousand billion dollars to attack and to defend ourselves against attack by our fellow human beings.

I'd like you now to compare two programs: one the world is already engaged in, and one I would like to see started. The world spends over $200 billion per year on defense. Of this, we alone spend about $80 billion. How many years this will go on I don't know. The worst possible outcome of all this human effort would be Armageddon—doomsday for man. The best we can hope for is that our weapons will never be used.

The other program is Cyclops, which would take less than 1 percent as much money for only a few years. At the very least, the enormous capability of Cyclops as a radio telescope would extend our knowledge of the universe, probably to the cosmological horizon, back almost to the beginning of time. The *worst* outcome of Cyclops—failure in its primary mission—is far more exciting than the *best* outcome of our defense programs. The best outcome of Cyclops is something we cannot yet conceive. I can only suggest to you that childhood's end may await us at the waterhole. □

Statement of ownership, management and circulation (Act of August 12, 1970: Section 3685. Title 39. United States Code). 1. Title of publication: Engineering and Science. 2. Date of filing: September 23, 1974. 3. Frequency of issue: 7 times a year. 4. Location of known office of publication: 1201 E. California Blvd., Pasadena, Calif. 91125. 5. Location of the headquarters of general business offices of the publishers: 1201 E. California Blvd., Pasadena, Calif. 91125. 6. Names and addresses of publisher, editor, and managing editor: Publisher: California Institute of Technology Alumni Association. Editor: Edward Hutchings, Jr., Managing Editor: Jacquelyn Bonner, 1201 E. California Blvd., Pasadena, Calif. 91125. 7. Owner: California Institute of Technology Alumni Association, 1201 E. California Blvd., Pasadena, Calif. 91125. 8. Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages or other securities: none. 10. The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes have not changed during the preceding 12 months. 11. Extent and nature of circulation: A. Total no. copies printed: average during preceding 12 months, 9535; actual number of latest issue, 9100. B. Paid circulation: 1. Sales through dealers and carriers, street vendors and counter sales: average during last 12 months, 20; actual number of latest issue, 20. 2. Mail subscriptions: average during last 12 months, 5800; actual number of latest issue, 5830. C. Total paid circulation: average during preceding 12 months, 5820; actual number of latest issue, 5850. D. Free distribution by mail, carrier, or other means: 1. Samples, complimentary, and other free copies: average during preceding 12 months, 3485; actual number of latest issue, 3067. 2. Copies distributed to news agents, but not sold: none. E. Total distribution: average during preceding 12 months, 9285; actual number of latest issue, 8917. F. Office use, left-over, unaccounted, spoiled after printing: average during preceding 12 months, 250; actual number latest issue, 183. G. Total: average during preceding 12 months, 9535; actual number of latest issue, 9100. I certify that the statements made by me are correct and complete. Edward Hutchings Jr.

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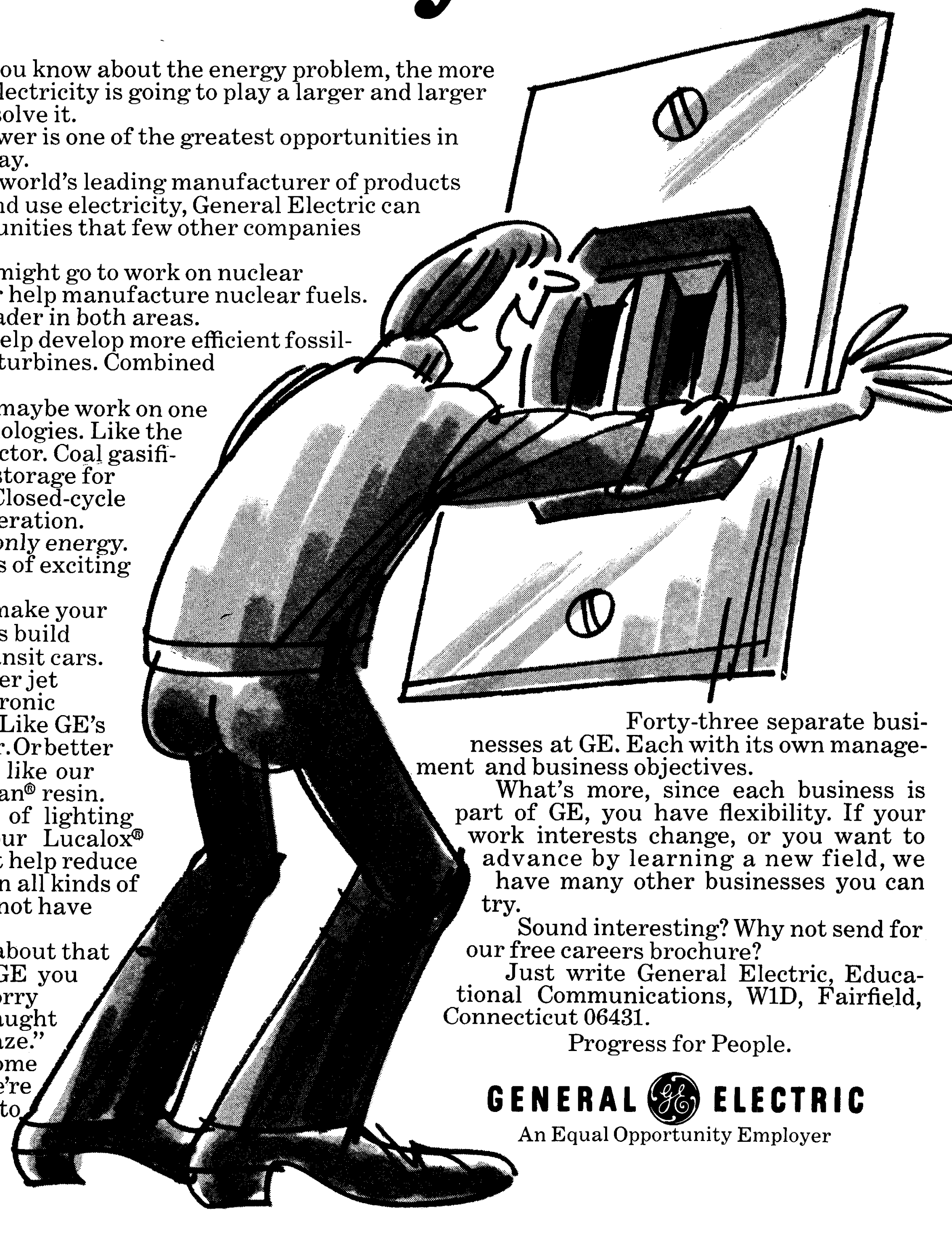

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