E&S

ENGINEERING AND SCIENCE

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May 1968

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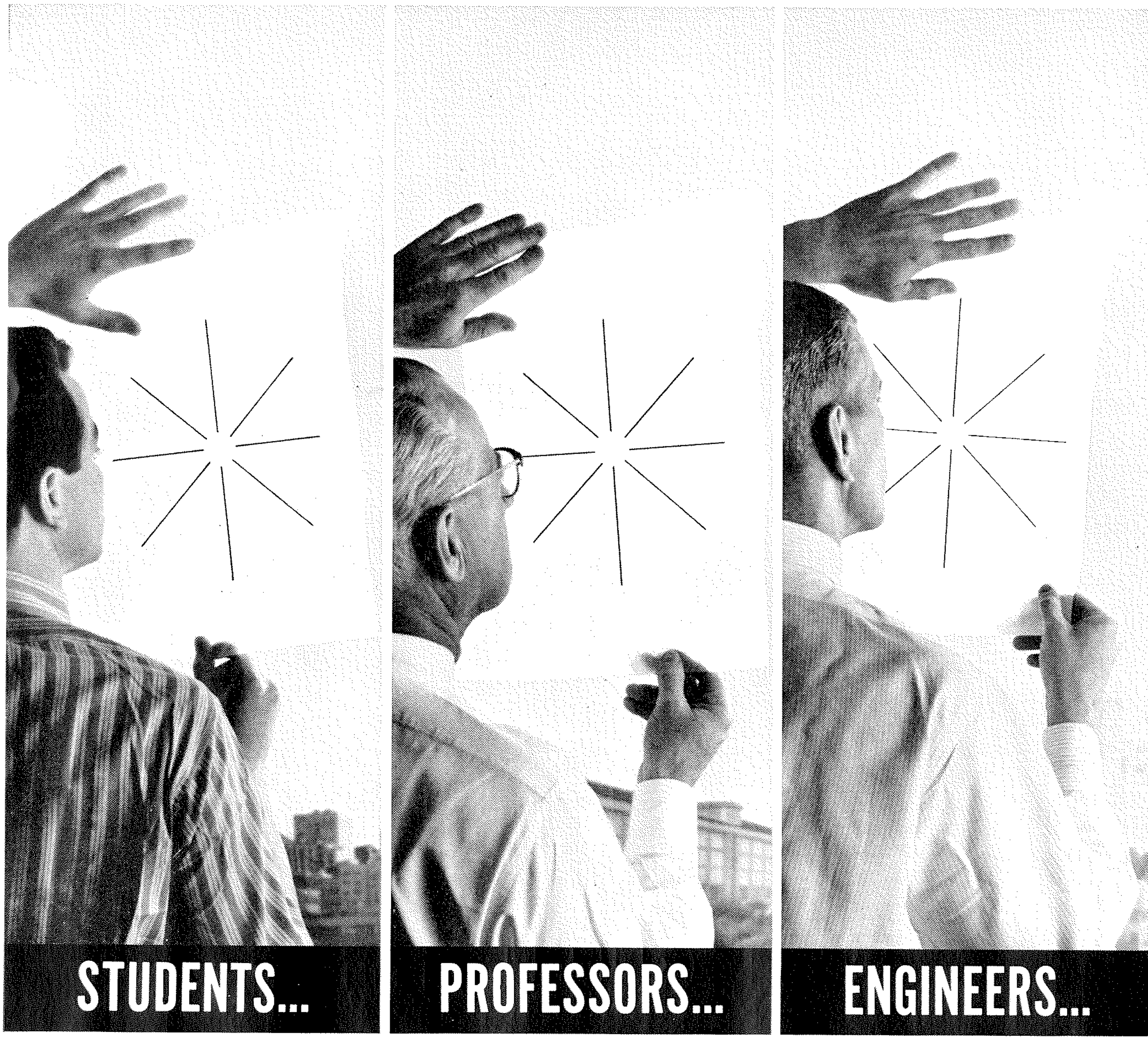

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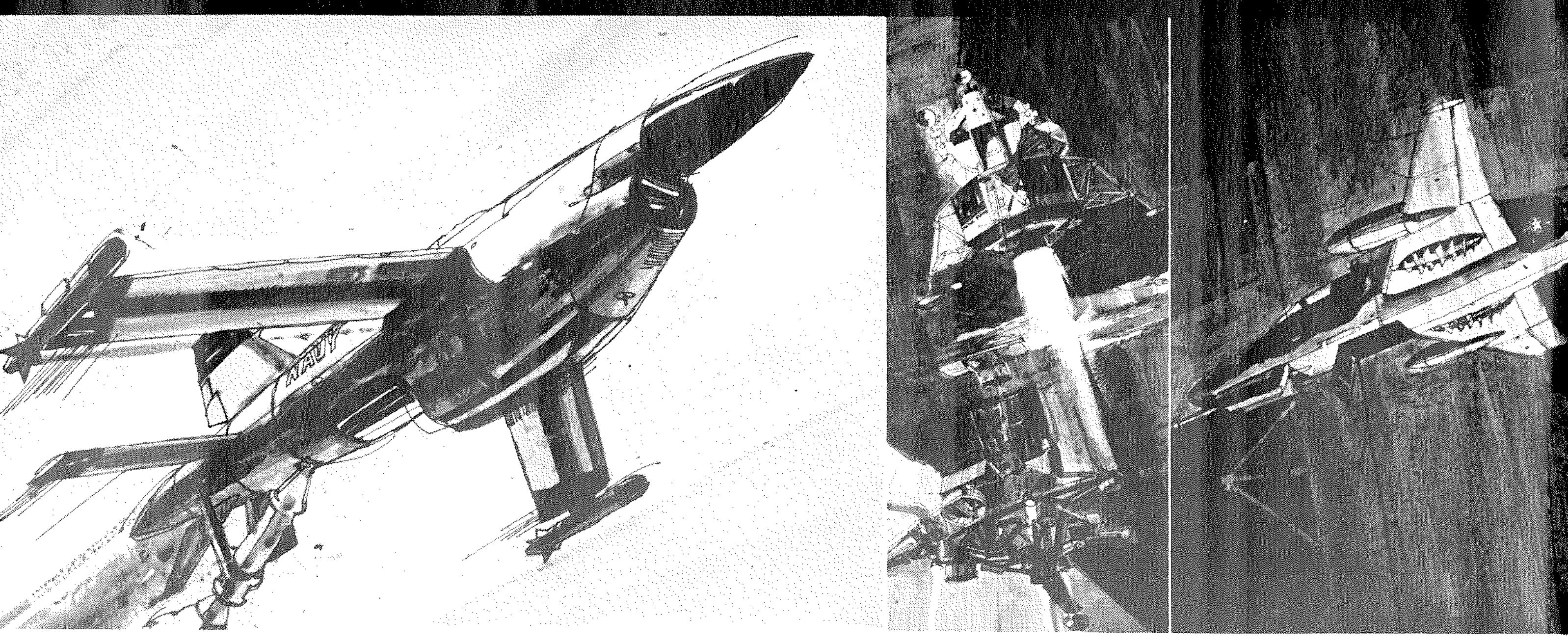

E&S

ENGINEERING AND SCIENCE

MAY 1968 / VOLUME XXXI / NUMBER 8

THE FAR REACH OF SCIENCE

A SPECIAL ISSUE

In this issue five Caltech scientists share their views of "The Far Reach of Science"—each from the perspective of his own specialized field of research. This broad spectrum of knowledge and experience was originally presented as a symposium, sponsored by *Life* magazine and Caltech, for more than 700 business leaders in New York and Chicago. The articles on the following pages serve as a written record of this attempt by a group of scientists to bring to businessmen some meaningful glimpses of the nature of science.

PICTURE CREDITS

Cover, 26—Doyald Young; 10—Walter Daran; 12, 30—Leigh Wiener; 15, 17, 18—Mount Wilson and Palomar Observatories; 21, 34, 40—James McClanahan; 38—Tom Harvey.

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LETTERS

Gaithersburg, Maryland

EDITOR:

The interviews with Dr. Bruce Murray on the U.S. space program (March *E&S*) are marvelous. Never before have I seen the reasons which I suspect are held by most of the backers of this program expounded with such refreshing candor.

Normally, our space expenditures are justified in terms of national security, the ultimate benefit to humanity of new scientific knowledge, or the enhancement of our prestige among other nations. But it's clear that in Dr. Murray's mind, he and his fellow explorers (a group which he identifies with the USA) are engaged in an exciting contest with their opposite numbers in the USSR (a group which he identifies with the Russian nation as a whole).

The object of any contest is, of couse, to *win*, and the way to win a space contest is to get there first—wherever "there" may be defined to be. Never mind what you find when you get there—just get there *first*. So it's Bruce Murray vs. the Russians in a race to Jupiter, and Mr. Congressman, please appropriate a few extra million so that Murray and his buddies (i.e., the entire nation) can feel a glow of pride and satisfaction because they WON!

PHILIP HAYWARD '49

Calgary, Alberta

EDITOR:

The excellent article by Milton Plesset, "Nuclear Power and Nuclear Proliferation" (January *E&S*), has given much food for thought to us in the mineral and fossil fuels industries. There would seem to be greater future change in energy sources than has been recognized by exploration programs.

I want to take exception, however, to the assertion that termination of programs of underground nuclear explosions should be effected by all nuclear powers. On the contrary, the potential benefits of subsurface nuclear applications are vast; and the step that needs to be taken is exactly the opposite of Professor Plesset's solution, namely, to rid the development field of political interference.

It is not reasonable and should therefore be unacceptable to any scientist considering matters of nuclear proliferation to proscribe nonmilitary subsurface nuclear development. In fact, such a course is the proverbial throwing out of the baby with the bath water.

C. WARREN HUNT '45

Berkeley

EDITOR:

There are those of us among the alumni readers of *E&S* who were startled to find an article entitled "The Radical Right" by Robert A. Rosenstone in the March 1968 issue.

Considering that the Institute (which welcomed the off-beat intellectuals of a past generation) now calls upon that Messiah of the reactionaries, anti-intellectuals, and supporters of shoddy materialism—Ronald Reagan—to kick off the current fund drive . . . it was a pleasant shock to think that maybe liberal thought had again, somehow, seeped into Pasadena.

What a letdown to find that the great leader of liberal thought for whom this drum is being beaten is that well-known intellectual and exponent of true American thought, Barry Goldwater.

ROBERT STIRTON '30

Ontario

EDITOR:

Dr. Robert Rosenstone in the March issue gave what *E&S* called "an account of the Radical Right as he sees it today."

It was a good expression of his opinion and, as such, well worth reading. There is no doubt that many of his points are valid.

However, it is my opinion that much of Dr. Rosenstone's dissertation is of the nature of preaching the admonition "be objective; don't generalize." This is good. It would then have been even better if he had ended with the old adage "do as I say, not as I do," nothwithstanding the generous admission in the body of his text that "There may be sound reasons for agreeing with some rightist views." The credibility of this admission is strained, however, since Dr. Rosenstone seems to imply that all rightists are, or will become, the mentally defective Radical Right adherents which he describes with such fear and fervor.

WILLARD E. BAIER '23

Kingsville, Maryland

EDITOR:

Generally, I find most of the material in *E&S* both informative and factual; in fact, that is the reason I enjoy reading it. In the March 1968 issue, I feel that you have done the magazine, the Institute, and the alumni a disservice in the publication of the article by Robert Rosenstone.

I am sure that Dr. Rosenstone undoubtedly sincerely believes what he says, but I am afraid that he has allowed himself to become a radical thinker of at least as serious a degree as the kind he punishes so severely.

Frankly, I just don't think that this kind of writing belongs in our alumni magazine. I feel that material to be considered should be factual, logical, and analytically thought out. I am unable to convince myself that this has been done. There is an almost infinite variety of shades of viewpoints between Dr. Rosenstone's, which to me appears to be well into the radical left, and the radical right . . .

I visited Caltech in January and was told at that time that Caltech had become rather socialist oriented. To me, this was disappointing to hear because in true socialism (as I understand it) there is hardly a need for schools of Caltech's calibre.

continued on page 45

We'll take a mini credit for the skirt.

About when the mini skirt lifted female hemlines and male morale, another revolution was sweeping the garment industry: permanent press fabrics. *Real* permanent press.

Now when a pleat goes into a skirt or a crease into a pair of pants, it's there to stay. You can't shake it out even in the wildest discothèque. Or iron it out in steam.

What turned out to be the key to the process is a chemical intermediate from Union Carbide. It's called glyoxal.

Glyoxal is the essential link in the chain of chemical reactions that gives clothes the best permanent press properties. And it has to be glyoxal of a very pure, highly refined grade.

With so many people now saying that ironing clothes is a thing of the past, high grade glyoxal seems to be a highly significant contribution.

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Anyone planning to use a magnetic material for anything more subtle than picking things up had better know its hysteresis curve. That's the curve that shows how much magnetic flux is induced in a material by applied magnetizing forces of either polarity. Western Electric uses many kinds of magnetic materials in the communications equipment we build for the Bell System. And for very subtle purposes indeed.

So we draw a lot of hysteresis curves. And, by old test methods it could take up to two hours to draw even one.

Since flux changes in many of the materials we use produce very weak forces, people have been trying for years to work out a hysteresigraph that will get these forces to move a recording pen. Until recently, the closest anybody had come was one of our engineers.

His device employed a galvanometer, a mirror, a pair of photocells, a servo amplifier and motor, and an elaborate set of balancing and positioning controls. It drew nice curves, but the slightest vibration threw it off, and getting it set to go again took time, skill, and infinite patience.

The same engineer who devised *that* hysteresigraph recognized the possibilities of a newly developed device called an electronic operational amplifier. He designed a new, all-electronic hysteresigraph around it that draws accurate curves in about five minutes, needs hardly any adjusting, and is completely indifferent to vibration.

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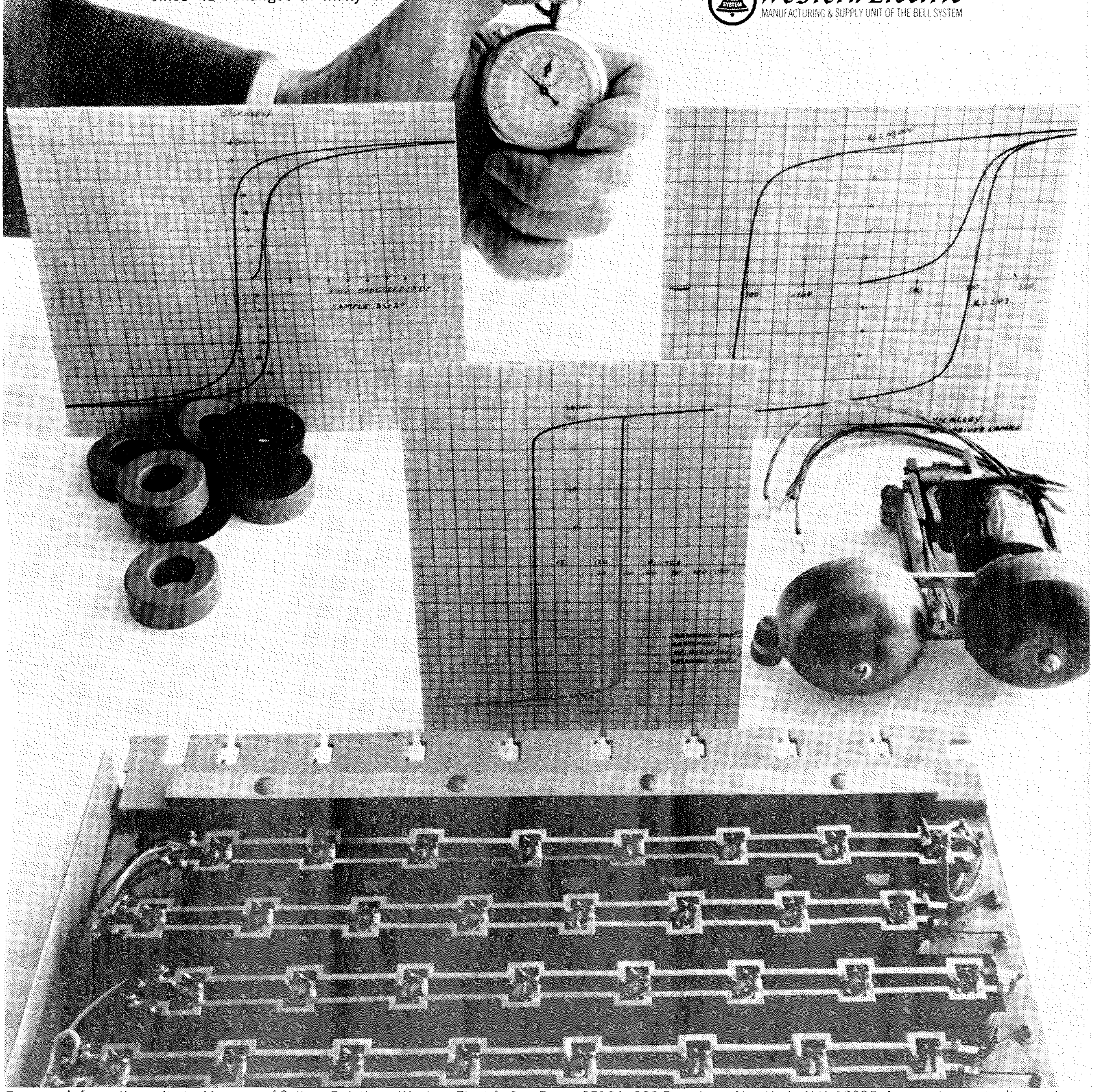

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The Far Reach of Science

Six distinguished Caltech scientists joined forces this spring to compress into a single symposium their knowledge of "The Far Reach of Science."

This day-long program was originally presented to more than 400 business executives in New York on March 18 and was repeated two days later for a similar audience in Chicago. The symposium was an invitational conference sponsored by *Life* magazine, in cooperation with Caltech, to give business and industrial leaders some insight into what modern science is all about.

The speakers addressed themselves to some of the most basic questions of science:

What is the nature of the universe?

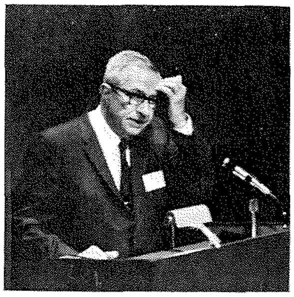
What is the nature of life?

How does such knowledge affect our daily lives?

Caltech president Lee A. DuBridge presented an introduction to this experiment in education and pointed up the interrelationships between the various scientific disciplines represented by the five speakers— William A. Fowler (astrophysics), Murray Gell-Mann (theoretical physics), Robert Sinsheimer (biophysics), James Bonner (biology), and Harrison Brown (geochemistry, and science and government).

This issue of *Engineering and Science* is devoted to these talks which so successfully prove why some understanding of modern science is not only important for businessmen but for every one of us.

Speaking of Science—*The men who took part in "The Far Reach of Science."*

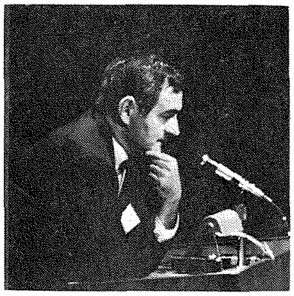


An Introduction

LEE A. DuBRIDGE. In the 22 years that Lee DuBridge has been president of the California Institute of Technology he has devoted endless energy and enthusiasm to improving the quality of education—in particular, scientific education. His participation in "The Far Reach of Science" is a further contribution to that cause.

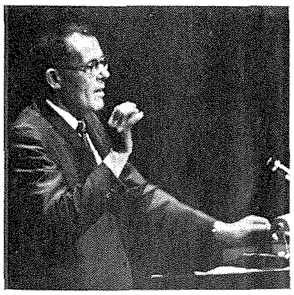
The Nature of the Universe

WILLIAM A. FOWLER has been studying the structure and behavior of atomic nuclei for 32 years at Caltech. In the last 20 years, however, he has used his knowledge and skills to do important research on the synthesis of elements in stars. Along with two colleagues he has outlined a theory of the origin of the solar system which may serve as a key to understanding the history of the entire universe.



The Nature of Life—I

ROBERT L. SINSHEIMER is professor of biophysics, chairman of Caltech's division of biology, and a gifted writer, particularly on the subject of the moral responsibility of the scientist for the future of man. His most recent scientific achievement—his part in creating the first artificial synthesis of active DNA of the virus Phi X 174.



The Nature of Life—II

JAMES BONNER. When Dr. Bonner first came to Caltech in 1935, he was involved in plant biology. Since then he has worked in biochemistry, biophysics, and on the molecular basis of the control of genetic activity in both plants and animals. Most recently he has become interested in the molecular problems of the brain and the basis of memory. With this wide range of interests Dr. Bonner is well qualified to make some interesting predictions about the future of genetics.

A Summing Up

HARRISON BROWN, professor of geochemistry and of science and government, has interests which go far beyond the confines of his specialties—geochemistry and planetary science. His absorption with the interaction of science and society has led him to devote his capacities to building up international relationships among scientists throughout the world—especially through his duties as foreign secretary of the National Academy of Sciences.

The Nature of Matter

MURRAY GELL-MANN, first Robert Andrews Millikan Professor of Physics at Caltech, established a theory predicting the pattern of subatomic elementary particles in 1962. Two years later the discovery of the omega-minus particle confirmed the theory. Dr. Gell-Mann's symposium talk, about these patterns and their origin, originally appeared in *Engineering and Science* in January 1967.

AN EXPERIMENT WORTH TRYING

An Introduction to The Far Reach of Science.

by Lee A. DuBridge

We are here to try an experiment. It is the essence of any experiment that its results cannot be predicted; otherwise it is not an experiment, it is only an event. Since we are always doing experiments at Caltech, we are willing to try this one.

The nature of the problem this experiment seeks to answer is simply this:

Can we as scientists bring to a group of business and professional leaders who guide the practical affairs of this country, and who have no professional concern with science, some insight into what modern science is all about and why it is important to every person on this planet? I don't know whether we can or not. But we firmly believe it is worth trying.

The advance of science in the past 300 years has had a profound effect on the way human beings now live and think. There is no moment in your life that you are not doing things, thinking things, using things that were unheard of or impossible to think about 300 years ago when modern science began. The food you eat, the clothes you wear, the medicines you take, the way you travel, the way you communicate with others, the products you make or sell, the industries you operate or invest in or persuade others to invest in, the way you think about the world—all of these things are new in the past 300 years or at least have been profoundly altered by scientific knowledge and understanding.

A handful of scientists plus a somewhat larger handful of engineers and technologists have radically changed the nature and quality of human life. Our ways of thinking have been altered too, because today we think not on the basis of superstition but on the basis of at least *some* understanding.

I am not suggesting that the nature and quality of human life is all that we would like to see it. But I am suggesting that, because we have much knowledge and because we are so rapidly acquiring more, the process of changing the quality of life is today under our control. This was not true 300 years ago or even 100 years ago. And it is not as true today as it will be in the decades and centuries to come. But it is sufficiently true today to suggest that all of us should be aware of the nature of the process of advancing the knowledge which is making it technically possible for us to make our dreams come true—or possibly, by inadvertence, fail to make them come true.

The human being is the one animal equipped with a brain capable of abstract thought. The brain is, in fact, man's principal instrument of survival. So it is not surprising that a prime urge of an animal with such a brain is to use it to acquire knowledge, to attain understanding, and to find ways of using his knowledge to make his life a better, safer, and fuller one.

We know that man's curiosity about the nature of the world he lives in is as old as man himself. Before the dawn of recorded history man looked at the stars, speculated about their nature, and plotted their motions. He looked at the world around him—at the wind, the rain, the earth, the sea, the heat, the cold, the burning fire—and he puzzled about these things. He puzzled also about himself, about birth and death and sickness and disease. He asked many questions: Why do the winds blow, the rains fall, the stars move? He asked also: How did it all begin? How will it all end?

Early man proposed many answers to these questions, and often the answers became a part of his religion or his philosophy of life. Indeed, what we now call science was once called natural philosophy, as distinguished from moral philosophy.

In view of the fact that man's penchant for speculating about the nature of things is so ancient, it seems remarkable that only moderately recently in human history did man finally discover a systematic way of answering his age-old questions and discovering the how and why of nature.

It may be even more surprising to realize how far man has progressed in that 300 years since science was born. For when Galileo first measured—not just looked and speculated, but measured—how bodies fell to the earth and when Newton enunciated the general principles which he found to govern these phenomena, mankind entered a new and exciting era.

The scientific endeavor has had an extraordinary history. Every now and then someone who is overly impressed by what has been learned has had the bad judgment to suggest that now we know it all, that the progress of knowledge is finished, and that the world is at last fully understood.

This was said by distinguished people at the beginning of this century. How fabulously mistaken they were! For every year the acquisition of knowledge has, in fact, accelerated. New discoveries have been made, new mysteries revealed, new tools for asking new questions of nature have been invented. And so today, while we perceive a vast sea of knowledge behind us, we see an even vaster sea of ignorance ahead.

But that sea of ignorance no longer frightens us; it challenges us to new ventures. For we now know that, bit by bit, knowledge will replace this ignorance.

The depth of our ignorance is suggested by the three basic questions that we are going to be dealing with in this symposium:

What is the nature of the universe?

What is the nature of matter and energy?

What is the nature of life?

About each of these questions much is known, but also there is much that is unknown. And the efforts to explore this unknown are more energetic and productive today than ever before.

What is the goal of all this effort? The goal is simply understanding—learning the facts of nature's behavior and trying to comprehend the principles that underlie this behavior.

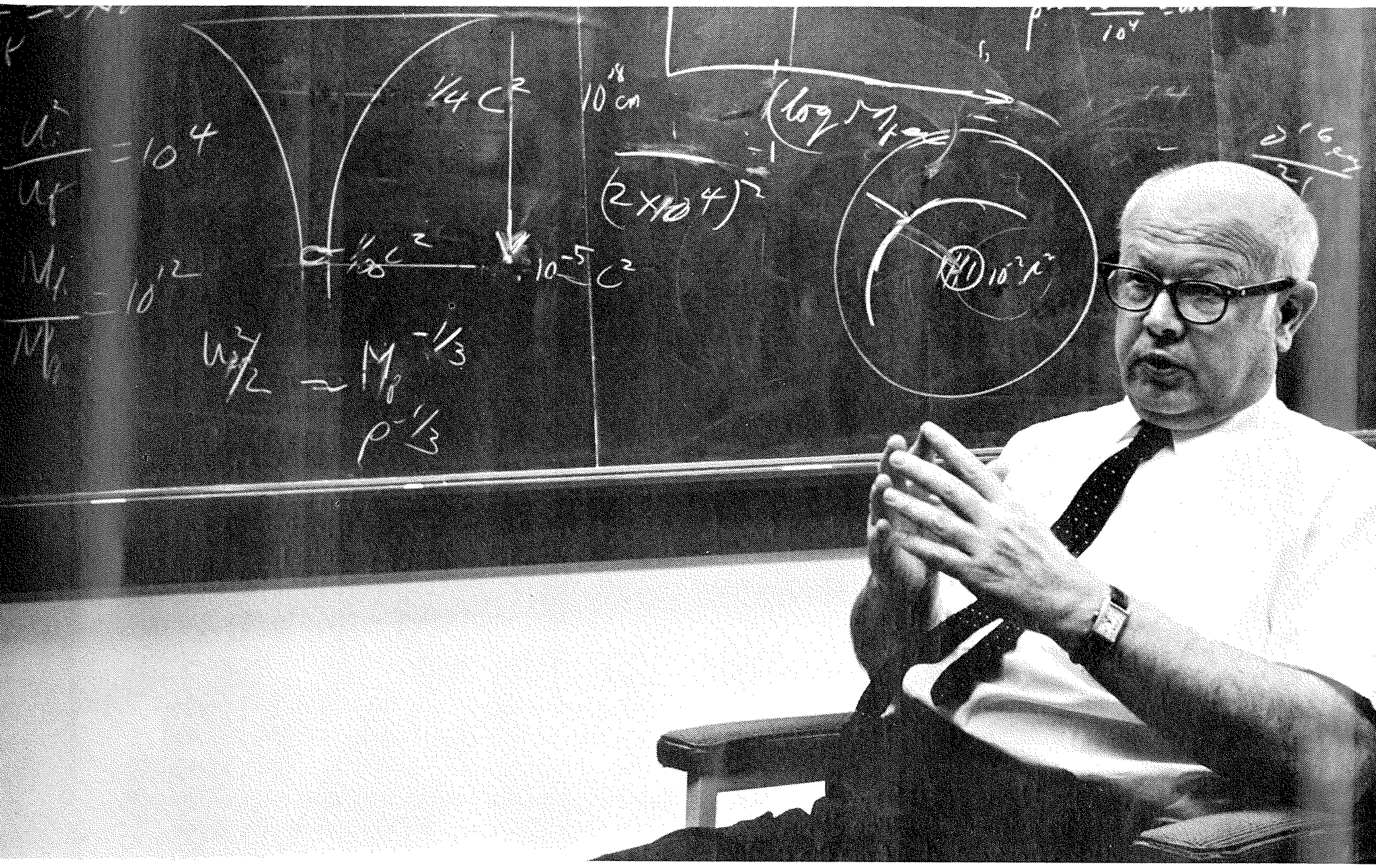
The principles that one seeks are, of course, more important than the facts that one finds; for tables of facts in themselves are sometimes pretty useless. You can have all sorts of statistics about what is going on in the world, but unless you have some general concepts which correlate and make the statistics meaningful, you do not have understanding. But when we *do* understand the laws which underlie the facts, the facts come to life. What is more, only then can we predict the relationships between facts and new facts, and only then can we predict with confidence the future behavior of nature.

Because we know the laws of motion and gravitation with astonishing accuracy, the trajectory of a spacecraft headed for Mars can be predicted and come out very close to the prediction. Because we understand the laws of electromagnetism, we can predict with precision and confidence the behavior of a new electric power plant or a television transmitter. Because we understand quantum mechanics, we can understand the behavior of atoms and molecules, including the very complex molecules that make up human beings. Because we understand a small number of basic principles, we see the unity of science. We see that the laws which govern the most distant galaxies are the same as those which govern the behavior of living cells and of the atoms and molecules of which they are made.

And that, I trust, will be the principal lesson for today—that science and its companion technology are not many unrelated subjects; they are one.

Once these three branches of science—the universe, the atom, and life—seemed to have very little relation to each other. But today we know better. These three fields are unified by a comprehensive set of principles which ties them all together, which makes sense out of the knowledge we have acquired, and which makes possible a more systematic quest for new knowledge.

We don't understand it all, but we do understand enough to see the unity of these basic principles and know that more basic principles await our examination and discovery.



THE EXCITED UNIVERSE

by William A. Fowler

A progress report on studies at Caltech and elsewhere on the frontiers of astronomy and astrophysics.

All of us have looked up at the sky on a dark, clear night. If we watch awhile, the stars seem to march steadily and majestically across the sky; the starry heavens appear serene and calm. Nothing could be farther from the truth! Telescopes and other instruments—on the ground, in balloons, in rockets, and in satellites—reveal to the astronomer and the physicist quite another picture, a picture of an excited universe in which exploding stars and exploding galaxies play dramatic and important roles.

A revolution in astronomy and astrophysics has taken place since World War II. In this period, optical astronomy—the study of ordinary light from celestial objects—has made great progress. But even greater progress has

"We work very hard
in our terrestrial laboratories
to understand what is going on
in the excited universe,
but so far our ignorance
is matched only by our bewilderment."

been made in other fields. It has been found that celestial objects emit radiation all across the electromagnetic spectrum—radio waves, infrared waves, x-rays, and gamma rays. Radio waves and infrared waves have longer wavelengths and lower intrinsic energy than ordinary light waves. X-rays and gamma rays have shorter wavelengths and higher intrinsic energy.

The principal heroes of this revolution have been the radio astronomers. The discovery of radio emission from galaxies, from the starlike objects called quasars, and from the newly discovered objects called pulsars has opened up a new era in astronomical observations and theory. We work very hard in our terrestrial nuclear and atomic laboratories to understand what is going on in the excited universe, but so far our ignorance is matched only by our bewilderment. This, then, is a progress report on studies at Caltech and elsewhere on the frontiers of astronomy and astrophysics.

All of these new and exotic radiations involve the emission of energy from atoms and nuclei or from swift electrons moving in strong magnetic fields. They represent the methods by which objects in the excited universe are de-excited—methods by which their apparently enormous supplies of energy are released into the vast reaches of space.

One of the principal questions raised by all these new observations is: What is the ultimate source of energy for these prodigious emissions of radiation? Is it nuclear energy, gravitational energy, or some new and unknown source of energy?

Nuclear energy is the basic source of power in ordinary stars. Stars are born, evolve, and come to a variety of untimely ends. During their lifetime, they shine on energy generated by the process of nuclear fission. Stars are truly nuclear furnaces.

The way in which stars operate as nuclear furnaces is one of the most exciting and important problems in science today. There are two reasons why. One, we know that nuclear fusion processes generate the energy which makes stars shine with an enormous output of light and heat. With our nuclear reactors we have successfully harnessed what we call nuclear fission, but we have not succeeded in putting nuclear fusion to work. We can study fusion in our laboratories, but so far we just cannot make it work on a practical scale as a source of power. Thus our studies of the nuclear fusion that takes place in the sun and other stars have long-range implications for all of us.

There is a second reason. Nuclear processes generate energy by changing one elementary form of matter into another. We often speak of these processes as the "transmutation of the elements." This was the age-old dream of the alchemists, and in the 20th century this dream has come true. In our laboratories we can change one element to another on a small scale, and in our fission reactors on a large scale.

On a far grander scale, fusion is transmuting elements in the stars. This has led us to the belief that perhaps all of the heavier elements, such as carbon, oxygen, iron, lead, and uranium, have been built up in stars from the lightest of all the elements—hydrogen—which we take to be the primitive material with which the universe began.

Let us now examine the role played by stars and galaxies in the generation of energy and in the creation of new elements.

Many of the observations on the astronomical universe have been made with the magnificent 200-inch telescope on Mount Palomar. The largest systems seen with telescopes of this type are called clusters of galaxies. If you look in the direction of the constellation *Virgo*, but far back of it, you see the Virgo Cluster of associated galaxies. Our own galaxy, the Milky Way, is in the so-called local group, which contains 16 other galaxies. Unfortunately we are imbedded in our own galaxy so we can't get an over-all view, but we know that our galaxy looks very much like its twin, the spiral Andromeda Nebula. Also unfortunately, we can't even see the center of our galaxy because of the large amount of obscuring gas and dust between us and the center.

Here I want to emphasize the exchange of matter between stars and the interstellar medium, which is filled with gas and dust particles. It is in the stars that the nuclear reactions by which energy is generated are taking place. It is in the stars that element synthesis takes place—the transmutation of one elementary form of matter into another.

It is in the interstellar medium, once this material is ejected by some kind of explosive phenomena, that the mixing takes place. Then, eventually, when new stars are formed by condensation, they not only contain the primordial hydrogen of the interstellar gas and dust but also contain the nuclear debris of the processes that have taken place in stars of previous generations.

What is the evidence that stars form? And what is the evidence that stars explode?

Evidence that stars form from the interstellar medium can be seen in the nebula in the constellation *Sagittarius*, located in our galaxy. This nebula of gas and dust is being illuminated by bright stars embedded in it, and it is reflecting light into the telescope and into our eyes. It is always in regions where there is a great deal of material from which stars could be formed that astronomers find the newly formed stars, which can be very bright—so bright, in fact, that they are exhausting their nuclear fuels on a very short time scale. This means that they must be young.

With this indirect evidence, namely that young stars are always found associated with great clouds of gas and dust, we believe that stars are forming in the galaxy all of the time and have been since the formation of the galaxy itself.

So now stars have formed. What happens to them?

Our galaxy looks very much like its twin, the spiral Andromeda Nebula. If our solar system were located in Andromeda, we would be somewhere halfway out from the central nucleus, nestled in the inner edge of one of the spiral arms.

"A revolution in astronomy and astrophysics has taken place since World War II . . . The principal heroes of this revolution have been the radio astronomers."

Just imagine that we are down deep in the interior of the sun, where the temperature is something like 15 million degrees. We know that the sun consists primarily of hydrogen and helium, with some mixture of heavier elements—only about 1 percent in total—which has been produced in previous stars. We are uncertain concerning the origin of the sun's primordial helium. It may have been produced in previous stars, or it may have been produced in the "big bang" at the beginning of the expanding universe.

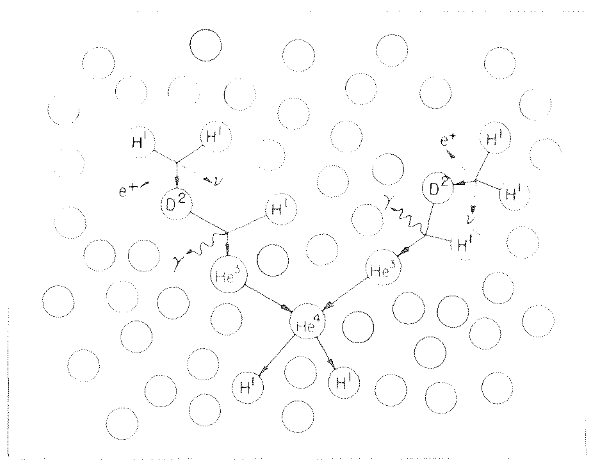
Because of the high temperature, all the nuclei and electrons are moving at high velocity, and two hydrogen nuclei, called protons, can collide at these high velocities. When they collide, we know that positrons and neutrinos are emitted. The main point, however, is that the nucleus of the heavy isotope of hydrogen, the deuteron, is formed. The deuteron has mass 2 on the scale used in nuclear physics. On this scale, the proton has approximately the unit mass or mass 1. The deuteron takes up the motions of the other nuclei and electrons, and eventually a deuteron collides with another proton. We know, from a reaction which we can study in detail in the laboratory, that when a deuteron and a proton combine with the emission of gamma radiation, they form a nucleus of mass 3, which turns out to be an isotope of the element helium, the second element in the periodic table.

For many years we didn't know what happened to the He^3 nuclei because they don't interact strongly with protons, and the deuterons are consumed mostly by their interaction with protons. We know from laboratory experiments that He^3 can collide with another He^3 produced in exactly the same way to form He^4 with two protons being given off. So six nuclei of hydrogen unite to form helium, and we get two of them back. The over-all result is that four hydrogen nuclei have been changed into a helium nucleus, and at the same time that this has been taking place energy has been generated. The mass balance is almost exact, but not quite. The He^4 weighs a little less than the four hydrogen nuclei, and by Einstein's principle, $E=mc^2$, the mass lost is converted into energy. In practical units, a pound of converted hydrogen gives 100 million kilowatt-hours of energy.

We have to work out detailed processes like this in the laboratory to tell astronomers some of the facts about the processes which they can use in their calculations of energy-generation and element-transmutation in the stars.

Actually this is a very old story. It was in 1920 that Arthur S. Eddington first suggested that the conversion of hydrogen into helium is the source of energy in stars. In 1920 Eddington's critics—and he had many of them because he was an outspoken man—pointed out to him that all these hydrogen nuclei are positively charged, and thus they electrostatically repel each other. They argued that even at the center of the sun the temperatures are not high enough that the hydrogen nuclei will have velocities great enough to overcome the electrostatic repulsions and thus form the deuterons and the He^3 and the He^4.

In 1920, when Newtonian mechanics was still the basis of physics, Eddington didn't



The fusion of ordinary hydrogen in the sun.

know the answer, but he had enough faith to give this reply to the critics: "We do not argue with the critic who urges that the stars are not hot enough for this process. We tell him to go find a hotter place."

Eddington's critics were saved from their fate by quantum mechanics, which tells us that even though the electrostatic barrier between two positively charged particles is a very great one, there is a finite probability of penetrating this barrier and forming compound systems.

To show how close the ancient Greeks were to these ideas, this is what the Greek philosopher Leucippus is reported to have said more than 2,500 years ago:

> They [atoms] move in the void and catching each other up jostle together, and some recoil in any direction that may chance, and others become entangled with one another in various degrees according to the symmetry of their shapes and sizes and positions and order, and they remain together and thus the coming in being of composite things is effected.

I don't know if we have really learned very much in the last 2,500 years or not. But the essential difference between the Greek philosophers and us is the fact that we can do experiments which show that these transmutations of the elements really come about.

In our laboratory at Caltech we use five electrostatic accelerators. In such devices we accelerate nuclei to velocities as great or even greater than they have in stars, and we study the details of the nuclear transmutations produced when these high velocity particles collide with stationary "target" nuclei.

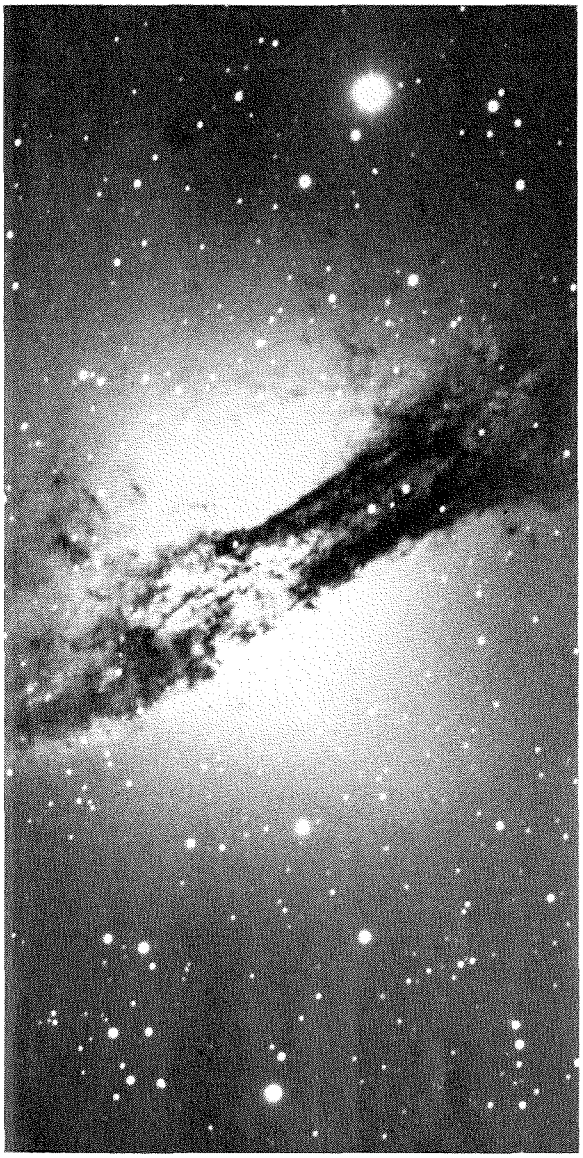
Now let us examine the idea that stars can eject their nuclear debris back into the interstellar medium. The most spectacular shape of this is the Crab Nebula, seen in the direction of the constellation *Taurus*. It is famous for the fact that in 1054 A.D. Chinese astronomers saw a new star appear where we now see the Crab Nebula. (We call these phenomena supernovae; they had a delightful term for it—"guest star.") And in the intervening period of 914 years the explosion has moved the material out from the central region. If you measure its velocity and size, you can show that in 1054 all of this material was back in a compact form—a star! We see no evidence for the central star that exploded, so presumably the whole star was disintegrated.

The Crab Nebula is the prototype of those celestial objects from which we can detect radiation from all across the electromagnetic spectrum. Radio astronomers find strong radio waves coming from the Crab, mostly from an extended region very close to the center. X-rays and gamma rays are also observed.

In addition to the luminous material, we think there are fast electrons moving in great spirals in the magnetic fields which thread all the nebula. And we know that electrons moving in the magnetic fields give off what is called synchrotron radiation—just as the electrons that we accelerate in our synchrotron accelerators give off radiation. This radiation covers the entire spectrum from radio waves through visible waves into the x-ray and gamma-ray regions.

The Crab Nebula, which consists of the expanding debris of a supernova that appeared in 1054 A.D., is the prototype of those celestial objects from which astronomers can detect radiation from all across the electromagnetic spectrum—radio waves, x-rays, and gamma rays.

There have been three supernovae in our own galaxy in the last 1,000 years—the one in



The elliptical galaxy Centaurus A is typical of what the optical astronomer finds at the point where the radio astronomer says there is a source of radio emission. This is a mixture of 1,000 million stars. Some catastrophic event produced the dust lane which circles the galaxy. The radio-emitting region of this galaxy is enormous compared to the size of the galaxy itself.

1054 observed by the Chinese, one in 1572 studied by Tycho Brahe, and one in 1604 studied by Johannes Kepler. Nowadays we see supernovae mostly in galaxies other than our own. In 1966, ten supernovae were discovered, so we can and do study supernovae occurring frequently—10 to 20 a year—in other galactic systems.

Caltech's radio telescopes, in the Owens Valley in California, are used by radio astronomers in somewhat the same way a human being uses his ears—to pinpoint the location of the radio emissions from outer space. Because of the instruments in locations all over the world—in Australia, England, Holland, Russia—radio astronomers can tell the optical astronomer, "There is a source of radio emission. Look and see what you can find there."

Typical of what the optical astronomer finds at the point where the radio astronomer says there is a source of radio emission is an elliptical galaxy called *Centaurus A,* observed in the direction of the constellation *Centaurus.* It has always been known that this galaxy is rather strange—a mixture of 1,000 million stars with a great dust lane that circles the galaxy and which is absorbing the light. Some type of terrific catastrophic event which happened in its history produced this dust lane and the radio emissions. The radio-emitting region of this galaxy (a galaxy comparable in size to ours) is enormous compared to the size of the galaxy itself.

The electrons and magnetic fields were ejected perpendicular to the obscuring material which forms the dust lane, and now synchrotron emission in the form of radio waves comes from two patches above and below the plane of the dust lane.

Even these radio galaxies are not the most exciting things that the radio astronomers have found. They also found the quasi-stellar objects called quasars. They are radio sources which, when viewed by the optical astronomer, look very much like a star. When the optical astronomer looks carefully at quasi-stellar objects, he finds they all show a very large red shift. That is to say, the optical lines which the astronomer sees in the emission from the object are shifted to the red in color.

The kind of evidence astronomers have gotten from studying the red shift of ordinary galaxies led to Hubble's Law: The more distant the object, the greater the red shift of its radiation. Previous to the discovery of the quasars this had only been found in galaxies. But with the discovery by Maarten Schmidt of Caltech of the quasi-stellar object, red shifts many times greater than are found in the most distant galaxies have been found in the quasi-stellar objects.

One of the most distant quasi-stellar objects that has been found so far is 3C191 (which means it is the 191st object in the third catalog of the Cambridge Radio Observatory in England). In its spectrum the lines of hydrogen and carbon are shifted to the point where their wavelength is three times that of the wavelength of the corresponding light that we can study in the laboratory. This means that the red shift is about 2, whereas all of the galaxies that have been studied previously have red shifts of, at the most, 3 to 4.

So, on the basis of the interpretation of the red shift (and this is not accepted by everyone) as implying greater distance, these quasi-stellar objects are the most distant things that we find in the universe. And being very distant means that in order to give the amount of radiation which we receive, they intrinsically must be pouring out a great amount of radiation at their sites.

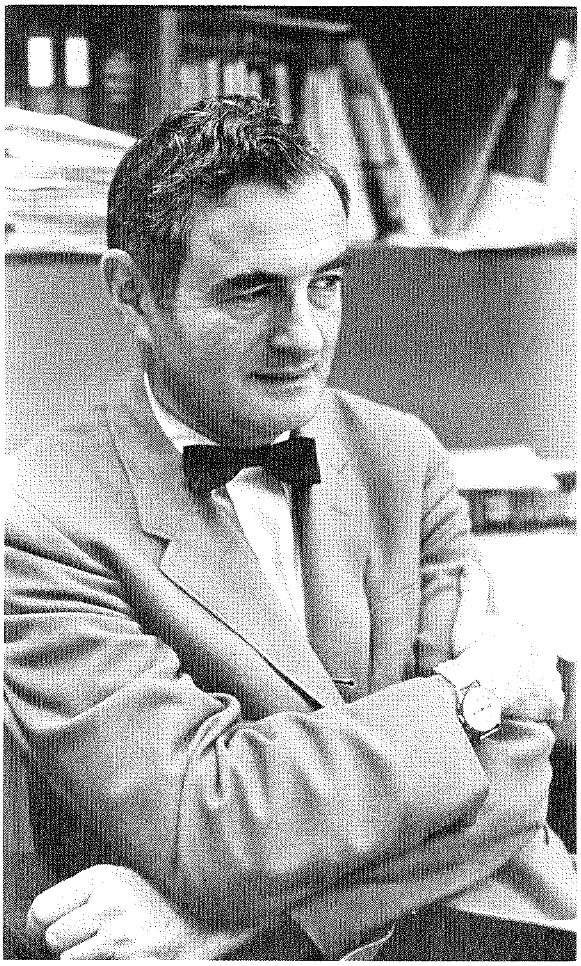
We would all be very skeptical of this if it wasn't for the fact that with the discovery of the quasars optical astronomers began to look at strange systems, such as the galaxy called M82. By studying M82, Allan Sandage of Caltech was able to show that there was an explosion in it, something like five million years ago, and the total amount of material ejected is something like five million times the mass of the sun.

We know, intuitively almost, that the large amounts of energy involved in the quasar emissions must involve large masses that have been ejected from some kind of an explosive, violent event in the galaxy.

Five years ago Fred Hoyle, Plumian Professor of Astronomy at Cambridge, and I were thinking of where the energy comes from that throws out this enormous amount of gas, and we came up with the idea that nuclear reactions couldn't possibly do it and that perhaps it was gravitational collapse, followed by explosion of the outer material around a central, imploding, gravitationally collapsing core. I talked about it at a meeting of the American Physical Society, and afterwards reporters talked to me. Two weeks later I picked up *Time* magazine (February 8, 1963) and read: "Astrophysicists Hoyle and Fowler from Caltech told the American Physical Society that galaxies *often* explode with *improbable* energy."

"Radio astronomers have just observed radio pulses at several points in the sky which come in remarkably steady periods of the order of one second . . . It is almost certain that these pulses arise somewhere in our galaxy but definitely from outside the solar system."

You may think that all I have told you is highly improbable. This could well be true. But there has recently been a discovery which seems more improbable. Radio astronomers at Cambridge, England, have just observed radio pulses at several points in the sky which come in remarkably steady periods of the order of one second. For one of the pulsing sources, or pulsars as they are called at the moment, the period has not varied by one part in one million over the six months since its first detection. It is almost certain that these pulses arise somewhere in our galaxy but definitely from outside the solar system. Numerous suggestions concerning the nature of the pulsars have already been made. Some think that the pulses come from vibrating white dwarfs, which are very small, very dense stars, or from vibrating neutron stars, which are even smaller and even more dense. There are even those—and I refer to respectable scientists—who think that the pulses represent signals from some advanced civilization somewhere in the galaxy. But in any case, here is one more example—a very current one—of the *excited universe* I have been talking about.



"The living organisms of today have had the benefit of two billion years of selective molecular evolution. Soon we shall have that cumulative ingenuity at our fingertips . . . and with it not only the power to alter the natural world, but to alter our very selves."

Sometimes in the din and gore of a Vietnam, in the fury of a ghetto riot, or even in the drab tension of a traffic snarl, it becomes difficult to remember our larger purposes—our ancient and endless need to understand the deeper sources of these festering trials. And the deepest source, the root cause, lies surely in our own nature, in the nature of man.

That the nature of man has been at once the source of his triumph and the seed of his tragedy has been evident since the Greek philosophers, if not before. In the lines of Alexander Pope:

> Know then thyself, presume not God to scan.
> The proper study of mankind is man.
> Placed on this isthmus of a middle state,
> A being darkly wise and rudely great.

And this is even more true in a world increasingly subject to man's dominion.

There are, of course, many ways to view the nature of man, but with all due respect to the philosophers and the poets, the prophets and the playwrights, I submit that in a scientific and quasi-rational age it is appropriate and indeed valuable to consider man a part of the natural universe—as the latter-day product of two billion years of evolution and as an astonishing evocation of the remarkable potentials inherent in organized matter—yet of one piece with the electrons and the atoms and the molecules, with the waves and the particles that comprise the bulk of the cosmos.

Modern biology is now poised to provide a new and profound approach to the understanding of the nature of man. And with that understanding will come wholly new powers to alter man's very being. If we are to channel these powers to our intent and not to the hapless contrary, then we must soon, in commensurate degree, alter and enlarge our conception of the place of man and his potential.

This year, 1968, is the 100th anniversary of the discovery of nucleic acid by Fritz Miescher. Today we know that Miescher's material—deoxyribonucleic acid, or DNA—is the chemical substance of the gene—the carrier of heredity. The year 1868 was but three years after the then unnoticed publication of Mendel's now famous papers which in one stroke resolved the age-old riddle of inheritance. It was but nine years after the publication of Darwin's *The Origin of Species*, with its revolutionary doctrine of the evolution of living creatures that marked the beginning of the rational attempt to view man as a product of nature.

But no one could have foreseen that these seemingly disparate discoveries made within a short period of years would, 90 years later, flow together into a great synthesis that gives us the deepest insight into the molecular strategy of life and a coarse sense at least of the craft of evolution as the architect of biology. This synthesis has conceptually bridged the long-mysterious gulf between the world of the living and the non-living and thus permitted an easy acceptance of the continuity between the inanimate and the animate matter, based upon a calm understanding of the potential for life inherent in molecular organization. Today we understand the self-renewing structural order and molecular flux intrinsic to a living cell. This synthesis had, of necessity, to await a prior maturation of physics and chemistry—the sciences of matter. With their maturity, in the early part of this century, with the insight they provided into the nature of atoms and molecules, and with the techniques and instruments that could be devised with this knowledge—with the radioisotopes, the ultracentrifuge, the x-ray camera, and the electron microscope—modern biology could truly begin.

And it is because modern biology has sought understanding at the molecular level where it could rely upon the sure footing of physics and chemistry that we have made the dramatic, self-confident progress of the past two decades.

This synthesis had also to await the slow, growing realization that living systems are in fact, if gently and widely dissected, surprisingly dissociable. A priori, this was not self-evident. A living cell could have been such an intricately integrated device that the isolated individual parts would be largely inert and functionless. But it is not so. With increasing skill and knowledge, we can perform more and more functions of the cell with purified components reassembled in a test tube.

It is probable that this dissociability is in fact a necessary consequence of an evolutionary mode that has proceeded by independent, unitary steps. If the biochemical networks be-

DARKLY WISE AND RUDELY GREAT

by Robert L. Sinsheimer

"Walter, explain DNA just once more and I promise I won't ask you again."

came too tightly interwoven, even if more efficient, they would soon have come to an evolutionary dead end, incapable of unitary change. There is in this perhaps a moral to be observed in our modern social structures.

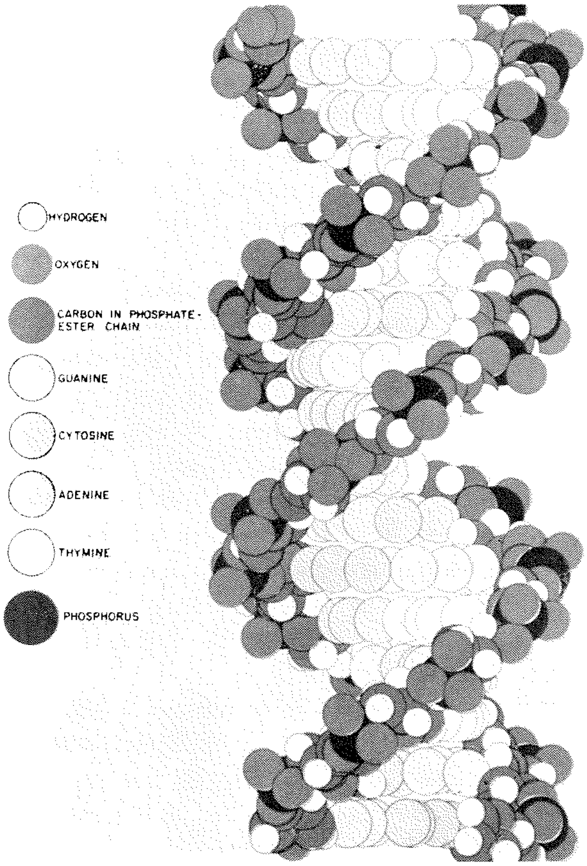
One relevant example of the dissociability of cellular function is the recent synthesis in a test tube of an intact, infective DNA molecule. One can only wonder if Miescher, fishing his nucleic acid out of an unknown soup of compounds with the crude chemistry of his day, could have foreseen the time when this nucleic acid would be combined with other functional cellular components, each carefully identified and isolated and purified, to bring about thereby, at will, a true molecular replication—the synthesis of new DNA molecules as exact copies of the old.

Now we all know what DNA is. Russell Baker, in his last list of New Year's resolutions, has as number seven: "Find out what the DNA molecule is." Of course, this came between number six: "Learn to speak Italian," and number eight: "Get an introduction to Sophia Loren." So there is some uncertainty as to what use he planned to make of this knowledge.

DNA is most often found as the now famous double helix. Each strand of the two-ply helix is composed of linked subunits, of which there are principally four kinds. And the two strands bear a defined relationship such that, if the sequence of units in one strand is specified, the sequence in the other is determined. The hereditary information is conveyed in a special code in the ordered sequence of subunits, which the cell, in effect, is able to read. Each gene, each unit of heredity, comprises a tract along this chain—a tract which may be several hundreds of subunits in length. Each cell must also, of course, be able to replicate these molecules to make an exact copy of each, so as to pass on the inherited information to each daughter cell.

And thus it has been, with gradual modifications, since the very beginning of life. For the code and the translation is the same in all life on earth.

In the dim world between the living and the non-living lurk the viruses. For these, too, the genetic substance is nucleic acid, sometimes in



DNA is most often found as a double helix—each strand being composed of linked subunits of principally four kinds. Hereditary information is conveyed in a special code in the ordered sequence of subunits.

curious and unusual forms. The simplest viruses consist of nothing more than nucleic acid and a protective coat. Upon invasion of the cell the coat is shed, and the viral nucleic acid—this foreign piece of genetic material—is seen as the true infective agent. It is possible under special laboratory conditions to dispense entirely with the coat and to accomplish penetration of the cell and infection with the free, viral, nucleic acid molecules alone.

The recent test-tube synthesis of DNA is an illustration of the capability of modern biochemistry to reproduce vital functions. The actual steps are few and not complex. The background knowledge behind these steps is considerable. The work, which was a collaborative enterprise between our Caltech laboratory and that of Arthur Kornberg at Stanford, started with a viral nucleic acid, a DNA.

For the sake of simplicity, we started with a small and unusually simple type composed of only one strand in the form of a ring. The actual DNA ring has some 5,000 subunits comprising about eight genes, and the circumference of the ring is approximately two microns, a micron being roughly one ten-thousandth of an inch. To these DNA molecules were added subunits—a small initiator molecule composed of a few appropriately linked subunits and two highly purified normal cellular components—two catalysts, enzymes normally concerned in the cell with the function of DNA synthesis, named, respectively, polymerase and ligase. The subunits of the original DNA and the free subunits always pair up in a particular complementary way. That they pair up in this way is determined intrinsically by their atomic geometry—by their electronic and molecular structures. The polymerase then progressively links the subunits of the newly forming chain as it grows around the old chain. However, the polymerase is unable to close such a chain; and thus the second catalyst, the ligase, is necessary to perform the final step.

In this way we can make a new ring—the same size as the original, but obviously not the same. Instead, the one we have made is the *complement* of the original ring. But now, in the laboratory, these two rings can be separated—the original from the complement. And after we isolate the complementary ring, we can start the process all over again using it as the template. Clearly, then, in the second

An electron micrograph of the DNA of the virus Phi X 174 that has now been synthetically produced for the first time.

round we will make *its* complement, which is now an exact copy of the original. The process is quite analogous to a negative and positive in photography.

It was just this synthetic copy of the original DNA that was obtained, and when this copy was tested, it was shown to be biologically active; that is, it was fully infective. It gave rise in the infected cell to normal progeny virus particles. The copied DNA looked just like the original. We had made, then, in a test-tube, a DNA which could serve as the progenitor of an indefinitely long chain of progeny virus from this day on throughout time.

The significance of this successful experiment is not simply that we have synthesized a viral nucleic acid, or that, having done so, we could now set out deliberately to introduce specific changes into our copy and to observe the subsequent effect on the nature of the virus—that is, to create modified forms at will. The significance is that the infectivity of the copy proves the accuracy of the whole process and proves that this process is open-ended. In principle it can be applied to any DNA, from a virus or a bacteria, from an amoeba or a mouse or a man.

The complexity, of course, becomes progressively greater. Six hundred thousand different DNAs would be needed to match the DNA content of man.

This is only a specific and a personal example of the power of our growing understanding of the world of life and of our growing competence to direct its processes to our ends. The living organisms of today have had the benefit of two billion years of selective molecular evolution. Soon we shall have that cumulative ingenuity at our fingertips as well as *in* our fingertips, and with it not only the power to alter the natural world but also the power to alter our very selves.

For we have learned not only to copy a virus, but we have learned to understand—at least in bold outline—the functional machinery of the living cell—the unit of life.

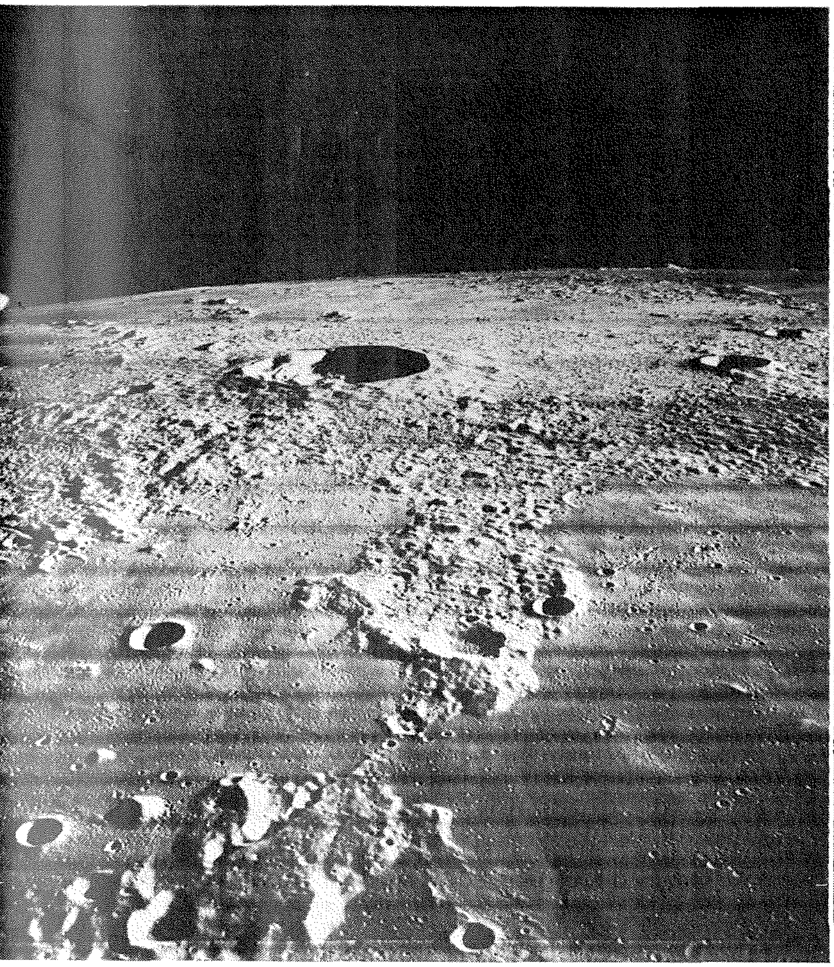
In a manner similar to our comprehension of nucleic acid replication, we now comprehend the principles of macromolecular architecture and the basic tactics of molecular recognition and of self-assembling systems. We understand the means of molecular information storage and expression, and the adroit use of a common energy currency. We appreciate the vital role of the processes of molecular repair and the pervasive importance of the phased, interacting cybernetic systems of molecular control that preserve balance and proportion. All of these together form the material basis of life.

It is of the greatest significance that these basic vital patterns of organization are essentially similar in all forms of life—including man. All of life on earth has evolved progressively, though in gradually divergent ways, from a common source. This kinship, this continuum of life, was first demonstrated by Darwin, largely with morphological evidence. But today we can document evolution anew on the most basic level—in the universality of all hereditary codes and in the detailed structure of common proteins.

It is even possible to recognize in our very molecules the traces of our descent from incredibly ancient progenitors, to whom all superficial resemblance was lost ages ago. It is possible to trace through the tens and hundreds of millions of years the progressive molecular changes that have permitted adaptation to more varied circumstance and allowed the evolution of life to a greater scope and freedom.

In the molecules of hemoglobin—the essential oxygen-carrying protein in our red blood cells—there are two large subunits called alpha and beta hemoglobin. The alpha subunit is a folded linear chain composed of a sequence of smaller subunits called amino acids. In nature there are some 20 different kinds of amino acids, and all proteins are composed of these same 20. In any particular protein there is a particular selection of these amino acids arranged in a particular and specific linear order.

It is the number, frequency, and sequence of its amino acids that determines the properties of the protein, whether it is a hemoglobin or an insulin or a cytochrome or a polymerase. In the amino acid sequence of the alpha chain of normal human hemoglobin, there are some 141 amino acids beginning with valine and ending with arginine. Each can be specified by an abbreviation of its name. This is known from modern biochemistry. We can similarly analyze the amino acid sequence of



The mysterious and unfamiliar terrain of the moon (left) and the interior of a simple cell (right), unknown in detail until recently, have now been mapped. Herein, perhaps, lie the keys to the mysteries of the universe and of life.

the alpha chains of the hemoglobins of other animals. When this is done for a related primate, such as the gorilla, one finds that the sequence differs in only one amino acid from that of the human hemoglobin. A glutamic acid has been replaced by an aspartic acid in *one* place. The rest are the same. If the amino acid sequence of the alpha chain of hemoglobin of a chimpanzee is analyzed, we find that it is identical with that of the human.

But not all hemoglobins are similar. As we go further back along the evolutionary course and examine the hemoglobin of species that have been on divergent paths from man for a longer time, we find increasing distinctions.

The evolutionary relationships between various animal species can, in fact, be firmly demonstrated in the molecular relationships of the alpha chains of their hemoglobins. The more closely related the species, the more similar are the hemoglobins; the more distantly related, the more disparate are the hemoglobins. In the alpha chain of the hemoglobin of the horse, there are some 18 differences from that of the human. Horse and human have been on separate evolutionary paths for quite a long time. Conversely, 123 amino acids that are common to the human hemoglobin and the horse hemoglobin must in all probability have been present in the hemoglobin of their common ancestor at some remote time. The alpha chain of the mouse hemoglobin also has some 18 differences from that of man. Interestingly, however, these are not the same 18 as are found in the horse. Indeed if one compares the horse and the mouse hemoglobins, there are 23 differences.

Hemoglobin only appeared in the course of evolution with the rise of vertebrates. Can we find traces of even older evolutionary ties? For this we must turn to an even more vital and ubiquitous protein—to the cytochrome found

Comparisons of the Amino Acid Chains of Cytochrome C from Various Species.

HUMAN

Gly · asp · val · glu · lys · gly · lys · lys · ilu · phe · ilu · met · lys · cys · ser ·
gln · cys · his · thr · val · glu · lys · gly · gly · lys · his · lys · thr · gly · pro ·
asn · leu · his · gly · leu · phe · gly · arg · lys · thr · gly · gln · ala · pro · gly ·
tyr · ser · tyr · thr · ala · ala · asn · lys · asn · lys · gly · ilu · ilu · trp · gly ·
glu · asp · thr · leu · met · glu · tyr · leu · glu · asn · pro · lys · lys · tyr · ilu ·
pro · gly · thr · lys · met · ilu · phe · val · gly · ilu · lys · lys · lys · glu · glu ·
arg · ala · asp · leu · ilu · ala · tyr · leu · lys · lys · ala · thr · asn · glu ·

TUNA FISH

Gly · asp · val · **ALA** · lys · gly · lys · lys · **THR** · phe · **VAL** · **GLN** · lys · cys · **ALA** ·
gln · cys · his · thr · val · glu · **ASN** · gly · gly · lys · his · lys · **VAL** · gly · pro ·
asn · leu · **TRP** · gly · leu · phe · gly · arg · lys · thr · gly · gln · ala · **GLU** · gly ·
tyr · ser · tyr · thr · **ASP** · ala · asn · lys · **SER** · lys · gly · ilu · **VAL** · trp · **ASN** ·
ASN · asp · thr · leu · met · glu · tyr · leu · glu · asn · pro · lys · lys · tyr · ilu ·
pro · gly · thr · lys · met · ilu · phe · **ALA** · gly · ilu · lys · lys · lys · gly · glu ·
arg · **GLN** · asp · leu · **VAL** · ala · tyr · leu · lys · **SER** · ala · thr · **SER** · . . .

MOTH

Gly · val · pro · ala ·
GLY · asn · ala · **GLU** · asn · **GLY** · **LYS** · **LYS** · **ILU** · **PHE** · val · gln · arg · **CYS** · ala ·
GLN · **CYS** · **HIS** · **THR** · **VAL** · **GLU** · ala · **GLY** · **GLY** · **LYS** · **HIS** · **LYS** · val · **GLY** · **PRO** ·
ASN · **LEU** · **HIS** · **GLY** · phe · tyr · **GLY** · **ARG** · **LYS** · **THR** · **GLY** · **GLN** · **ALA** · **PRO** · **GLY** ·
phe · **SER** · **TYR** · ser · asn · **ALA** · **ASN** · **LYS** · ala · **LYS** · **GLY** · **ILU** · thr · **TRP** · **GLY** ·
asp · **ASP** · **THR** · **LEU** · phe · **GLU** · **TYR** · **LEU** · **GLU** · **ASN** · **PRO** · **LYS** · **LYS** · **TYR** · **ILU** ·
PRO · **GLY** · **THR** · **LYS** · **MET** · val · **PHE** · ala · **GLY** · leu · **LYS** · **LYS** · ala · asn · **GLU** ·
ARG · **ALA** · **ASP** · **LEU** · **ILU** · **ALA** · **TYR** · **LEU** · **LYS** · glu · ser · **THR** · lys · . . .

HORSE

Gly · asp · val · glu · lys · gly · lys · lys · ilu · phe · **VAL** · **GLN** · lys · cys · **ALA** ·
gln · cys · his · thr · val · glu · lys · gly · gly · lys · his · lys · thr · gly · pro ·
asn · leu · his · gly · leu · phe · gly · arg · lys · thr · gly · gln · ala · pro · gly ·
PHE · **THR** · tyr · thr · **ASP** · ala · asn · lys · asn · lys · gly · ilu · **THR** · trp · **LYS** ·
glu · **GLU** · thr · leu · met · ilu · phe · ala · gly · ilu · lys · lys · lys · thr · glu ·
pro · gly · thr · lys · met · ilu · phe · **ALA** · gly · ilu · lys · lys · lys · **THR** · glu ·
arg · **GLU** · asp · leu · ilu · ala · tyr · leu · lys · lys · ala · thr · asn · glu ·

YEAST

Thr · glu · phe · lys · ala ·
GLY · ser · ala · lys · **LYS** · **GLY** · ala · thr · leu · **PHE** · lys · thr · arg · **CYS** · glu ·
leu · **CYS** · **HIS** **THR** · **VAL** · **GLU** · **LYS** · **GLY** · **GLY** · pro · **HIS** · **LYS** · val · **GLY** · **PRO** ·
ASN · **LEU** · **HIS** · **GLY** · ilu · **PHE** · **GLY** · **ARG** · his · ser · **GLY** · **GLN** · **ALA** · gln · **GLY** ·
TYR · **SER** · **TYR** · **THR** · asp · **ALA** · **ASN** · ilu · lys · **LYS** · asn · val · leu · **TRP** · asp ·
GLU · asn · asn · met · ser · **GLU** · **TYR** · **LEU** · thr · **ASN** · **PRO** · **LYS** · **LYS** · **TYR** · **ILU** ·
PRO · **GLY** · **THR** · **LYS** · **MET** · ala · **PHE** · gly · **GLY** · leu · **LYS** · **LYS** · glu · lys · asp ·
ARG · asn · **ASP** · **LEU** · **ILU** · thr · **TYR** · **LEU** · **LYS** · **LYS** · **ALA** · cys · glu · . . .

The evolutionary relationships between various species can be documented in the universality of the detailed structure of their common proteins. When the chain of 104 amino acids making up the cytochrome C of the human is compared to that of the tuna fish, 19 differences are seen (indicated here in bold face). In the horse there are 12 differences. When we compare *similarities* of the amino acid chains, yeast is found to have 64 in common with the human, and the moth has 77 in common with man.

in every cell, where it plays an essential role in the metabolism of nutrients to provide energy. The cytochrome of the human is a chain of 104 amino acids. That of the Rhesus monkey is identical with the human. The cytochrome of the horse has 12 differences from that of the human. Going farther back in time, the tuna fish cytochrome has 19 differences from that of the human cytochrome and actually one less amino acid at the far end of the chain.

But since cytochrome is common to all cells, we can go farther back. If we examine the cytochrome of a still more remote species—an invertebrate, the moth—we find 26 differences from that of the human. In addition, four amino acids have been added at the near end and one deleted at the far end of the chain. But if we emphasize the *similarities*, we see how closely related the cytochromes of the human being and the moth are, even though the evolutionary paths relating to these two species must have diverged in a very remote time.

But we can go still farther back. In what far-distant era did the lines that led to yeast cells and man diverge? In the cytochrome of yeast we find there are five more amino acids at the near end of the chain and one removed at the far end. Of the remaining amino acids, 64 are identical to those in the human cytochrome. It is most reasonable to suppose that these same amino acids were present in the same position in the cytochrome of that unremembered common ancestor. Thus we bear, in every cell, the indelible imprint of a long-vanished, incredibly ancient past—our past.

When the historians of a hopefully more humane future look back at this, the 20th century, one may wonder what they will consider worthy of note. Our recurrent wars? Our ideological and racial fanaticism? Hardly likely! More likely they will recall that this was the century in which man first left earth or the century in which man first kindled nuclear fire. And they will surely recall that this was the century in which man first understood his inheritance and evolution, first saw clearly how he came to be. For the first time in all time, a living creature understood its origin.

No doubt I am biased, but of these I believe the last will seem the most extraordinary. The unimagined becomes reality. We are the heirs of Icarus; we have become the latter-day Prometheus. But even in the ancient myths men were men and the gods were gods, and man could not rise above his nature to chart his destiny. Now we can begin to confront that chance and choice; soon we shall have the power consciously to alter our inheritance, our very nature. Not even the Greeks had a word for DNA.

But there is more to come. Whereas biology had to await the maturity of physics and chemistry, so we now believe that psychology, the science of the mind, has had to await the maturity of biology. We now comprehend life as a manifestation of inherent properties of organized matter, and we have a belief that we will learn how to see mind as a further consequence of the inherent properties of organized matter—as a property of living cells highly specialized and intricately organized.

If we consider the brain as the seat of the mind, we now understand much of its basic physics and chemistry. We know of what it is made. We know the basic structure and properties of its unit cells. We do not yet know its superstructure. We do not yet know the connections and functional interactions, the complex integrations and cybernetics. But we do know increasingly well the substructure, its properties and its potentials—and this is an essential base and springboard for the future.

In recent research it has become increasingly clear from studies of vision and optical illusions and the processing of visual information in the brain, from the studies of color and of predictable color illusions, from studies of motivation, of imprinting and ethology that very much of our being is built into the brain from the beginning, in terms of preformed circuits and prescribed chemical transmitters and receptors. It is clear that so much is genetic, and thus it is reproducible; it can be studied and analyzed just as we have learned to analyze other genetic phenomena.

A short scientific film made in the laboratory of James Olds at the University of Michigan shows a rat learning his way about in a maze—a not entirely unfamiliar situation. At first he is not very skilled; he makes all kinds of mistakes and doesn't know where he is supposed to go. He goes up blind alleys, but eventually he gets to his goal. Then he wants to get back to the other end, but he doesn't know the way. However, he does increasingly well. With experience and motivation to get to each goal, he learns very quickly and remembers well. What was the motivation of this rat? What was his reward for which he performed so capably? The reward was nothing more than a small electric current sent into a microelectrode implanted into what is called a reward center in his brain. When the rat pressed the lever at each end of the maze, he received a pulse of current for three presses. After three presses, he had to return to the other end for more. He liked it; indeed, he liked it very much.

Such a current is one of the most powerful rewards known, and by coupling a task to this reward the rat is quickly motivated to learn a wide variety of procedures. These centers which bring about such strong positive reinforcing behavior are genetically built into the rat's brain in various well-defined regions. Similar centers are known in monkeys. The biochemical and physiological bases of the action of these centers are not known at present, nor has their psychological significance to the function of the animal as yet been defined. But there is certainly a strong suggestion that here is a direct clue to the origin of behavior.

I do not wish to imply that human behavior may be so simply engendered. But evolution is most often conservative—an add-on process. And as there are motivation centers in other primates, it is not a far inference to suggest that similar processes have some part to play among the causes and courses of human action. Other investigations are beginning to probe into the way in which the brain acts to analyze visual and other sensory input data, or into the stages and events in the deposition of memory traces. It becomes increasingly clear that there are built-in, inherited pathways for these processes, immensely complex but reproducible and subject to analysis.

In the past decade, man has learned how he came to be. In the future he will seek to understand understanding—to know how he comes to know. I believe that here, not in mescaline, lie the true doors to perception. Here, not in ancient scrolls, lies the path to the understanding of man. And here, not in carnage and strife, lies the greater promise for the future of man.

The great discoveries in genetics and the great discoveries yet to come open a new dimension of human potential, a new route for the improvement of man. There are surely the gravest of risks ahead in our use of this potential. The Cassandras of our time see this very well, sometimes with gray or black humor, sometimes with lament for a simpler age, sometimes in an essayist's alarm. Archibald MacLeish has written, in an essay entitled *When We Are Gods:*

> There is in truth a terror in the world, and the arts have heard it as they always do. It is the sound of apprehension. We do not trust our time because it is we who have made the time—and we do not trust ourselves as gods. We know what we are.

In part, I disagree. There is no terror in the known. The fear is that we do not know what we are. We fear the unknown within. We are, for better or worse, the one creature with reason. It is the mark of man, and we are committed to its path—committed to the unending use of reason to free us from the external tyrannies of nature and the internal constraints of our inheritance. If there is a hidden, fatal flaw, if behind reason there is the abyss, then it is our destiny and we can do no better. But it seems to me that all of knowledge speaks otherwise.

"The proper study of mankind is man," Pope wrote, seeing with a clear vision. But he was ahead of his time, for it is only now that the analytic study of man can properly begin. Some will be distressed by this view of man, and I would not presume that it is complete or final. It is part of our folly when we claim the one eternal truth of man. Nevertheless, I believe that this truth is a valid one for our time. It is our answer to the ancient exhortation at the entrance to the temple at Delphi, "Know thyself."

I also conceive that some such orientation of thought will be essential from this time on as a frame of reference if we are to use in a wise and wholesome, rational and constructive manner the potential implicit in the great discoveries of modern biology. We, mankind, are to have the opportunity to design the future of life, to apply intelligence to evolution. What an astounding chance and infinite challenge.

On yet another plane it seems to me that one underlying cause for the malaise of man for many millennia has been his seeming divorce from the rest of nature and the physical universe. Man has seemed a creature apart, a lonely alien "placed on this isthmus of a middle state."

This problem has been met in various ways over the centuries by various conceptions and theologies which have served to provide a rationale for man on which to base his existence. And thus these have provided, over moderate areas of the earth, that reasonably common set of aims and goals that is necessary for any coherent society.

But today, in an age of science molded implacably by the triumphs of rational thought—if not always rationally applied—the older rationales come to seem unsuited, and to many, unacceptable. Many need a newer charter for man.

Perhaps we can provide a new anchor for man in a lucid understanding of our roots in nature—in the clear demonstration that man in his complex and often erratic behavior is, in fact, the logical outcome of his evolutionary origins; in the conception that we are in and of nature, an extraordinary product of unfulfilled and perhaps undreamed potential. But we are not alien.

And, as "darkly wise and rudely great" we climb, arduously, out of ignorance, out of the shadowed depths, to look back from time to time may help us to understand where we are. And to see how far we have come can help us to sense how very far we may yet advance.

In the words written in an old church, "You are a child of the universe, no less than the trees and the stars. You have a right to be here."

Life Without Father —the Future of Genetic Control

by James Bonner

One of the great triumphs of biology in recent years has been finding out in molecular detail how living things work. Here, briefly, is the take-home lesson about how a cell operates and what its strategy is—the strategy of life.

A cell in a very real sense is the smallest unit of living material, the smallest unit of an organism which can multiply itself and make two new objects like itself.

We know that the reason the cell is alive and can pass on its characteristics to its progeny is that each cell has in it a complete recipe about how to make all of the things that it takes to put inside the cell. This recipe is the genetic material, and it is written in the language of DNA.

Before the cell divides into two, the DNA must replicate itself to form two new identical copies of the recipe, so that each daughter cell can get a copy of the whole. In order for the DNA to replicate itself, it is necessary to have the building blocks for DNA-making.

In the good old days—or maybe I should say the bad old days—about 3.5 billion years ago, the first lonely little DNA molecule appeared in the aboriginal soup of the ocean made by random chemistry. That DNA molecule could replicate itself using the building blocks which were also present in the aboriginal soup, because in those far-off days there were no living organisms to eat up organic molecules.

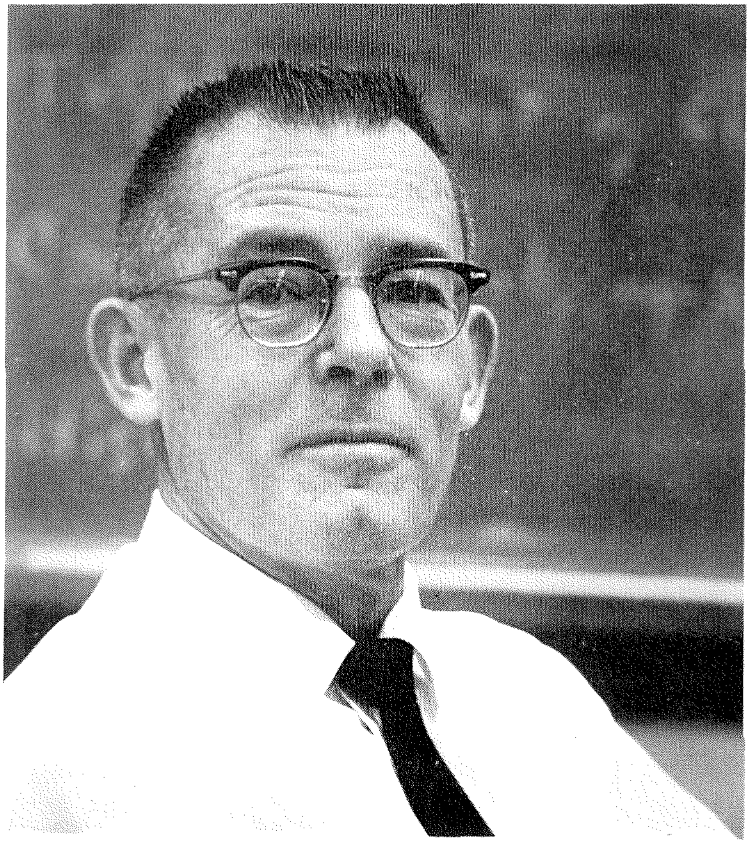
Today when a DNA molecule wants to replicate itself, it has to make the monomeric building blocks for replicating by itself. They are not available in the outside world. An organism has to make the material which it is going to use to replicate its DNA. And basically, in all cells and organisms, all of the machinery in the cell—except for the DNA itself—is merely machinery for making the building blocks so that the DNA can replicate itself.

This is the way the DNA goes about its task of making the building blocks so it can replicate: DNA is divided into message units (each message unit is a gene) and each unit contains information about how to make one particular kind of enzyme molecule—one particular kind of protein. The duty of those protein enzyme molecules (in a typical cell, there are a few thousands) is to transform the available kinds of food molecules into the materials necessary to make more enzyme molecules. And the machinery is there so that the duty of some kinds of enzyme molecules is to transform the available food into building blocks for DNA replication.

So it is as simple as that. The DNA makes enzymes, and the enzymes take the food and make it into the building blocks so the DNA can replicate so there can be more cells.

Now, if we are a simple organism like some miserable bacterium in which all cells are identical, that is all there is to it. The bacterium has about 2,500 genes for making 2,500 different kinds of enzymes, and the majority of those genes are continuously and at all times during the life of the cell making all the kinds of enzymes contained in that cell.

But let's not look only at microorganisms. Let's look at impressive creatures like ourselves or pea plants. Pea plants are more impres-



"Maybe some day your doctor will say, 'Well I think your heart isn't so good now. We had better start growing you a new one, and in two or three years it will be grown, and we can plumb it in.'"

—JAMES BONNER

sive than we are because they have twice as much DNA per cell as we do. The reason they have all that genetic information is that they have to know more organic chemistry, because pea plants (and indeed all plants) have to be able to synthesize all of the materials required for making cells out of the simplest of materials—carbon dioxide, inorganic nitrogen, a few inorganic minerals, and sunlight.

Even the cleverest physicist or chemist cannot make all of the building blocks that he requires. He has to eat plants in order to get the amino acids which he needs for making enzyme molecules.

In complicated creatures such as ourselves, there are about a trillion cells living together in harmony. These cells are of many different kinds—epidermal cells, nerve cells, muscle cells, and all the other kinds it takes to make us work.

It is odd when you think about it, because each of us starts out from a single cell—a fertilized egg which divides into two, then into four, and then multiplies and multiplies. And gradually, during the course of development, the cells which were originally all alike start to become different from one another and turn into specialized cells.

This problem of how a complex adult creature arises by the multiplication of a single cell is the problem of development and differentiation. Before we understood the nature of cell operation, about all that could be done was to observe that there *is* such a phenomenon as development and differentiation. That is the science of embryology. Today, however, we can try to find out the molecular basis of what it is that causes cells to become different from one another during the course of development.

When we look at the developmental process in the light of our new knowledge of molecular biology, we find that in higher creatures (like us) all the different kinds of specialized cells have the same amount and kind of DNA. This means each cell contains *all* of the genetic information about how to make the whole creature. This isn't immediately obvious, so let me tell you about a clever experiment that shows dramatically how this is so. In this experiment my former colleague John Gurdon, now at Oxford University, uses *Xenopus laevis*, the South African clawed toad. He takes the cells of the lining of the intestine (specialized cells that are never going to divide again but are just going to sit in there and make digestive enzymes for the toad, ultimately die, and never leave any progeny) and scoops out the nucleus that contains all of the genetic material. He then takes that genetic material and puts it into the cytoplasm of an egg of the toad. He has previously scooped the nucleus out of this egg.

When this body-cell nucleus is put into the environment of an egg, with all of the egg goodies in it, it thinks that it must be an egg nucleus, and so it starts to make more DNA and to divide. And from this egg containing the genetic material from a body cell develops a tadpole and then the adult *Xenopus laevis*.

So then, all of the genetic information about how to go through the whole developmental and reproductive cycle of an adult animal is contained in the specialized body cell.

Since there are many different kinds of specialized cells in an adult organism, each containing all of the genes for making the whole organism, it is apparent that in a given kind of specialized cell most of the genes must be turned *off*—that is, not making their gene product.

For example we have the genes for making the two hemoglobin proteins polymerase and ligase. Those genes produce the hemoglobin proteins only in a very restricted number of cells—those that give rise to the red blood cells. Those same genes which are present in each of our body cells are turned off everywhere else. How lucky! Otherwise we would make hemoglobin on the outside of our bodies.

In order to find out about how the developmental process works, we see immediately that we should focus our attention upon what makes it possible for some genes in the cell to be turned off (repressed), and in other cells to be turned on (derepressed). Next we need to learn how a gene that is turned off can get turned on again. And finally, to study development we ought to find out something about how the programming of genetic activity works. Clearly there must be, in the genetic material of the organism, some further system that provides that the right genes be turned off and on in the right place in an orderly sequential way, so that the right specialized cells end up in the right places to make an adult organism.

Obviously this programming of gene activities must reside in the genetic material, because our adult form is hereditary, and everything hereditary is contained in the DNA.

During the last few years, biology has made a considerable amount of progress in understanding all three of these aspects of the developmental process. This is, in part, because the functions of the cell are divisible and separable from one another. We know how to remove the genetic material from the cell and put it into a test tube—out in public where you can see what it does and where you can diddle with it and find out about the chemistry and physics of this material.

We have found that in any given kind of specialized cell of a higher organism *90 percent or more* of the DNA is turned off and unavailable for expressing itself by making its protein products. It is turned off by one kind of enzyme—one of many thousands of kinds of enzymes in a cell—whose duty it is to sit on the DNA and make that DNA be turned off. These repressive proteins are very similar in all organisms, from humans to the lower organisms.

In addition, we have found out something about how the switching of gene activity is controlled. We know that there are small molecules which can enter a cell and cause genes which were previously turned off to be turned on again. One example of such molecules are the hormones. The hormones are simple chemical substances which have only a few dozen atoms in them, so they are simple enough to be studied by chemists.

Hormones are made in a particular spot in the body, and then they go to other spots called "target organs" where they evoke certain effects. For example, the adrenal cortical glands make the hormone cortisone. The cortisone enters the bloodstream, goes to the liver, and says, "Liver, make me some of each of the following 12 enzymes." There are 12 genes in the nucleus of each cell in the liver which have been repressed and which are then derepressed by the arrival of the cortisone. So the cortisone does its work by entering the cell and, after a series of intermediate steps, complexing with the genetic material and removing the repressors of the genes which are to be derepressed.

We know that many different classes of small molecules besides hormones have the same effect. They can enter the cell and transform the genes from the turned-off to the turned-on state and vice versa.

There is one other important concept in the programming of gene activity that contains two basic principles. The first is that in some instances, when a particular gene is turned on, the product of that gene can then go and turn on a second gene. So there are chains of a successive turning-on of one gene, resulting in the turning-on of a sequence of genes.

The second principle is illustrated by the following: Suppose we want to study about how the orderly development of an organism occurs. I have found that a good way is just to imagine that you are a cell and think about what kind of instructions would enable you to divide and divide and turn into something sensible.

We know that cells in the developing organism are continuously monitoring their environment and seeing what kinds of things are out there, and as a result they are turning on the right genes to develop into the kind of cell appropriate to that environment.

Let me just give you a very simple example of how this *developmental test* works in a particular organism. A potato tuber is made of cells just lying doggo waiting for somebody to come along and eat them. Essentially they have all their genes turned off. But if you cut a thin slice out of a potato tuber, the cells at the edge of the slice all get busy and start dividing trying to make a new skin.

We can imagine the cells in the potato tuber each day monitoring the outside and saying, "Aha, there are potato cells everywhere, and it says here I'm not supposed to do anything." But one day they look out and the cells at the edge say, "Aha! I have potato cells on one side and nothing on the other side. And in that case, it says here, 'Go to page 47—or to gene 47. There are the instructions on how to turn on the right genes for becoming new epidermal cells.' "

It does no good to preserve
the other parts of the body intact
if the head goes to wrack and ruin.

The way potato cells tell whether they are on the inside or the outside is that they are continuously producing a diffusible substance; as long as the potato is whole, that substance diffuses very slowly. Its high concentration is what turns off the genes of the tuber cells. But as soon as it is cut, the substance diffuses away from the cells on the edge. That results in the turning-on of the correct genes for the epidermis.

Even more dramatically, if a single potato cell is put all by itself in a nutrient solution that contains the embryonic growth goodies that plant embryos grow up in, that single cell will turn into an embryo, develop into a seedling, and go through the whole life cycle of growing into a higher plant.

We know enough about the developmental process to realize that it will one day be possible to know *so much* about it that what is left to find out won't be interesting. We will know enough about the developmental process to be able to use this information in very specific and useful ways.

Let me cite some examples: We know that many lower organisms have embryonic cells left at the base of the limbs which, if the limb is lopped off, can then regenerate a whole new limb or a whole new organ. And we know now how to take a cell—as in the case of the toad or the potato—and change its stance of gene activity to make it think it is a fertilized egg. So in the future we should be able to reset the genetic program of a cell to any desired point to make that cell or group of cells turn into a new organ. Maybe someday your doctor will say, "Well, I think your heart isn't so good now. We had better start growing you a new one, and in two or three years it will be grown and we can plumb it in."

In a very real sense the regeneration of organs with the same genetic constitution as that of the potential recipient would, of course, have all sorts of advantages. We'd get around the whole host-rejection phenomenon.

One of the most troublesome problems in the longevity of human beings is concerned with the nerve cells which make up our brain. Each of us is endowed with ten billion nerve cells in our brain. They are given to us in embryonic life. In later life we never make any new ones. After the age of 35 or so they start to die off at the rate of about 100,000 a day. You don't notice it for a few days, but ultimately you do. Loss of memory and the senility of old age are due to this continuous dying-off of the nerve cells of the brain. They die because of little accidents in the circulation that deprive them of oxygenation. Maybe some of them get fallen on by fallout and all sorts of accidents like that. And it does no good for our National Institutes of Health to preserve the other parts of the body intact if the head goes to wrack and ruin.

We might try to fight this process. There are other cells in the cortex of the brain that are not nerve cells. So with our new knowledge of how to control the developmental process, we might hope to be able to judiciously turn the required number of both cells into the pathway that causes them to develop into new neurons and to replace the 100,000 that die each day by a new 100,000 neurons. Of course these new neurons would not contain any information—they would just be new empty neurons. But we are told today that we should spend one-third of our total time in continuing adult education or we will become obsolete. So maybe to have 100,000 nerve cells dying each day, removing obsolete information, would actually be a good thing. We could use the new nerve cells to help us learn all of the new information we have to keep constantly acquiring in order to avoid obsolescence.

The normal expectation would be that some better kind of creature will come along and make us extinct.

Then, most importantly, I would expect that our information about the developmental process, and indeed our whole new knowledge of the molecular basis of heredity, could be used to control man's evolution.

Since the beginning of life on earth, there have been more than 100 million different species of plants and animals invented by evolution. And 98 percent of them are now extinct. The normal expectation for a species such as our own is that we will ultimately become extinct too. That is the *statistical* likelihood, and it is not a very tasty prospect. We know from the works of anthropologists that there have been other species which have preceded us—like Neanderthal man—and he is extinct. He lived contemporaneously with *Homo sapiens* on earth, and we probably extincted him.

So the normal expectation would be that some better kind of creature will come along and make us extinct, were it not for the fact that we are the first species of organism to understand and, hopefully, to be able to control and direct our evolutionary processes.

Among the steps which our human species might take to improve its genetic endowment and its chances for survival are these: One is the controlled breeding of human beings in order to disseminate more widely the best genes. Another is to undertake vegetative reproduction of those individuals who possess desired characteristics. There is nothing to prevent us from taking two body cells from that same donor and growing two identical twins having the genetic constitution of the donor of the body cell. In fact, there is nothing to prevent us from taking a thousand.

Also in principle there is nothing to prevent us from growing any desired number of genetically identical people from individuals who have what we asses as highly desirable genetic characteristics. They won't, of course, have the learning and the wisdom of the donor. Learning and wisdom have to be acquired. Our genes give us the structure of our brain, not its thought content.

Those are some ways in which our knowledge of developmental and molecular biology could be used to improve our human race by improving its quality of genes. By the same token, as we acquire more information about the operation of the brain and about the optimum methods of teaching and training and educating and optimum modes of personality formation, we will, of course, extend these kinds of control of the environment over our young to expose them to the optimum influence for development of stable, intelligent, highly educated, highly motivated individuals. And when the time comes when we pursue these policies, we will have, indeed, a new and super species of human being.

In any case, it really appears to be within our power—if not today, then in the very near future—to cause our species to develop along any lines which we deem desirable.

We are learning a great deal today about the way information is carried by living organisms. And the temptation becomes very strong to apply that information. Indeed, throughout the whole course of the history of technology, there has been a lot of application without much thought of long-term consequences.

We might better understand the application of this information in the perspective of the long and varied history of our own planet. We now know that about 4,560 million years ago—give or take a few million years—a series of chemical and physical processes took place which led to the formation of our planetary system, and we know that planets of various types were formed. We think we understand what those types are in relation to the medium from which they were formed and in relation to the composition of stars generally.

But perhaps the most important thing we have learned is that this process almost certainly has not been unique. We have had systems of bodies being formed for many billions of years. If these bodies happen to be large enough, they ignite and we have stars; and if they are not large enough to ignite, we have cold bodies; and if those bodies happen to be in the vicinity of a star, there will be planets.

We know that there are three types of such planets: planets which are small, very dense, and composed primarily of rocklike substances and metals—planets like Mercury, Venus, Earth, and Mars. Add to that a lot of ice and methane and ammonia, and you will have planets like Uranus and Neptune; and add to that a lot of hydrogen and helium, and you will have planets like Jupiter and Saturn, which can be looked upon as sort of embryo stars. If they had become larger, they would have ignited, and we would be living in a planetary system with two or three suns. Or perhaps more precisely, we wouldn't be living.

The more we look into the early geochemical history of the earth, the more it becomes apparent that life is not a miracle, but that life arose as a natural end-product of a sequence of chemical events. Life arose on a planet which had certain characteristics conducive to this origin—first, a medium in which complex chemical reactions could take place and second, a temperature which was neither too hot nor too cold. If it is too hot, the complex

"If there is any meaning and purpose to life, it is learning what our universe is all about and what man's place in that universe is."

THE UNFINISHED CHAPTER

by Harrison Brown

compounds simply are not stable. If it is too cold, chemical reaction rates are so slow that reactions don't take place.

Now we can ask the question: Given a planet that is not too large (like Jupiter which is really an embryo star); that is not too small (like Mercury or the Moon which cannot hold onto a liquid or a gaseous medium on which chemical reactions can take place); that is not too hot (like Mercury where complex compounds won't be stable); that is not too cold (like Uranus or Neptune) so that reaction rates won't be too slow: What is the probability that life will arise? The evidence indicates that the probability is very high.

On earth there has been a beautiful sequence of developments starting with very primitive organisms, or with the first replicating molecule. Because all of them were exposed to ruthless selection effects and to dramatically changing environments throughout earth's history, certain developments took place. Perhaps one of the most important of the fairly recent ones was the oriented, controlled deposition of calcium, which enabled the existing organisms then to develop supporting and protective structures. This, in turn, combined with the emergence of the lung, enabled creatures to move onto the land. In sequence there appeared first amphibians, then reptiles, and then mammals. And finally, in a period which corresponds to but an instant of time, something brand new emerged which changed the entire course of evolutionary history. This was the emergence of what Julian Huxley called the power of conceptual thought—the ability to conceive of things, to solve problems, and to communicate with one's offspring in such a way that the whole process of learning becomes a cumulative process from one generation to the next. This power enabled man to invent weapons for hunting and fishing and tools for gathering food. Then it enabled him to invent perhaps the most important single cultural invention of man's long history—agriculture.

With this development, man quickly became the dominant animal on earth. It made it possible for a small percentage of the population to engage in occupations other than that of just gathering or growing food. It made it possible for the great ancient civilizations to emerge. This happened less than 10,000 years ago.

With civilization's development, increasing levels of technological complexity evolved. This technological complexity, however, leveled off because it proceeded about as far as it could go within the existing framework.

Then not very long ago—indeed less than 300 years ago—we entered the Industrial Revolution, which has carried us since to an extremely high level of technological complexity—at least in the part of the world in which we live. And it raises a number of very important questions.

But when we look at the framework in which we live in the world, when we look at the problems that have been created as the result of our technology and the haphazard application of our discoveries, we can see very real dangers ahead. For one thing, we have seen a fantastic increase in our ability to destroy—in our military capability. We have seen weapons of fantastic power, thermonuclear weapons, come into the hands of first one nation, then two, three, four, and five. And there is no reason for us to suspect that it will stop.

A WORLD OF CONTRASTS

We can couple that with the fact that we are really living in an anarchical world in which there is no real law and order. And because we are living in a world in which technology has been applied in a very haphazard way, some people have become very rich, and others remain very poor. In the countries that have shared in the blessings of technology which produce an abundance of food and things, we seem to have gotten ourselves into what James Bonner refers to as a "positive feedback cycle" in which richness begets richness.

By contrast, those areas of the world—and this includes most people—where starvation is the rule rather than the exception, and where deprivation and misery prevail, find themselves in a negative feedback cycle in which poverty intensifies poverty. Indeed, the economic positions of these two groups are diverging very rapidly.

This raises a very real question. Can a high-energy civilization be stabilized? We don't know. It's the first time it's happened on earth. It might well be that it can't, but certainly we shouldn't stop trying. But it may well be that it can. This in turn raises another rather interesting question. If it is true that planets are abundant and that life is abundant in our universe, might it not also be true that the power of conceptual thought has arisen in many places within our universe and that many other high-energy civilizations may have arisen as well?

UNINTENTIONAL COMMUNICATION

It is clear that we are in a position to send out signals should we wish to. Indeed we are doing that unintentionally already. Frank Drake, the director of the Aerocibo Station radio telescope in Puerto Rico, pointed out some time ago that the world is reaching the point where an external observer could detect that something is going on here that could not be explained on the basis of natural processes. This is because of our large outpouring of microwaves in the form of television programs and television microwave communications. Drake has suggested that we ought to scan stars systematically and look for this same kind of effect, although it is much easier and much less expensive to just listen. Perhaps we ought to just systematically *listen*. A positive result could be the most exciting scientific discovery of all of human existence.

These discussions aren't entirely in the realm of science fiction. Serious scientists are discussing these things: If contact were made, what one could learn and what the philosophical impact of our realizing that man is not alone would be. I think the implications are profound.

When we look at the grandeur of our universe and the processes that have taken place, the grandeur of life and the beauty of life processes, and at the tiny speck of rock on which we live, it makes the quibblings and the arguments and the hatreds between individual groups of human beings seem rather inconsequential. Indeed, I feel that we might well be on the edge of a great tragedy. The tragedy would not just be the disappearance of a species. That would be tragic enough. The tragedy would be this: For the first time in the history of life on earth a creature has emerged which has the power to control his destiny and which, above all, has the power to wonder and learn how the universe operates, and even to ask the philosopher's question, "Why?" And he has developed tools which enable him to answer these questions. Then the power for answering them is taken away from him by some kind of a major catastrophe of his own doing. This, I think, would be the grand tragedy of our earth and its entire evolution.

It is clear when we look at the power that science and technology have given us and at the problems which confront us, that from a purely technological point of view those problems can be solved. For example, our existing knowledge today makes starvation in the world inexcusable. We know how to *learn* how to grow much more food than we now know how to grow. Deprivation in the world is inexcusable. We have the technology to support a considerably higher population of human beings than now exists, at a level of abundance where all persons could be free from starvation and misery. But, although we know how to do this from a technological point of view, we do not yet know how to do it from a social or a political point of view.

Long ago we recognized that when we wanted to learn how to grow more food we supported agricultural research. When we wanted to learn how to make new weapons, we supported military research and we learned how to make new weapons. Somehow, in some way, we learned that basic research is needed as backup for research on these applied problems. Somehow a National Science Foundation was established, and basic research has been supported by individual government agencies in addition.

SOCIAL SCIENCE RESEARCH

This has all been in the natural sciences. When it comes to research on how individual human beings act with each other, when it comes to our learning how groups of individuals interact with each other, when it comes to the broad spectrum of social sciences, there's virtually no research! There is some, of course, but it is supported at a tiny level compared with the need and compared with the support given other areas of research endeavor.

There are many reasons for this, I suppose. Each one of us is our own psychologist and our own economist, and certainly we are all our own political scientist. Yet it is a constant source of wonder to me that there is no foundation supported by our government for research in the social sciences—that virtually none of the government agencies has the wherewithal, or none of them devotes whatever wherewithal it might have available to research in these areas. And yet when we look at the tremendous problems of population growth in advanced societies, the problems of urbanization, the problems of slums, of transportation—just the problems of people getting along with people—clearly the social component is as great or greater than the purely technological one.

The same thing is true when we look at the basic problems of the social and economic development in those vast areas of the world which are now living at starvation levels—where population is getting completely out of hand, and which threaten at any time to explode in a sequence of explosions which I think is going to pale Vietnam into insignificance.

IN SEARCH OF MEANING

I think all of the questions which have been raised bring up another important point. What really is the meaning and purpose of life? Is it just to get enough to eat? Is it just to get enough gadgets to put in our home? Is it just to reproduce—no matter how beautiful, intelligent, and free of disease the human beings might be who emerge from the factory Dr. Bonner is proposing?

No! I think that if there is any meaning and purpose to life it is learning what our universe is all about and what man's place in the universe is. All of these other things are really problems which stand in the way of that and are diversions from man's long-term goals of learning what we are, where we came from, where we're heading, and perhaps even why. I believe that the meaning and purpose of life was well phrased in words of Shakespeare's Hamlet when he asked:

> What is a man,
> If his chief good and market of his time
> Be but to sleep and feed? a beast, no more.
> Sure, he that made us with such large discourse,
> Looking before and after, gave us not
> That capability and god-like reason
> To fust in us unused.

Charles C. Lauritsen

A tribute by
William A. Fowler

I was one of Charles Lauritsen's first graduate students, and I speak for all of us for whom he was *the Professor*. One of the most precious relationships in the whole of scientific life is that between the graduate student and the professor who supervises his doctoral research. Those of us who were Charles Lauritsen's students had the opportunity to savor this relationship to the fullest extent. With his students Charlie was magnificent. He taught us everything from how to run a lathe to how to design and build electroscopes, ion sources, cloud chambers, magnetic spectrometers, electrostatic analyzers, and high voltage accelerators. But most of all he taught us how to do experiments—in simple, direct, elegant ways.

It was always the case that Charlie saw through to the heart of any problem. Whereas most of us tend to overdesign apparatus and to use redundant procedures in our experiments, Charlie delighted in designing inexpensive and simple devices which would make the experiment and its theoretical interpretation as straightforward as possible. He delighted too in convincing us in his logical manner that his suggestions were the right ones. When agreement had been reached, he got perhaps his greatest satisfaction in going to the lathe and turning out the most difficult parts and pieces himself. But withal he always taught us why he did thus and so, and we learned, insofar as we were able, something of his marvelous insight into how to *do* physics, as he so frequently expressed it.

Charlie was primarily an experimentalist, but it was his close personal relationship with theorists which broadened and deepened the experiences of his students. This continued throughout his lifetime, but it was especially true before World War II when what we now call classical nuclear physics was in its golden age. It was truly golden for all of us in Kellogg, because first of all there was Charlie Lauritsen, one of the great men in the field along with Rutherford and Cockcroft and Lawrence and Tuve, but also there were his two friends Richard Tolman and Robert Oppenheimer.

They were giants—all three in their different ways—but all three were truly great men. It was exciting and even awe-inspiring to listen to their discussions about our experiments and what the experimental results meant in terms of the nuclear theory of that time. Tolman and Oppenheimer were delighted with the discoveries in nuclear physics which came out of Charlie's laboratory—the discovery of resonance in proton-induced reactions; the first production of high-energy gamma rays, neutrons, and radioactivity with accelerators; the discovery of the "mirror" nuclei; and the proof of the annihilation of positrons, among many other firsts.

What we did not know at the time was that Oppenheimer was laying the foundations for a good part of our present understanding of the nucleus; what we *did* know was that he and Tolman were keenly interested in our results and that Charlie was guiding our efforts in a manner which was significant and important to the theorists.

I have used the word "guiding" advisedly. Charlie never gave any consideration to being designated the director of the Kellogg Radiation Laboratory. He did not direct, he guided. This was very important to him, and it made all the difference in the world to us in our growth and development into independent scientists. It is true that in those early days we called Charlie the "boss," but this was in the same admiring yet somewhat irreverent spirit that we called Robert A. Millikan the "chief."

Charlie guided us as individual students with keen insight into our capabilities and potentialities, but in a much broader sense he guided the entire effort of Kellogg into the most active and promising branches of physics. He was never afraid of change. He started with Millikan in the field of cold emission but soon went independently into the development of high voltage x-ray tubes for research both in physics and medicine. He became a Fellow of the American College of Radiology, one of the first of his many honors. It was quite natural that he was able to adapt his high voltage tubes to positive ion acceleration when nuclear physics, as we know it now, broke on the scene in 1932. Charlie pioneered in the elucidation of the excited states of the light nuclei and of the interaction of protons, deuterons, and alpha particles with these nuclei. In 1939 Hans Bethe pointed out that the carbon and nitrogen reactions which we were studying in the laboratory were of crucial importance in the generation of energy in stars. There was nothing he could do about it at the time, for World War II soon involved him and all of us in defense work on proximity fuses, rockets, and atomic ordnance. But with the end of the war Charlie made a most difficult decision regarding the future direction of research in Kellogg. Rather than guiding us into high-energy nuclear physics he encouraged us to continue our prewar efforts in low-energy nuclear physics and to emphasize the applications in astronomy and astrophysics. To accomplish this he arranged a series of meetings between astronomers and nuclear physicists with Ike Bowen who had just then become the new director of the Mt. Wilson Observatory. Thus he started a unique program in nuclear astrophysics which has been so rewarding for all of us since that time.

With all of this, Charlie was more to us than just our professor. He influenced our entire lives. We were in many ways a high-spirited crew with strong loyalties to and strong identification with Kellogg—Charlie's laboratory. We worked hard and we played hard. We were proud of our capacities, intellectual and otherwise. Very early Charlie started the Friday evening seminars which still bear the indelible mark of the Kellogg spirit. After the seminar we always went to Charlie's home for refreshments and argumentative discussions of physics, medicine, and philosophy. Sigrid Lauritsen was always there to make us feel at home. Frequently her medical collaborators in radiology joined us, and Stewart Harrison from the clinical group then operating in Kellogg was often there. Tommy Lauritsen played the piano, and Charlie sometimes accompanied on the violin. At other times Charlie sang and taught us the wonderful songs of Carl Michael Bellman in Danish.

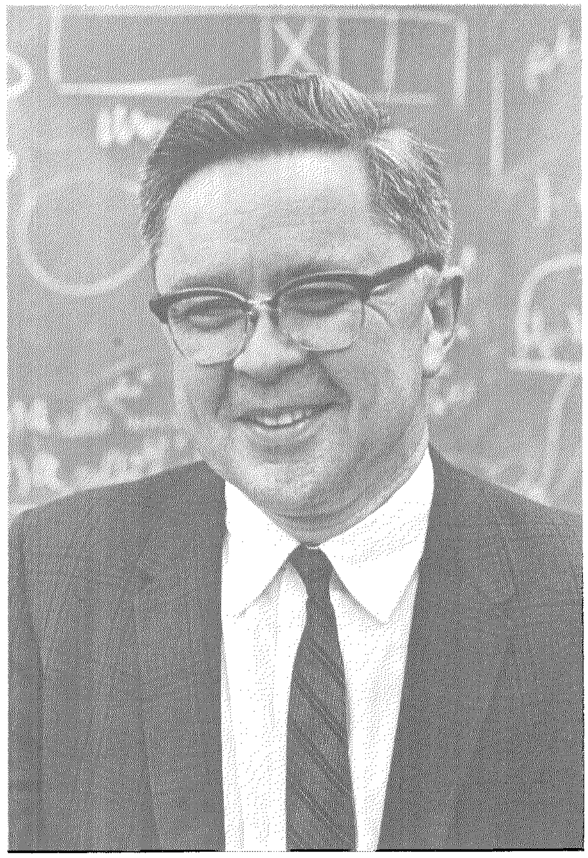
And so our professor was more than just our mentor in the laboratory; he was confessor and confidant, and he introduced us to a rich world outside of physics and science. I suppose the simplest way to put it was that for many of us he was a second father. We were his sons; and as his sons we came to love and admire him very much—for he was a very great man.

Charles C. Lauritsen, professor of physics, emeritus, died April 13 at the age of 76. A member of the Caltech faculty for 43 years, Dr. Lauritsen was a pioneer in nuclear physics, rocket research, and radiation therapy for the treatment of cancer. He directed research in Caltech's Sloan and Kellogg Laboratories for over 30 years. William A. Fowler delivered this tribute at a memorial service for Dr. Lauritsen on the Caltech campus on April 29.

THE MONTH AT CALTECH

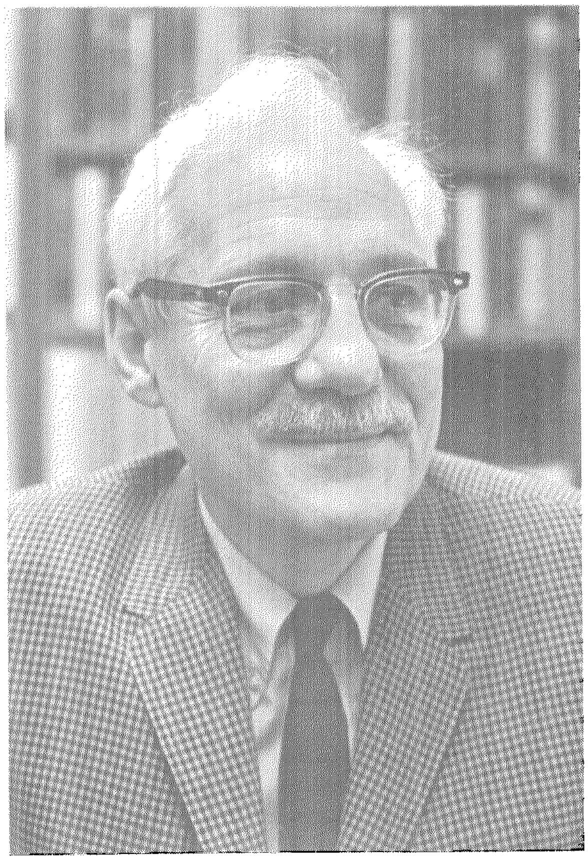
NATIONAL ACADEMY ELECTION

Two Caltech faculty members have been elected to the National Academy of Sciences in recognition of their outstanding achievements in scientific research. They are Edward B. Lewis, who is Thomas Hunt Morgan Professor of Biology, and Jerome Vinograd, professor of chemistry and biology. Their election brings to 32 the number of Caltech faculty who are now members of the Academy. Caltech has the highest percentage of Academy members of any university faculty.



Edward B. Lewis

Dr. Lewis has made major contributions to the field of genetics and has developed techniques that are widely used in studying chromosomes. He has also studied the relation between radiation dosage and the incidence of cancers. Past president of the Genetics Society of America, Dr. Lewis serves with the genetics study section of the National Institutes of Health and is a member of the Radiation Bioeffects Advisory Committee of the U. S. Public Health Service. He was graduated from the University of Minnesota and received his PhD from Caltech in 1942, joining the faculty in 1946.



Jerome Vinograd

Dr. Vinograd recently discovered a new form of DNA shaped in a series of loops connected in a chainlike manner. His discovery was made possible by a centrifuging technique developed by him and his colleagues. Dr. Vinograd and his associates also found other previously unknown forms of DNA, including molecules that are tightly twisted rings. He received his master's degree from UCLA in 1937 and his PhD from Stanford University in 1940. He has been a member of the Caltech faculty since 1951.

SCIENTIST OF THE YEAR

Robert L. Sinsheimer, chairman of the biology division at Caltech, has been named Scientist of the Year by the California Museum of Science and Industry and the California Museum Foundation. Nominated for his synthesis of biologically infective viral DNA, Dr. Sinsheimer was chosen from among 100 leading scientists.

The award will be presented at a banquet on June 5 by Luis W. Alvarez, professor of physics at the University of California at Berkeley and chairman of the selection committee of eight scientists.

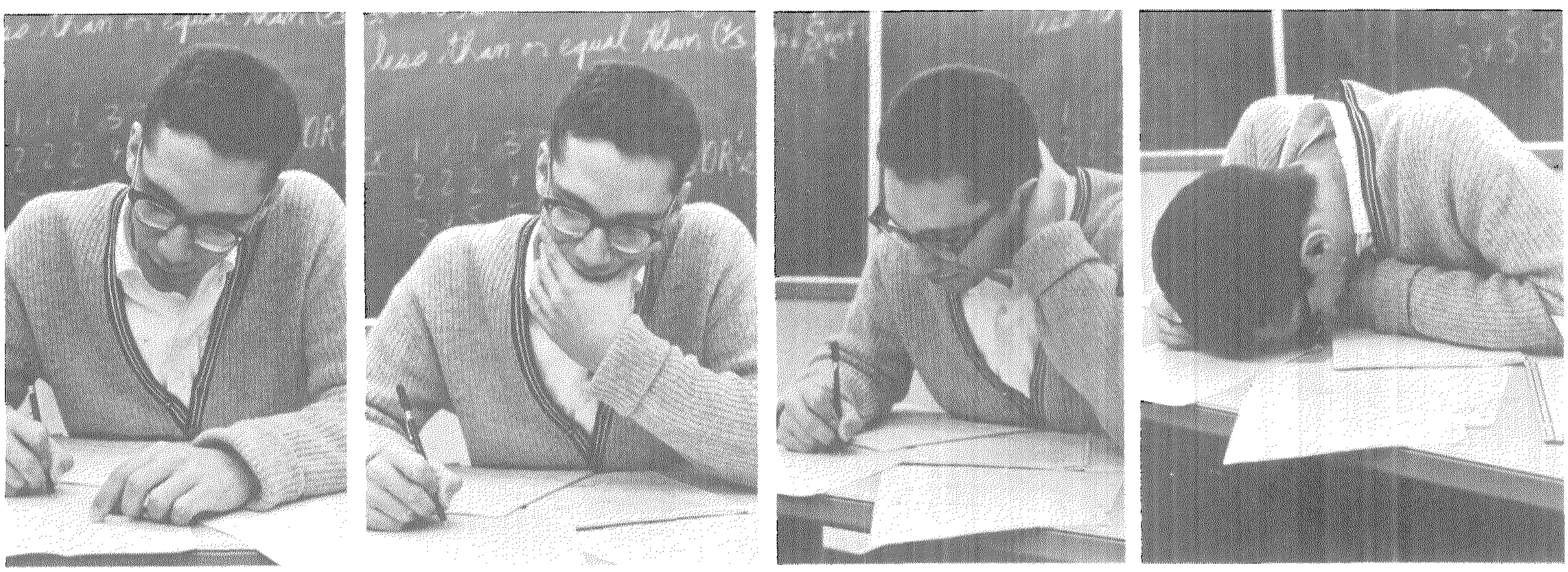
Dr. Sinsheimer is the fifth Caltech faculty member to receive the award, which has been given to 13 individuals since it was first established in 1957. Former winners are Jesse L. Greenstein, professor of astrophysics and staff member of the Mount Wilson and Palomar Observatories; William A. Fowler, professor of physics; and Frank Press, former director of Caltech's Seismological Laboratory who is now head of the geology and geophysics department at the Massachusetts Institute of Technology.

HONORS AND AWARDS

Don L. Anderson, associate professor of geophysics and director of Caltech's Seismological Laboratory, has been elected vice president of the American Geophysical Union's tectonophysics group, and James N. Brune, associate professor of geophysics, has been elected to represent the AGU's southeast section in the field of seismology. Their two-year terms of office begin July 1.

Jesse Greenstein, chairman of Caltech's department of astronomy and staff member of the Mount Wilson and Palomar Observatories, and Richard Feynman, Richard Chace Tolman Professor of Theoretical Physics, have been elected to membership in the American Philosophical Society, the oldest honorary society in the United States.

Caltech president Lee A. DuBridge has been named chairman of the Greater Los Angeles Urban Coalition of educational leaders and top executives in business, finance, industry, and labor whose purpose is to mobilize local resources to help solve the city's social and physical problems. The local coalition is part of the National Urban Coalition, formed in August 1967 in Washington, D.C., with John Gardner, former secretary of the Department of Health, Education and Welfare, as the chief executive officer. Dr. DuBridge is also chairman of a new special advisory committee set up by Los Angeles District Attorney Evell J. Younger to study the possible legal implications of organ transplants.



TIME TO GET ORGANIZED For the Caltech undergraduate June means finals—which means May means cramming, with all its attendant perils.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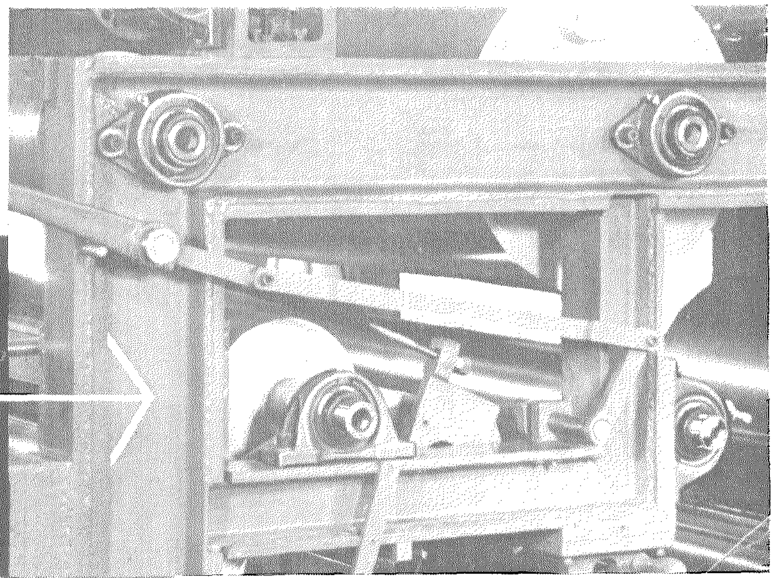

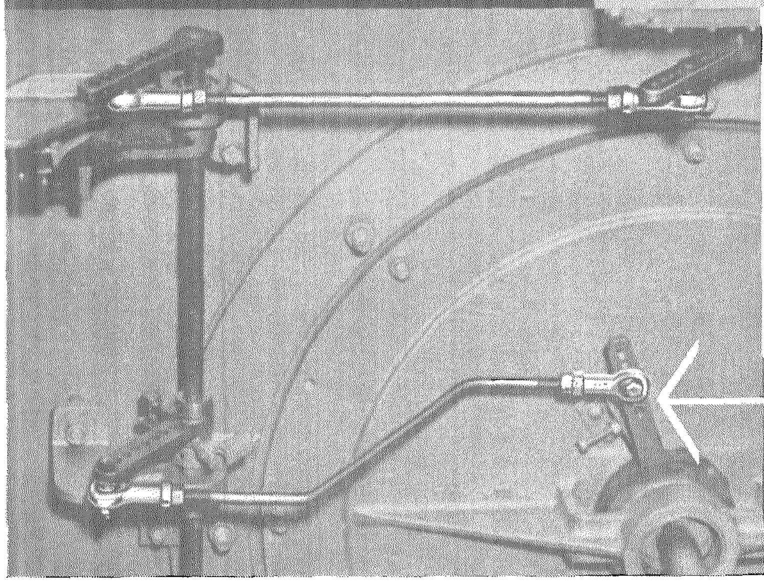

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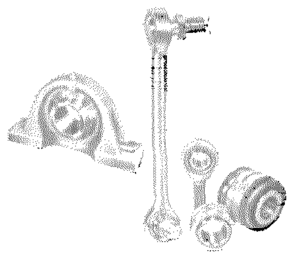

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I am willing to allow the author his point of view as a writer *insofar as he can soundly document its validity,* just as I will do the same for Linus Pauling or even Robert Welch on those few things of his which *can be so documented.* But I insist that all ideas, including my own if I were to publish such a paper, should be tested historically by study of past civilizations and by measure against the nature of man psychologically and also as an animal. (The veneer of civilization really isn't very thick, you know). If one's ideas stand up as factual against such a test, then it is worth considering them for publication.

I hope you understand the intent of these comments.

KEATS A. PULLEN, JR. '39

Santa Monica

EDITOR:

It makes me more than a little disappointed to see the article by Robert A. Rosenstone in the March issue of *Engineering and Science.* If it is satire, it has succeeded so well that it gives me the impression that it is sincere. If it is sincere, it appears to me to be one polarized opinion pointing an accusing finger at another presumed polarized opinion, damning a presumed technique and using the technique at the same time. It is not clear to me what purpose there was in publishing the article.

A. C. REED '29

Engineering and Science *is a magazine about the California Institute of Technology—about the people who teach and study here, about their research and their ideas. The articles in the magazine are written by Caltech faculty, research men, students, and alumni—and by distinguished visitors to the campus. They are intended to give a sample of some of the current life, work, and thought at Caltech. On February 21, 1968, Robert S. Rosenstone, assistant professor of history, gave "The Radical Right Revisited: Some Perspectives" before the YMCA Luncheon Forum in the Athenaeum.* E&S *considered the talk newsworthy and edited it for publication in March.*

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