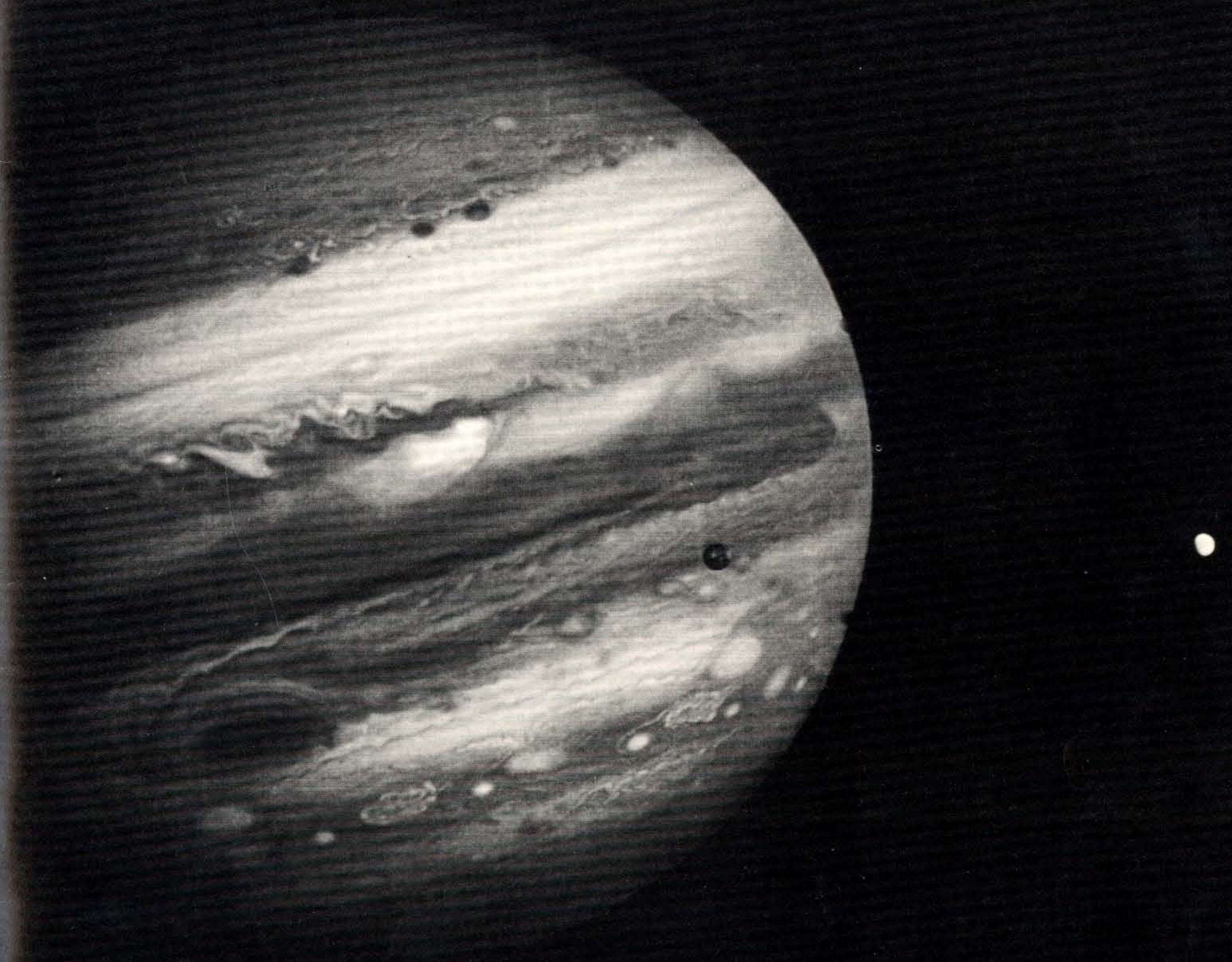
Engineering & Science

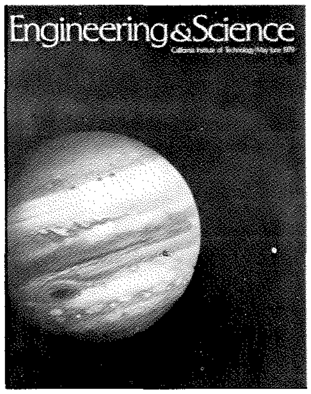
California Institute of Technology | May-June 1979



Engineering & Science

May-June 1979/ Volume XLII/Number 5

In This Issue

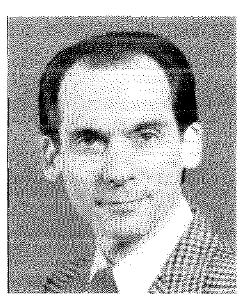


By Jove
On the cover — the largest planet in the solar system, Jupiter, with the Great Red Spot showing near its lower left edge. This photograph was taken by Voyager 1 on February 5, when the spacecraft was a month and 28.4 million kilometers (17.5 million miles) from its closest encounter with the giant planet. Two of Jupiter's four largest satellites are also visible. Io, the innermost satellite, appears as a dark spot not far from the right edge of the planet and just south of the equator. Europa is the white dot near the right edge of the photograph.

This is only one of thousands of spectacular images sent back to Earth by Voyager 1's cameras. And while those pictures delight the eyes of most of the general public, they are mind-boggling for the equally delighted space scientists — suggesting both answers to old questions and new problems to be solved.

Edward C. Stone, whose own research interest is cosmic rays, has been NASA's Project Scientist for the two Voyager space missions since 1972, which means that he coordinates Voyager's scientific studies. These days he is deeply involved with the minute-by-minute plans for Voyager 2's encounter with Jupiter in July.

Stone came to Caltech as a research fellow in 1964 after receiving his PhD at the University of Chicago, and he has gone steadily up in the academic ladder ever since, becoming professor of physics in 1976. Recently, he has found himself increasingly in demand as a Voyager interpreter — for TV, radio, and newspaper reporters, for other scientists, for an assortment of groups, and for *E&S*. "Voyager 1 at Jupiter: An Encounter with Five New Worlds" on page 3 is his informative account of this mission.


Edward C. Stone


Judith Goodstein

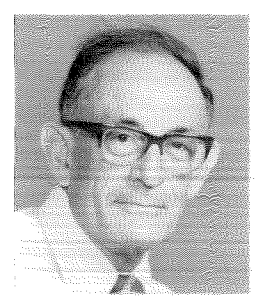
Birthday Greetings
One of the most important events of the year 1879 was the birth of Albert Einstein, an anniversary that was celebrated in 1979 by all kinds of people, in diverse ways, and in a number of places. At Caltech, students gave a giant block party (*E&S*, March-April), a tongue-in-cheek appeal for funds for an Einstein memorial was circulated (see page 27), and archivist Judith Goodstein mounted a handsome Einstein display in the cases in Millikan Library's foyer.

Goodstein also mounted several platforms to speak on various aspects of Einstein's life and career and particularly on his experiences during the three visits he paid to Caltech in the early 1930's. "Albert Einstein in California" on page 17 is adapted from the talks she gave recently at Santa Barbara City College and for the Caltech Y's Evening Spotlight Series.

Goodstein has been Caltech's archivist ever since 1968 when she came here from the University of Washington where she had just earned a PhD in the history of science. Under her direction Caltech's rather small and disorganized miscellany of archival material has grown to more than 60 research collections, about 500,000 documents, 5,000 photographs, 100 pieces of scientific apparatus, and 500 sound recordings. Her latest project is collecting oral histories of the early days of Caltech from the people who were here to observe them.

A Case Study
One of the trends in education these days is a growing movement of college students into engineering options — a fact that makes evaluating and upgrading engineering education of prime importance to concerned educators. Fortunately, that process is not new to the faculty members of GALCIT (the Graduate Aeronautical Laboratories of the California Institute of Technology), who have been analyzing their educational system and its results for several years. In fact, last fall GALCIT's director, Hans Liepmann, was invited to lecture on the subject at the Second International Congress of Engineering Education in Darmstadt, Germany. "Engineering Education for a Rapidly Changing Technology" on page 20 is an adaptation of that talk.

Liepmann's qualifications for giving such a talk are impressive. He has been associated with engineering research and education ever since he came to Caltech in 1939 as a research fellow. He became a full professor in 1949, director of GALCIT in 1972, and Charles Lee Powell Professor of Fluid Mechanics and Thermodynamics in 1976. The receiving of a named chair was, of course, one recognition of his many contributions to aeronautical and engineering research. He has had many others as well, including election to both the National Academy of Engineering and the National Academy of Sciences. He has also been awarded the Ludwig Prandtl Ring, the highest distinction of the German Society for Aeronautics and Astronautics, the Worcester Reed Warner Medal of the ASME, and the Monie A. Ferst Award.


Hans Liepmann

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

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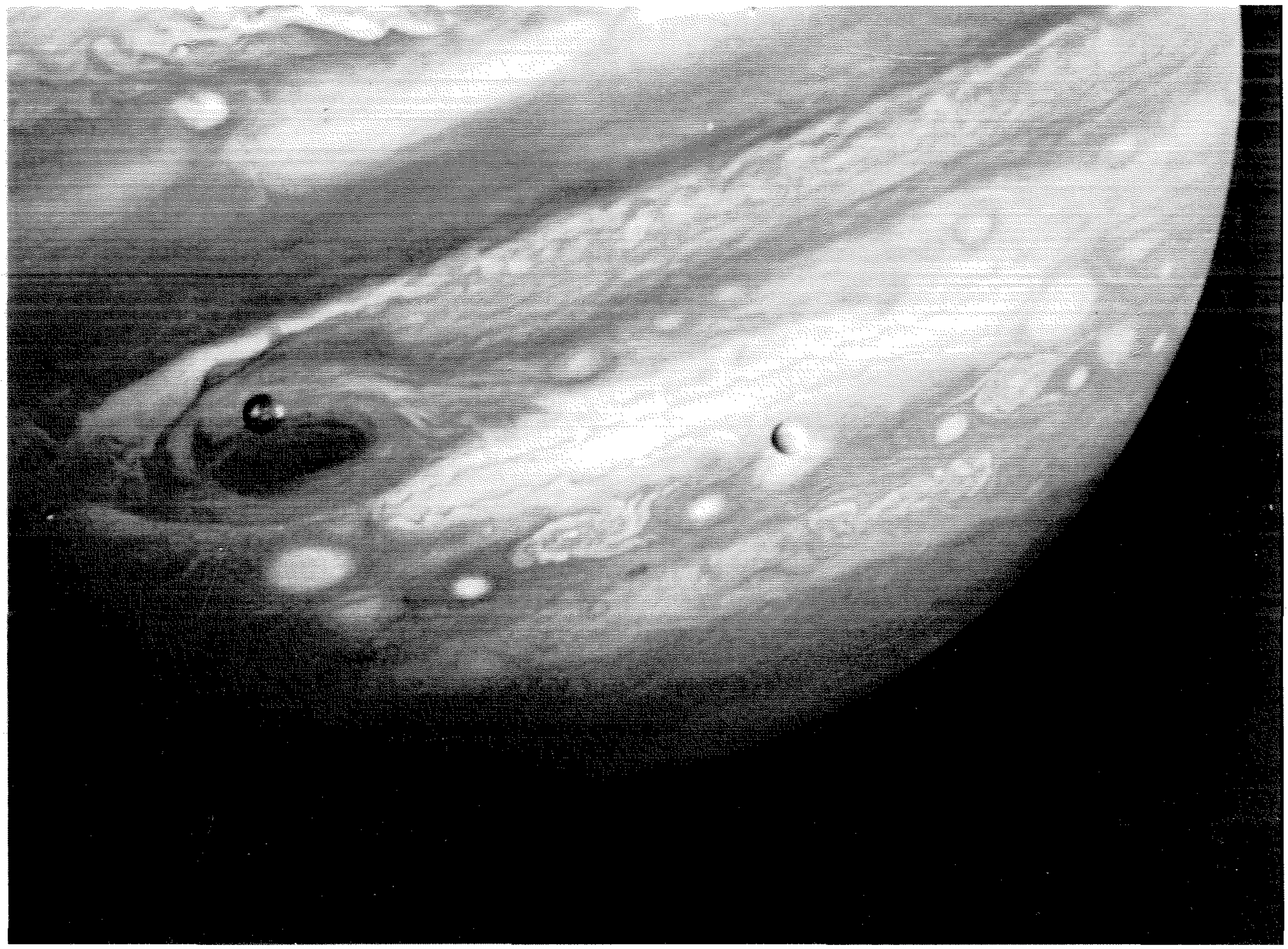


A dramatic view of three of the five new worlds encountered by Voyager 1 at Jupiter. Silhouetted against the giant planet are two of its satellites, Io (220,000 miles above the Great Red Spot) and to the right Europa (375,000 miles above the clouds). The two satellites are about the same size but of very different appearance and history.

Voyager 1 at Jupiter

An Encounter with Five New Worlds

by Edward C. Stone

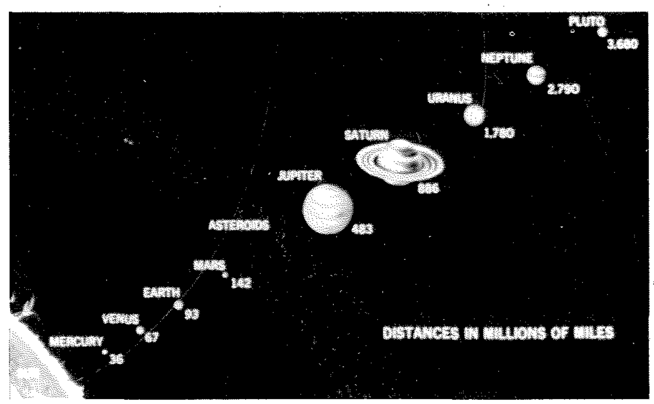
Voyager 1 at Jupiter

In January, February, and March 1610, Galileo first turned his newly developed, eight-power telescope toward the celestial sphere, discovering that four smaller bodies were orbiting Jupiter and providing him with his first direct evidence supporting the Copernican theory. Those four Jovian satellites are now called the Galilean satellites. Three hundred and sixty-nine years later, also in January, February, and March, Voyager 1 carried a complex array of sensors past Jupiter and the Galilean satellites, producing results that are in many ways as surprising as Galileo's discovery.

The Voyager 1 observations are, of course, the result of the combined efforts of many individuals over a number of years. Engineers and scientists at Caltech's Jet Propulsion Laboratory have the responsibility for conducting the Voyager Project for NASA. In addition, more than 100 scientists from the United States and Europe are associated with the 11 scientific investigations selected by NASA in 1972. (One of those investigations is headed by R. E. Vogt, chairman of the Division of Physics, Mathematics and Astronomy.) Although the 11 investigations use separate instruments to measure quite diverse phenomena, the resulting studies can nevertheless be assigned to three general areas: studies of the atmosphere, of the magnetosphere, and of the satellites of Jupiter.

In the first of these areas are studies of the composition and the dynamics (or weather) of the Jovian atmosphere. There is interest in the composition of the planet because it is thought that Jupiter has managed to retain a more representative sample of the material out of which the solar system was made than has the Earth. Since Jupiter is five times as far from the Sun as the Earth, it retained amounts of the lighter elements such as hydrogen and helium that are more nearly proportional to the amounts present when the planets and the Sun formed some four and one-half billion years ago. The more volatile materials are missing from the inner planets of our solar system — Mercury, Venus, Earth, and Mars — resulting in rather small rocky bodies, while the outer planets — Jupiter, Saturn, Uranus, and Neptune — which formed far from the heat of the Sun, more closely resemble it. Thus Jupiter is a massive sphere of gas, possibly with a small, molten rock core. As a result, there is no solid surface to Jupiter, and what is seen in the images of Jupiter are cloud layers at the top of a very deep atmosphere.

The banded appearance of the Jovian clouds is a clear indication that the Jovian weather patterns are different from Earth's. Obviously, the same basic processes are involved, but the factors that control those processes are present in different proportions. By studying how those



The planets of the solar system, ranked in order of distance from the Sun and drawn to scale in size. The largest, Jupiter, is five times as far from the Sun as Earth, eleven times as large as Earth, and a sphere of gas instead of a ball of rock.

different proportions alter the weather patterns, we expect to better identify which are the most important factors and to improve our understanding of the basic processes.

One example of an important difference between Jupiter and Earth is the source of heat for the polar regions. Jupiter, unlike Earth, has a significant internal heat source, evidently because it is still cooling off from the heat generated during the gravitational-contraction phase of its formation. The net result is that the heat coming from the inside of Jupiter is about equal to the amount of heat it receives from the Sun. This internal heat source may thus provide heat to the polar regions without requiring the transport of solar energy from the equator as must happen on Earth. This could be an important factor in the formation of the uninterrupted horizontal banded pattern of clouds that is evident in photographs.

Another important factor is that Jupiter lacks a solid surface so that large differences in pressure can't be maintained deep in the atmosphere. The fact that Jupiter has a 10-hour rotation period and a very large radius means that it has very high surface velocity (approximately 28,000 mph), and this too changes the proportion of the factors that go to make up the Jovian weather system.

From ground-based observations it was known that the broad regions of clouds on Jupiter possessed a somewhat regular pattern of eastward and westward winds. Voyager, however, discovered an unexpected prevalence of vortical or rotational motion. In both the northern and southern hemispheres there are numerous small high-pressure regions or spots ("small" on the Jovian scale means something like half the size of Earth) that rotate rapidly — clockwise in the northern hemisphere and counterclockwise in the southern. The spots in the northern hemisphere, which are a brownish color, occasionally collide, rotating about each other in a clockwise motion.

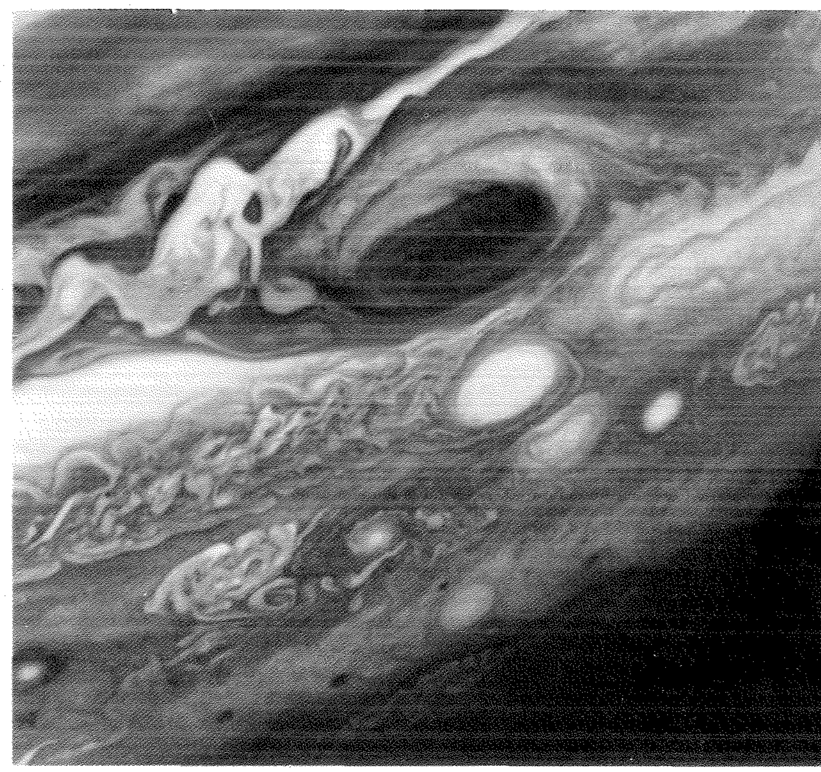
The Great Red Spot is the most obvious vortex in the southern hemisphere and flows counterclockwise. But there are also three white ovals and other white cloud structures that are regularly spaced around the planet at latitudes just south of the Great Red Spot and that also rotate in a counterclockwise direction. All of these have great dynamical stability. The Great Red Spot was first observed more than 300 years ago, and the formation of the white ovals out of the collapse of a zone of clouds was observed about 40 years ago.

The source of energy that drives these rotational flows is unknown. One possibility is that they are driven by an upwelling of gaseous material in the center of a spot. The material condenses as it reaches the top of the cloud deck and in the process releases heat. Or just the reverse could occur. Energy could be fed into the spots by the east-west winds that blow past them. Very careful measurements of the rotational flows may indicate whether the material is diverging (spiraling outward with latent heat from the condensation) or converging (spiraling inward because energy is being fed in by the zonal winds).

There are also a number of discrete white cloud structures that encounter the Great Red Spot as they circulate about the planet. Even though the shapes of the individual structures are severely distorted as they circle around the Great Red Spot, they nevertheless maintain their individual integrity, sometimes circling a second time, and then breaking away and continuing on around the planet. Simple, unstructured clouds would be unable to maintain such integrity. A study of the interaction of these objects may provide important clues to the dynamics of the Jovian atmosphere.

Since pressure differences in the upper atmosphere drive the winds, another important tool in the study of the weather on Jupiter is the measurement of temperature as a function of depth or pressure. The temperature and pressure of the atmosphere decrease with increasing distance from the center of the planet where the temperature is tens of thousands of degrees. The temperature at the level of the visible clouds, which are condensed ammonia, is only about 150°K, and at a level 40 km higher it drops to a minimum of about 110°K. At still higher altitudes, the temperature again rises partly because of solar heating. Water ice clouds, similar to those on Earth, form a layer well below the visible clouds where the temperature is near the freezing point of water (273°K) and the pressure is about five times that on the Earth's surface.

There are, of course, some trace chemicals among the

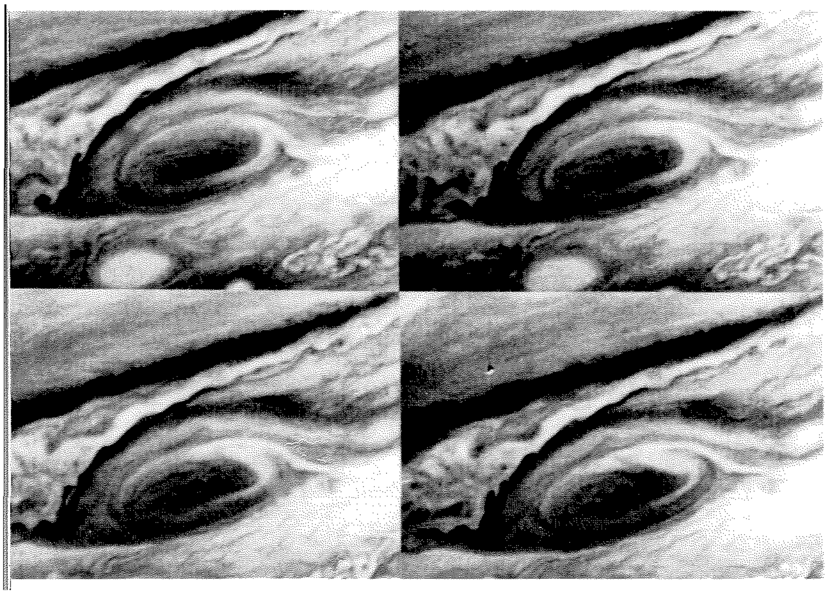


Almost a closeup of Jupiter's Great Red Spot, taken when Voyager 1 was 5.7 million miles from Jupiter. In addition to the complexity of the cloud patterns around and within it, the Great Red Spot offers other challenges to understanding. For example, in general the dark regions on Jupiter are warmer, but the Great Red Spot, dark as it is, is colder than neighboring areas. It is believed to soar about 15 miles above the surrounding clouds, and its length is about three times the diameter of Earth.

constituents of Jupiter, and they are almost surely the basis for the different cloud colors. Considering the pressures and temperatures that are also present, it seems likely those trace chemicals are rather complex molecules. The lightning activity that Voyager observed on Jupiter may have a significant role in the formation of at least some complex molecules.

A second area of study was that of the Jovian magnetosphere, that is, the magnetic field and trapped radiation environment surrounding Jupiter. The Jovian magnetic field is the largest structure in the solar system, extending more than two million miles from Jupiter. If you could see it from Earth, it would appear as large as the Sun even though it is five times as far away. Because of the great extent of the magnetic field, all of the major Jovian satellites are buried deep inside the magnetosphere. By comparison, Earth's Moon is safely outside of the region of intense magnetic field and radiation. The satellite Io, however, acts as a conductor moving in Jupiter's magnetic field, and some 400,000 volts are generated across its diameter. Such a large voltage could result in a large DC current flow.

The existence of such a current was suggested by observation some 15 to 20 years ago of very intense radio emission from Jupiter at frequencies ranging between 20 and 40



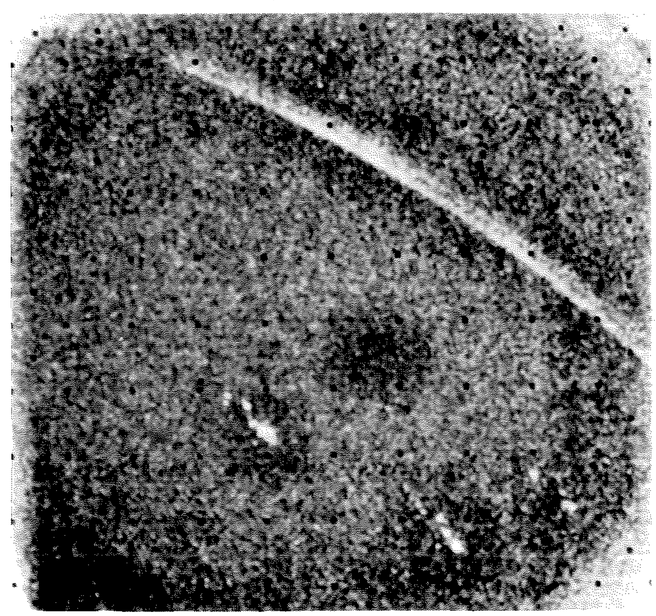
Taken one Jupiter rotation apart, these photos depict four days in the life of the Great Red Spot. Changes in circulation during the 40-hour period are clearly visible, particularly the flow of light material at the spot's right edge.

megahertz (just a little less than Channel 2). Whether or not the radio bursts were observed at Earth depended on where Io was in its orbit about Jupiter. That led to formulation of a model about 10 years ago by Peter Goldreich and R. M. Lynden-Bell that there was a large DC current flowing between Io and Jupiter, driven by the 400,000 volts across Io. When the current approached Jupiter, it generated radio waves. Goldreich and Lynden-Bell estimated that there might be a million amperes flowing from Io down the Jovian magnetic field to Jupiter, returning to Io along adjacent magnetic field lines much as the current to an electrical appliance flows along one wire in a lamp cord and returns in the other. The magnetic field lines along which the current flows are labeled the Io flux tube.

Voyager was targeted to fly through the flux tube in order to measure the current flow and thus confirm the nature of the interaction between Io and the magnetic field. Voyager did indeed fly through the targeted region, but there was so much current flowing along the flux tube that it was twisted by the current itself and displaced about 7000 km. So Voyager flew beside the flux tube, but was still able to measure the current, which was about five million amperes. Since the current in the flux tube is limited by the conductivity of Io and of Jupiter's ionosphere, it should eventually be possible to learn something about their electrical conductivity. Studying the physics of such a large rotating magnetic field and its interactions may also indirectly lead to a better understanding of the much larger, much faster rotating magnetic fields associated with pulsars.

There are other unusual aspects of the Jovian magnetosphere. For instance, Voyager discovered that the ultraviolet auroral activity (northern lights) was so intense that it was easily observable in the daytime. The extent of the activity was indicated by a darkside image in which the visible auroral activity near the north pole extended across the entire frame, a distance of more than 30,000 km (18,000 miles). Terrestrial auroras are caused by the spiraling of charged particles from the Van Allen radiation belts along the magnetic lines of force into the atmosphere, causing the atoms to glow as in a neon lamp. Similar processes probably cause Jupiter's auroras but on a much larger scale. Further study of this enormous feature at Jupiter should provide information on large-scale magnetospheric processes that can be compared with the smaller scale processes on Earth.

There is another important result of the immersion of the satellites deep in the Jovian radiation environment. From ground-based observations it was known that there was a cloud of neutral sodium atoms that remained in Io's vicinity as Io orbited Jupiter. It was suggested that there were large salt flats on Io's surface from which the sodium was being ejected by the intense radiation bombardment. Pioneer had indicated that there might also be some neutral hydrogen associated with Io in its orbit, and other ground-based observations indicated the presence of singly ionized sulfur. As soon as any of these species became ionized (electrically charged), the ions would become attached to



This Voyager 1 image was taken of the dark side of Jupiter from a distance of 320,000 miles. The long bright double streak is an aurora near Jupiter's north pole. The other bright spots are probably lightning, and if that is what they are, the flashes are comparable to the brightness of superbolts seen at the tops of terrestrial tropical thunderstorms.

Jupiter's magnetic field, which rotates with Jupiter's 10-hour period. Since Io's orbital period is about 42 hours, the ionized particles are carried away from Io by Jupiter's rotating magnetic field and form a complete torus or doughnut around Jupiter. The singly ionized sulfur did appear to form such a torus with a temperature of about 10,000°K.

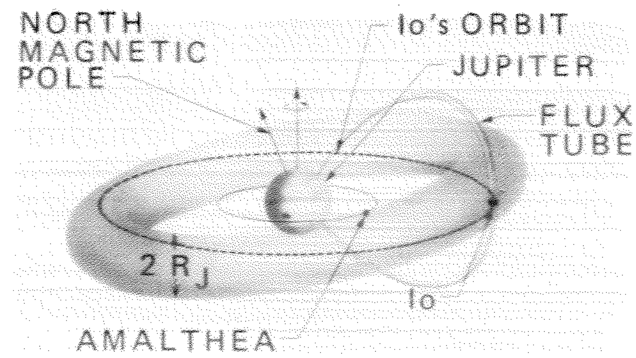
As Voyager 1 approached Jupiter, it was discovered that there was a much more intense ultraviolet emission from Io's orbit than had been observed by Pioneer in 1974. The emission was from doubly ionized sulfur and doubly ionized oxygen ions and indicated a temperature of 100,000°K in the torus. Since Pioneer had instruments sensitive enough to detect the same kind of radiation and saw nothing, there must have been a major change in the radiation and plasma environment around Jupiter since 1974.

Io is, of course, embedded in the torus and is presumably feeding the torus the material of which it is composed. As Voyager flew through the torus and under Io, it was possible to analyze the material directly. Sulfur, oxygen, and probably sulfur dioxide were identified. Though it couldn't be measured directly, there is likely hydrogen as well.

The Io torus thus appears to be a major link between the magnetospheric and satellite studies. The mechanism by which Io fed material into the torus was not immediately apparent. However, four days after the closest approach, with the discovery of active volcanoes on Io, it appeared that Io might be injecting into the torus such volcanic gases as sulfur dioxide, which would eventually be broken down into sulfur and oxygen, the ionized species that make up the plasma torus.

Unusual amounts of sulfur and oxygen are detected not only at Io, but right out to the edge of the Jovian magnetic field, and inward from Io as well. Inside of Io's orbit, the Voyager team led by Professor Vogt discovered that some of the oxygen, sodium, and sulfur ions have velocities greater than 10 percent of the velocity of light. The acceleration process by which ions from Io acquire such high velocities is the subject of more detailed study.

The torus, then, is the dense nucleus that feeds the rest of the magnetosphere with sulfur and oxygen — and probably also hydrogen. Possibly the torus material is coming out of the active volcanoes on Io, and perhaps the changes in the torus and the auroral activity since the Pioneer observations in 1974 are the result of changes in the volcanic activity. Certainly, if the volcanoes turn on and off, that could grossly affect the intensity of the plasma and therefore the intensity of the ultraviolet emissions. It could also affect the auroral activity. The difficulty with such a simple explanation is that since there were seven active volcanoes on Io during the Voyager 1 encounter, it's not easy to understand a possible cessation of volcanic activity in 1973-1974.

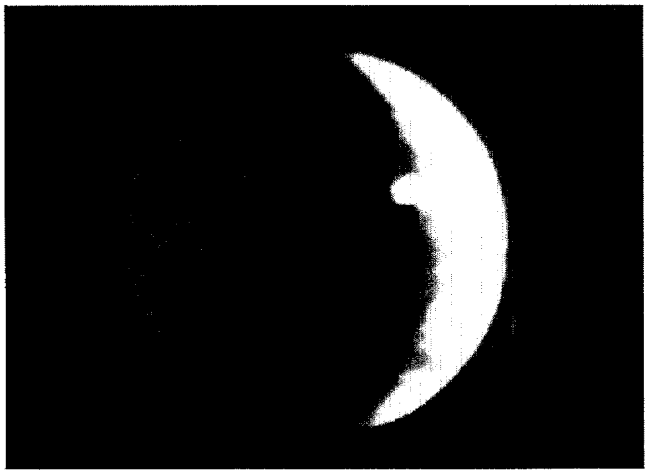


Jupiter is a ringed planet in more ways than one. First, it is orbited by a number of satellites; the paths of two of them — Io and Amalthea — are shown here. The large doughnut-shaped ring in which Io's orbit lies is a sulfur torus, with a diameter of 2 R_J (twice the radius of Jupiter) and a temperature of approximately 100,000°K. The magnetic field lines along which a five-million-ampere DC current flows from Io down to Jupiter and back again are called the Io flux tube. Not shown on this drawing, but in a circle inside Amalthea's orbit, is the thin layer of dark colored rocky material that Voyager 1 discovered orbiting Jupiter at about 35,000 miles above the cloud tops.

Although the observation of active volcanism was the most surprising Voyager 1 result, there was a calculation published shortly before the encounter which suggested that the heating due to the tidal distortions of Io's rocky crust would be sufficient to melt Io's interior. Like Earth's Moon, all four Galilean satellites, having long ago lost almost all of their rotational energy, are locked so that one side always faces the planet. If any one of them were a solitary satellite, it would probably — like Earth's Moon — have a permanent tide or distortion of its surface, slightly oblong and pointing toward its parent planet. But Io, the innermost Galilean satellite, is associated with three other large satellites, and the gravity of each of them exerts force on Io. When Europa and Ganymede are on the same side of Jupiter as Io, they pull Io slightly further away from Jupiter. When those two are on the other side of Jupiter, Io moves closer to Jupiter a small amount. As Io is pulled in and out, the tide in the rock crust changes by up to 80 meters. Such recurrent tidal stretching heats Io much as a piece of metal is heated by repeated flexing. Although continuous tidal dissipation could eventually cause Io to spiral into Jupiter, evidently the rotation of Jupiter itself is pumping energy back into Io's orbital motion. Thus the ultimate source of energy for the continued volcanic activity on Io may well be Jupiter's rotational energy.

As interesting as Io is, it is just one of four major satel-

Voyager 1 at Jupiter



Taken for navigational purposes, this picture of Io is nevertheless one of the most scientifically exciting of all of the thousands of images returned to Earth by Voyager 1. It gave the first proof of volcanic action on Io and set scientists to reexamining other photos — eventually to come up with evidence of seven active volcanoes on the satellite and a possible explanation for how Io feeds material into the sulfur torus. In this photo, one volcano can be seen on the limb, with ash clouds rising more than 150 miles above the surface. The second volcano is the bright area on the terminator, where the volcanic cloud is catching the rays of the rising Sun.

From a distance of 18,480 miles, one of Io's volcanic craters looks like this. The region in the photo is about 147 miles wide, and the caldera itself is about 30 miles in diameter, with dark flows of lava radiating from its rim. Some of the flows are over 60 miles long and almost 10 miles wide. Similar but smaller flows and craters occur on the island of Hawaii.

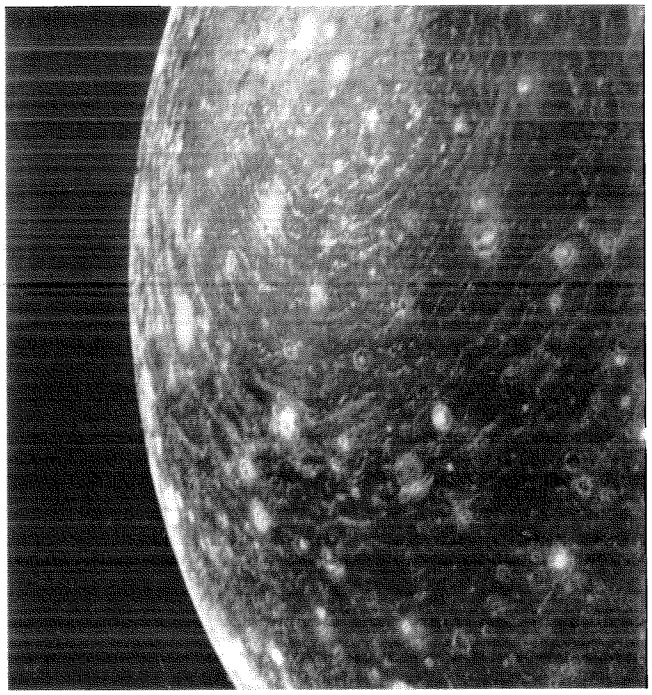
lites that are the subject of the third major area of Voyager studies. As Galileo first observed, the four satellites — two of which are about the size of the Moon and the other two similar in size to Mercury — form a miniature solar system about Jupiter. There is an important similarity between the solar system and the Galilean system that Galileo could not have known. The inner two satellites, Io and Europa, are dense rocky objects, as are the inner planets, while the outer two satellites, Ganymede and Callisto, are low-density objects, as are the outer planets. Thus there are two systems in which the formation of secondary bodies about a primary can be studied.

The outermost Galilean satellite, Callisto, has a density less than twice that of water, suggesting that it may be half water or ice. Callisto has the oldest surface, probably four billion years old. It is very dark colored, possibly a mixture of rock and ice. The surface is heavily cratered, with one huge ghost of an impact crater, which is a series of fairly regularly spaced concentric circles. The very regularity and spacing of these rings will provide information about the mechanical properties of the material at the time of impact. Callisto's surface evidently has not been significantly modified by internal processes.

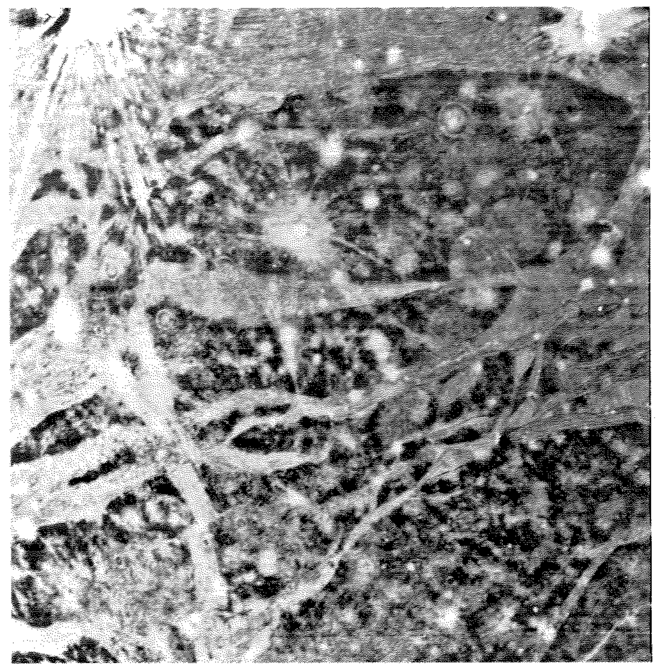
Although Ganymede is almost the same size and density as Callisto, there is clear evidence that its surface has been severely modified by internal processes. There are large dark areas that are older, separated by lighter, younger highly striated regions, as though it were ice under compression. There appears to have been some internal process that has resulted in the movement of the darker regions around on the surface in a way that may have some similarity to continental drift here on Earth. Thus the evolution of Ganymede and Callisto has been quite different and will be studied in detail.

Since Voyager 1 did not fly close to Europa, there is currently less known of this satellite, which is similar to Io in size and density and orbits Jupiter between Io and Ganymede. Europa is a rocky body with a thin ice crust that is marked by long curvilinear streaks that are 50 to 200 km wide. These streaks may be large cracks in the glacial cover, perhaps extending into the rocky surface itself. There are at least two ways such cracks might occur. One is that tidal forces pulling on the satellite caused cracking of the surface long ago. Another is that Europa, like Io, is internally active, and the cracking is evidence of continuing internal thermal activity. Of course, the streaks may not be cracks. Voyager 2 will fly much closer to Europa in July and should greatly improve our knowledge of this fourth different Galilean satellite.

Voyager 2 should also provide more information about the ring discovered around Jupiter about 35,000 miles above the cloud tops. A number of additional images have



Heavily cratered Callisto is the outermost and darkest of Jupiter's satellites and probably has the oldest surface. It is thought to have a rocky or muddy core with an icy crust. Most of its craters are from 12 to 30 miles wide, but one exception is the huge impact basin at the upper left. The basin is more than 370 miles wide, and its concentric rings extend outward more than 800 miles. The ripples probably were formed as the fragile, icy crust heaved under the impact of a large meteorite and then quickly froze again. Incidentally, dark as Callisto appears, it is still more than twice as bright as our Moon and considerably larger — about the size of the planet Mercury.

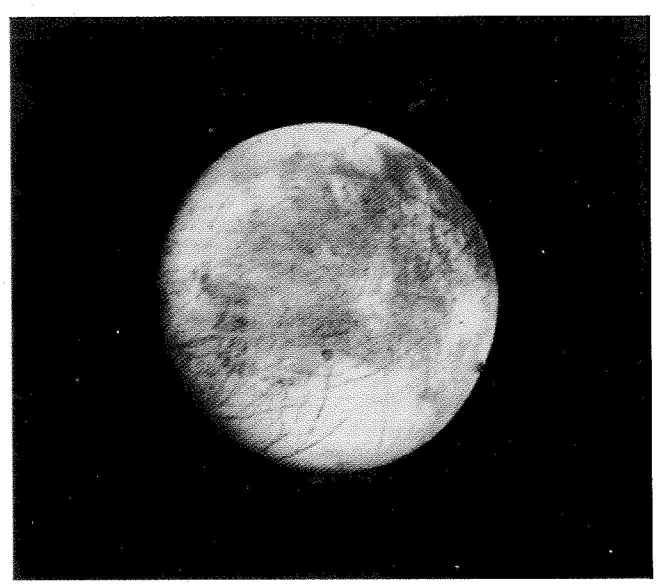


The largest of the Galilean satellites is Ganymede, which is about 1.5 times the size of our Moon and about half as dense. It has numerous impact craters, many with extensive bright ray systems. A bright band trending in a north-south direction in the lower left-hand portion of this picture is offset along a bright line. This offset is probably due to faulting, and this is the first observation of such a fault anywhere in the solar system outside Earth.

been scheduled in order to determine the inward radial extent of the ring, which seems to be a very thin layer of dark colored rocky material. It's interesting that this is the third giant planet with a ring, leaving Neptune the only one without a known ring.

Voyager 2 will also take a series of images of Io over a 10-hour period so that time-lapse sequence of the volcanic plumes will be available for study of the variability of the volcanic processes. Much more extensive darkside imaging of the lightning and auroral activity on Jupiter is planned for Voyager 2, which will also provide closeup views of the sides of Ganymede and Callisto that were not viewed closely by Voyager 1.

Both Voyager 1 and 2 will continue on to Saturn, arriving in November 1980 and August 1981, with an option to send Voyager 2 on to a January 1986 encounter with Uranus. Thus, the Voyager 1 encounter with Jupiter is just the first of a series of encounters with the many different and surprising worlds in the outer solar system. □



The long linear structures that criss-cross the surface of Europa could be faults or fractures. Some of these features are as much as 1000 miles long and 125 miles wide. Voyager 2 is expected to furnish considerably more detail about this smallest of the Galilean satellites.

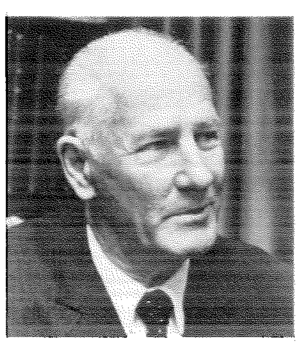
Genes, Cells, and Behavior
A View of Biology Fifty Years Later

by Norman H. Horowitz
Chairman of the Division of Biology

A symposium on "Genes, Cells, and Behavior: A View of Biology Fifty Years Later," marking the 50th anniversary of the founding of the Division of Biology, was held on the Caltech campus on November 1-3, 1978. Eighteen papers, covering topics ranging from molecular genetics of bacteriophage to human behavior, were presented in five sessions. The speakers were all alumni or former members of the Division. Over 700 alumni, students, and friends of the Division attended the symposium, which was moved to Beckman Auditorium after overflowing Ramo.

In the following article, we summarize the talks given in the last three sessions of the symposium. Summaries of the first two sessions appeared in the March-April issue of *Engineering & Science*.

Session III — Evolution, Genes, and Molecules



The Origin of Maize

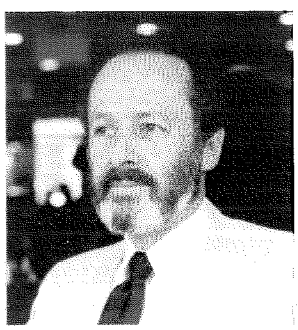
Dr. George W. Beadle
Nobel Laureate
President Emeritus
University of Chicago

Maize was the most important food plant of pre-Columbian America, and it is today the third most important grain crop in the world, after wheat and rice. Its origin has long been a mystery. There are no wild representatives of maize; in fact, it is the sole member of its genus, *Zea*. Maize cannot survive without human intervention, owing to its lack of effective seed dispersal and its vulnerability to birds, rodents, and insects. In the early 1930's, R. A. Emerson and Beadle concluded that the most probable ancestor of maize was *teosinte,* a relative that grows wild in Mexico and Nicaragua. *Teosinte* hybridizes with corn, and the hybrids are fertile. It has the same number of chromosomes (10 pairs), and Emerson and Beadle showed that crossing-over occurs normally between maize and *teosinte* chromosomes. Despite this evidence, the two plants are so different morphologically that some botanists questioned whether they are actually close relatives. Furthermore, *teosinte* has a tough seed case — so tough that it was doubtful whether primitive man would have found the plant edible and therefore valuable enough to cultivate.

In 1938, Mangelsdorf and Reeves proposed that *Tripsacum,* a more distant relative of corn, was the ancestor. This seemed unlikely on genetic grounds: *Tripsacum* and maize hybridize only with difficulty, and the hybrids are sterile. *Tripsacum* has 18 pairs of chromosomes, none of which pairs with those of corn.

Beadle decided to clarify the corn-*teosinte* relationship by further study of their hybrids. He grew 16,000 F_2-backcross plants in a plot near Mexico City and found that parental phenotypes appeared in approximately one out of 500 plants. It was clear from this that there could not be a large number of major gene differences between maize and *teosinte*. Beadle also found that the seeds of *teosinte* can be made edible in several ways. They can be popped; they can be ground between stones with the seed cases and made into edible tortillas; or the shells can be separated from the seeds after grinding by flotation in water, and the seeds can be eaten. Thus, the Indians of Mexico would have had ample reason to cultivate *teosinte* and, by selecting random variants, gradually transform it into maize. Beadle considers this man's most impressive plant-breeding achievement.

This work has practical significance. *Teosinte* is an endangered species in Mexico because of overgrazing. Since it is the only wild relative of corn that can be exploited for desirable genetic traits, seed-banking and preservation of populations of *teosinte* should be carried out to save the species.



DNA Sequence Organization and Its Evolution in Drosophila

Professor M. S. Meselson
The Biological Laboratories
Harvard University

In this paper, Meselson described a study in his laboratory of certain segments of DNA that he termed "mobile genetic elements." These are short fragments of chromosomal DNA from *Drosophila* that Meselson and his co-workers find in some flies but not in others of the same or a closely related species. These fragments may be related to "transposable genetic elements" that have been known for some time in maize and in the bacterium *E. coli*. To detect the mobile elements, random pieces of *Drosophila* DNA (previously cloned in *E. coli* to obtain sufficient quantities) were made radioactive and then were reacted with giant salivary chromosomes under conditions that allowed the fragments to combine with their complementary sequences in the chromosomes. By autoradiography, the number and locations of the binding sites for each fragment could be determined.

Experiments were performed with *D. melanogaster* and *D. simulans,* which are closely related species. They can be crossed, and their genetic maps and the banding patterns of their salivary chromosomes are very similar. Of 27 random pieces of DNA from these species that were reacted with the salivary chromosomes of both species, 19 combined with a single site (the same site) in both species. The other 8 combined with more than one site in the species of origin and with fewer sites (in some cases, none) in the other species. For example, one fragment from *D. melanogaster* combined with 23 sites in *melanogaster* chromosomes, but only 3 in *simulans;* of these 3, 2 were the same as the *melanogaster* sites, and one was different. These multisite fragments also showed differences within the species of origin. One fragment, called 232.2, was investigated in detail. It is a segment 1,500 nucleotides long from the Oregon-R race of *D. melanogaster*. It combines at five positions in one stock of Oregon-R, but at only four in another, and at none of these sites in *D. simulans*. Of particular interest is that it combines with a site of heat-shock puffing in the *melanogaster* chromosomes. (Puffs are enlargements of the chromosomes induced by temperature shocks; they are sites of intense transcription and translation of genes into RNA and proteins.)

It was hoped that this association would make it possible to identify the protein and the biological function of 232.2. By genetic methods, a portion of the puff region containing the binding site of 232.2 was deleted. The resulting flies were apparently normal in the production of all the heat-shock proteins. The function of the mobile element is still a mystery.

The Molecular Analysis of Genes in Drosophila

Professor David S. Hogness
Department of Biochemistry
Stanford University Medical Center

David Hogness and his students were the first to apply molecular cloning, or recombinant DNA techniques, to *Drosophila*. They isolated and cloned the first *Drosophila* gene in 1973, and since then they have cloned about two dozen more. Hogness discussed the state of the cloning art as applied to *Drosophila,* with the objective of showing both the possibilities and the limitations of this technology. One advantage that is not often emphasized is that

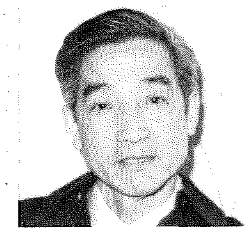
Drosophila has one of the smallest genomes (total amount of nuclear DNA) of any higher organism. He briefly summarized the steps involved in producing a library of cloned genes — i.e., a collection of fragments of DNA, each one incorporated into the DNA of a self-replicating vector (a plasmid or a bacteriophage) that can be multiplied indefinitely.

Having produced a library that includes all the genes of an organism like *Drosophila,* the next problem is to select from among the many thousands of cloned fragments the one that includes the gene of interest. Current methods for solving this problem depend on the availability of a complementary copy of the desired gene. The copy is made radioactive and is allowed to combine with the gene by complementary base-pairing; the gene is then identified by its radioactivity. Such complementary copies exist in cells in the form of messenger-RNA, but usually in amounts too small to be useful for this purpose.

This was the case in the example that Hogness discussed in detail — that of the genes for the histones of *Drosophila.* (Histones are five proteins that are combined with DNA in chromosomes.) Histone messenger-RNA's had been obtained from the sea urchin, however, and it is known that histones have undergone little change in evolution. Taking advantage of this fact, Hogness and his coworkers used sea urchin RNA to identify clones bearing the histone genes of *Drosophila.* These were grown up, and the *Drosophila* genes were isolated from them. The usual procedure could now be reversed and, by use of the purified *Drosophila* genes, the messenger-RNA could be isolated from extracts of *Drosophila* cell cultures. It was found that the five histone genes are clustered on the second chromosome, and the cluster of five is repeated about 100 times. Studies on the ''leader sequence'' — the stretch of DNA immediately preceding the genes — are under way to identify the signals involved in translation of the genes.

More difficult cases are those in which it is not ever certain that the gene makes a messenger-RNA. One such example is the bithorax complex of genes. This is a cluster of eight or more genes that control the development of the thoracic and abdominal segments of *Drosophila.* These genes are typical of the majority of genes that have been studied in this organism in that the molecular mechanism of their action is unknown. This problem is approachable if a gene with an identified messenger-RNA exists in the neighborhood on the same chromosome, as is true in this case. By use of a series of overlapping DNA sequences, it should then be possible to reach and identify the gene (s) of interest.

Genetics of Bacterial Nitrogen Fixation



Dr. S.-C. Shen
Institute of Plant Physiology
Academia Sinica, Shanghai
People's Republic of China

The biological fixation of nitrogen is carried out by nitrogenase, an iron- and molybdenum-containing multiprotein complex found in certain bacteria; this enzyme complex catalyses the fixation and reduction of N_2 to NH_3. Nitrogenase is specified by a set of nitrogen-fixation *(nif)* genes. (There is currently much interest in these genes, motivated by the desire to gain an understanding of the mechanism of nitrogen fixation and also by the possibility of applying genetic engineering methods to the *nif* genes of the bacterium *Klebsiella penumoniae.*)

The *nif* genes of *K. pneumoniae* were first mapped by Dixon and Kennedy, who placed nine genes in two clusters in the neighborhood of the *his* operon (a group of genes controlling the synthesis of the amino acid histidine). The two clusters were separated by a ''silent region'' some 9,000 nucleotides in length. This result has been reexamined by Shen and his co-workers, using newly isolated as well as previously known *nif* mutants. No silent region was found. Seven different genes were identified among 21 mutants, and these all mapped in a single cluster in the *his* region. It is not yet known whether the *nif* cluster is organized into a single operon (a group of genes that are switched on and off as a unit).

Recently, Brill has identified 14 *nif* genes in seven operons in *K. pneumoniae*. It was shown that three of the genes determine the structure of three nitrogenase polypeptides, and four others determine the iron-molybdenum cofactor and an electron-transport factor. Results from Shen's laboratory show that one *nif* gene, N-120, is needed for the synthesis of the two components of nitrogenase. Whether N-120 is a 15th gene for N-fixation remains to be proved.

Shen also reported that *nif* mutant C-7 produces 60 percent of the normal level of glutamine synthetase activity and only 30 percent of the normal amount of glutamate synthetase activity. Extracts of the same mutant contain only traces of components I and II (major protein components of nitrogenase). C-7 is an example of a class of *nif* genes that exert a regulatory effect on other *nif* genes, besides specifying their own product. In view of such complexities, difficulties in the cloning of *nif* genes can be anticipated.

Session IV — Biology of Cells

Hormones and Tissue Culture: Basic and Health-Science Aspects

Professor Gordon H. Sato
Department of Biology
University of California
San Diego

Gordon Sato began his lecture with an autobiographical note. He recalled his youth in a tough neighborhood of Los Angeles, his job as a gardener in Pasadena, and his admission to Caltech as a probationary graduate student after he had a disabling fall from his truck. A guest in the audience — a physicist from the East Coast — wrote later to say that as long as Caltech remains flexible enough to admit students like Gordon Sato, it need not worry that it will suffer the decline he sees in some other elitist universities.

Sato then described the two major achievements that have been made in his laboratory in the last 20 years. The first of these was the discovery that the commonly observed overgrowth of animal-cell tissue cultures by fibroblasts was not caused by "de-differentiation" of differentiated cells, as was formerly believed, but by the fact that fibroblasts — which are ever-present in tissues — were selectively favored by the culture conditions then employed and outgrew all other cells. Having established this, the next step was to learn how to make the desired cell types grow. The accomplishment of this goal is the second achievement.

The key to the problem turned out to be hormones. It appears that each type of cell requires a particular set of hormones for growth. For example, a line of pituitary cells studied in Sato's laboratory requires for optimal growth insulin, transferrin, thyroxin, parathyroid hormone, thyroid-releasing hormone, fibroblast growth factor, and somatomedin C. These hormones are usually provided in calf serum, which is customarily used in cell-culture media. The hormones can replace serum and thus make possible a chemically defined medium for this cell line.

Other cell lines require other hormones, and approximately 20 different kinds of cells have been cultured in this way in Sato's laboratory. In some cases, growth is better in the defined medium than in serum-containing medium. The importance of the discovery that every cell is dependent on a specific complex of hormones is, first of all, that it constitutes new knowledge about the organization of the animal (including human) body. It makes it possible to establish new, primary cell cultures more readily than before. And it could lead to practical benefits, as in cancer biology, where knowledge of the specific hormone requirements of different kinds of cancer cells may offer, to quote Sato, "the possibility of manipulating the physiology of these tumors and combining them with chemotherapy to optimize treatment."

Genetic and Functional Dissection of the Major Histocompatibility Complex

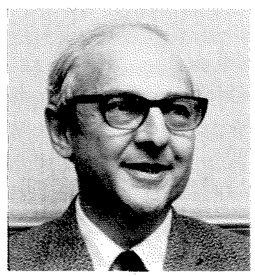
Professor Donald C. Shreffler
Chairman
Department of Genetics
Washington University
School of Medicine

Donald Shreffler's subject was the major histocompatibility complex (MHC), which is a closely linked cluster of genes that is present in recognizably homologous form in mammals, birds, and amphibians. It contains the genes responsible for the classical histocompatibility, or self-recognition, function that is manifested in graft rejection. More recently, the MHC has been found to be involved in certain immune mechanisms and in susceptibility to various diseases. Shreffler's talk focused on these newer aspects. He pointed out, for example, that there is a strong association between ankylosing spondylitis (a form of arthritis) and HL-A B27, an antigen determined by one form of a gene of the MHC of man. Over 90 percent of patients with ankylosing spondylitis have this antigen, but fewer than 10 percent of the unaffected controls show it. Other associations between particular MHC genes and disease are found in pharyngeal carcinoma in man and in virus-induced leukemia of mice.

Other recent findings relate to cell-recognition responses — for example, that involved in the interaction between so-called B- and T-lymphocytes, which cooperate in the production of antibodies. Shreffler and others have shown that, for this reaction to occur, the B and T cells must be identical in the I gene of the MHC. Similarly, in killing reactions against virus-infected cells, the target cell and the killing lymphocyte must share the same K and D regions of the MHC in order that the reaction may take place. Mutations in either genetic region lead to failure to kill virus-infected cells.

Another interesting finding has been the identification of serum protein Ss (first detected by Shreffler when he was a student at Caltech and mapped by him to the MHC region of the mouse) with one of the components of complement, which is the name given to a group of proteins in the blood that act cooperatively to lyse foreign cells.

Shreffler also summarized evidence showing that considerable duplication of genes has occurred in the course of evolution of the MHC complex. Duplicate genes are common within the complex, and the proteins determined by these genes are very similar in structure. He concluded by observing that the MHC system is becoming one of the most useful in molecular genetics.



Simple Social Cells

Professor Dale Kaiser
Department of Biochemistry
Stanford University
Medical Center

Myxobacteria are rod-shaped bacteria about five microns in length. Although bacterial in structure, they exhibit multicellular behavior and may be the simplest social cells. Their social behavior is shown in their movements. Large groups of cells move together, in cell-to-cell contact, like rafts of logs. The mechanism of this movement, called "gliding," is unknown. It occurs only on solid surfaces and is always in the direction of the long axis of the bacteria, with frequent reversals. Individual cells are capable of movement, but movement is more frequent and continuous in groups. A moving group leaves a trail of slime that is followed by other groups. When starved, myxobacteria aggregate to form stalked fruiting bodies that produce spores.

The social behavior of myxobacteria can probably be explained by the fact that they secrete enzymes into the external medium to digest the cells that form their food. Single cells cannot produce enough enzyme to support their growth at a maximal rate, but a large number of cells can do so by pooling their enzymes.

Kaiser and Hodgkin have isolated a large number of non-motile mutants. In many cases, the mutants complement one another; that is, they become motile when mixed together. This effect, called "stimulation," is phenotypic only. Re-isolated cells are still non-motile. There are six complementation groups of mutants, any two of which will show the stimulation response when mixed. Transduction crosses have revealed 22 loci, 17 of which belong to one of the six complementing groups. The other groups map to single loci.

Study of revertants has shown that there are two kinds of motile cells — those that can move as single cells and those that move only in groups. The former movement is determined by a set of genes called system A, the latter by system S. Wild type has both systems. System A consists of the genetic loci described above, and any cell with a complete set of these genes can move singly. System S contains at least nine genes. The two systems have one gene in common but are otherwise independent.

Social movement is associated with the possession of pili — long, hairlike processes growing out of one end of the cell. Pili production is controlled by the S genes. Pili apparently bind cells together and enable them to move as a group. Complementing S mutants stimulate one another to move, and — remarkably — they do so by inducing pili formation.

Session V — Neurons and Behavior

Variations in Human Brain Organization

Professor Jerre Levy
Department of
Behavioral Sciences
University of Chicago

It was discovered in 1836 that speech is localized to the left side of the brain. By the end of the 19th century it was believed that all sensory understanding and cognition were the function of the left hemisphere. The right side of the brain was thought to receive and send information but not to process it. As recently as the 1940's, studies on split-brain patients (individuals whose corpus callosum — the large tract of fibers connecting the two hemispheres — had been severed to control intractable epilepsy) failed to detect any effects of hemispheric separation on brain function.

In the 1960's a series of split-brain patients of Drs. J. E. Bogen and P. J. Vogel were studied in Roger Sperry's laboratory. These studies revealed a distinct syndrome. Sensory inputs directed to one hemisphere did not cross to the other. For example, an object placed in the left hand (hidden from view) was sensed by the right hemisphere but could not be named by the patient, since that hemisphere is speechless. The right hemisphere nevertheless recognized the object, as shown by the ability of the left hand to select a matching object.

Although the two hemispheres were completely isolated from each other, the performance of the patients in everyday life was normal, showing that the integrative function of each hemisphere had not been disrupted by the disconnection. This was one important result of these experiments. Another was the demonstration that the right hemisphere is a conscious, thinking half-brain. The cognitive functions of the hemispheres were explored by a variety of tests. The right hemisphere dominates in pattern recognition, especially facial or other complex patterns encountered for the first time. It is weak in verbal and phonetic abilities, but strong in extracting spatial and physical relationships nonlinguistically. Its memories are rich in the sensory qualities of the objects recalled. The left hemisphere understands logical causality; it is abstract and analytical; and its reasoning is propositional. These are all qualities associated with speech and language.

The foregoing applies to nearly all right-handed persons, but only 60-65 percent of left-handers have language in the left hemisphere. The others are lateralized in the opposite sense, or are only weakly lateralized. Those with left lateralization have the problem that when writing they need access to linguistic information from the left hemisphere, but normal motor pathways are crossed. In many cases it appears that ipsilateral (same-sided) motor pathways are used. Tests indicate a correlation between hand posture in writing (hand inverted above the line of writing) and the use of ipsilateral pathways.

Navigation by Honeybees

Professor James L. Gould
Department of Biology
Princeton University

Ethology is the study of animal behavior. It owes its existence as a scientific discipline to two basic discoveries. First, animals live in unique sensory worlds, separate from our own; and second, animals are to a large extent robots, pre-programmed by their genes. After outlining the evidence for these conclusions, Gould summarized the present state of knowledge of honeybee navigation.

Bees fly great distances in search of food, often 1 to 10 kilometers — the equivalent of a journey of 60 to 600 miles for a human being. To locate food and then find its way back to the hive without getting lost, the bee uses conspicuous landmarks and celestial navigation. The latter is performed with reference to the sun. Karl von Frisch, the founder of this field, showed that bees know the sun's position even when it is hidden behind trees or clouds or when it is below the horizon. This capacity resides in the ability of bees to perceive both ultraviolet (UV) and polarized light. (We are blind to both.) The advantage of polarized UV for navigation is that polarization (caused by Rayleigh scattering of sunlight in the atmosphere) contains information concerning the position of the sun, and clouds are nearly transparent to UV.

In trying to learn how honeybees use polarized UV to locate the sun, Gould and a colleague first train bees to use an artificial food source. They then observe the bees when, after their return to the hive, they communicate the location of the food to the colony by means of their "dance language." This communication is performed under artificial sky patterns controlled by the experimenters. Wavelength distribution, elevation, angular size, brightness, and polarization are varied, and the interpretation given by the bees to different patterns of sensory cues is deduced from their dance. Current evidence suggests that forager bees in the field somehow record a picture of the sky. On their return to the hive, they match the cues visible in the sky overhead with the recorded picture. They use a set of fixed rules to relate the visible cues to the location of the sun, and they then orient their waggle dance in the direction of the food. Since the attendant bees use the same rules to interpret the dance, it does not matter if, as can happen under the rules, the dance is in fact misoriented.

The goal of ethological research is to analyze behavior at all its levels of organization down to the genetic and molecular level. Another challenge for ethology, to quote Gould, "is to apply its insights to our own species — to discover how the unseen hands of evolution are directing or predisposing our behavior now that we have, at least overtly, left our hunter-gatherer heritage so very far behind."

Genes, Cells, and Behavior

Plasticity of Transmitter Mechanisms in Sympathetic Neurons

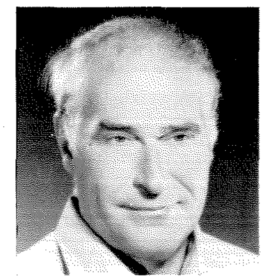
Professor Edwin J. Furshpan
Department of Neurobiology
Harvard Medical School

One of the fundamental ideas of neurobiology is that neurons make connections only with a specific subset of other neurons. The resulting pattern of specific connections underlies the information processing that takes place in the nervous system. Another important idea is that neurons can be characterized by the specific neurotransmitter — or "flavor" — that they secrete. Thus, so-called cholinergic neurons secrete acetylcholine, and adrenergic neurons secrete norepinephrine. When the nervous system is formed in development, neurons have to make contacts with their proper target neurons, and the chemical transmitters have to be matched with the correct receivers. The heart provides a familiar example: Sympathetic neurons release norepinephrine onto the heart and cause its beat to increase, while parasympathetic neurons release acetylcholine and slow the beat. It is obviously important that each neuron secrete the appropriate transmitter.

The experiments in Furshpan's laboratory are designed to answer the question of what it is that determines transmitter flavor during the development of the nervous system. He and his colleagues worked with sympathetic neurons from the superior cervical ganglion of the rat. These neurons were grown in tissue culture. It was possible to use microelectrodes to stimulate and record action potentials from individual neurons in the cultures. When this was done, it was found that the responses were mostly cholinergic ones. Normally the majority of sympathetic neurons in the superior cervical ganglion are adrenergic. Only a small fraction — about 5 percent — are cholinergic. Further investigation showed that up to 75 percent of the cultured neurons were cholinergic, provided that the culture also contained non-neuronal cells. In pure neuron cultures, on the other hand, not over 2 percent were cholinergic. The rest were either adrenergic or were mixed. This effect of non-neuronal cells is due to the production of a diffusible chemical factor by these cells, and it does not require direct contact between neurons and non-neurons. The factor changes the fate of what would normally be adrenergic cells to cholinergic ones.

The factor is not the well-known nerve-growth factor, since experiments show that NGF simply increases the amount of transmitter the cell is already committed to make. Current information indicates that the factor is another large molecule, possibly a glycoprotein.

Finally, it has been found that if the cells in culture are stimulated electrically so as to imitate the nervous input they would normally receive in the animal, they fail to respond to the factor. This suggests that the timing of events in development may be important in determining the transmitter flavor of neurons.



The Leech Embryo

Professor Gunther S. Stent
Department of Molecular Biology
University of California
Berkeley

The last paper in the 50th Anniversary Symposium was, in the words of its author, "an old-fashioned, almost entirely descriptive" account of the embryology of the leech, a study that has its roots in a paper published 100 years ago by Charles Otis Whitman, who was one of the teachers of Thomas Hunt Morgan. The leech is a representative of those animals in which the cells of the early embryo are completely determined with respect to the role each will later play in development. In his 1878 paper on leech development, Whitman gave the first analysis of developmental cell lineages. Stent took up the account where Whitman left off.

Although his principal interest is in the neurobiology of the animal, Stent's description of leech embryogeny is a general one. Points of special interest included the adaptation of the horseradish-peroxidase cell-staining technique to the problem of tracing cellular pedigrees in development. Another method involves the use of the proteolytic enzyme pronase to kill individual cells and, by observing the effect on subsequent development, deducing the normal role of the killed cell.

The paper includes a detailed description of the development of movement in the leech embryo, beginning with simple, irregular contractions of muscle fibers and ending with the highly coordinated movements of locomotion. Stent concluded with an expression of his belief that by the time the Division of Biology celebrates its 75th anniversary, "the leech will have become both the phage and the fruit fly of embryology." □

Albert Einstein in California

by Judith Goodstein

He was welcomed with a mix of show business, hero worship and real affection

Two Einsteins in front of the brand-new Athenaeum in 1931 — Albert himself and a puppet from the play called *Mr. Noah.* Albert said the puppet was "good but not fat enough."

In the annals of 20th-century science, 1905 was a vintage year because in that year Albert Einstein, Technical Expert (Third Class) in the Swiss Patent Office, published four papers in the prestigious *Journal of the German Physical Society*. One dealt with the motion of particles suspended in a stationary fluid — popularly known as the theory of the Brownian motion. A second paper dealt with the nature of light, and the ideas embodied in this piece of theoretical research — more commonly known as the photoelectric effect — ultimately earned the author a Nobel Prize. The third paper discussed the electrodynamics of moving bodies, and those ideas soon became known as the theory of special relativity. And the fourth paper dealt with the relation between the inertia of a body and its energy content, which can be summed up in the equation $E=mc^2$.

The ideas in those four papers ushered in a new era of theoretical physics. In fact, Robert A. Millikan liked to say that even if Einstein had never published a word on relativity, his other papers of 1905 and his subsequent discoveries in radiation theory and statistical mechanics would have won him an enduring place in the history of ideas.

Fortunately, Einstein did think, write, and publish on the subject of relativity. In fact, he spent eight years transforming his special theory of relativity into the more comprehensive general theory of relativity. He began toying with the problem of incorporating gravitation into the special theory in 1907, and in 1916 published the fundamental paper on general relativity.

The theory of general relativity made a number of predictions, one of which — the bending of a ray of light in the vicinity of the sun — was confirmed by two astronomical expeditions in 1919. That confirmation, almost single-handedly, turned Einstein the theoretical physicist into a 20th-century folk hero. From then on until his death 36 years later, wherever Albert Einstein traveled, throngs of people gathered around him.

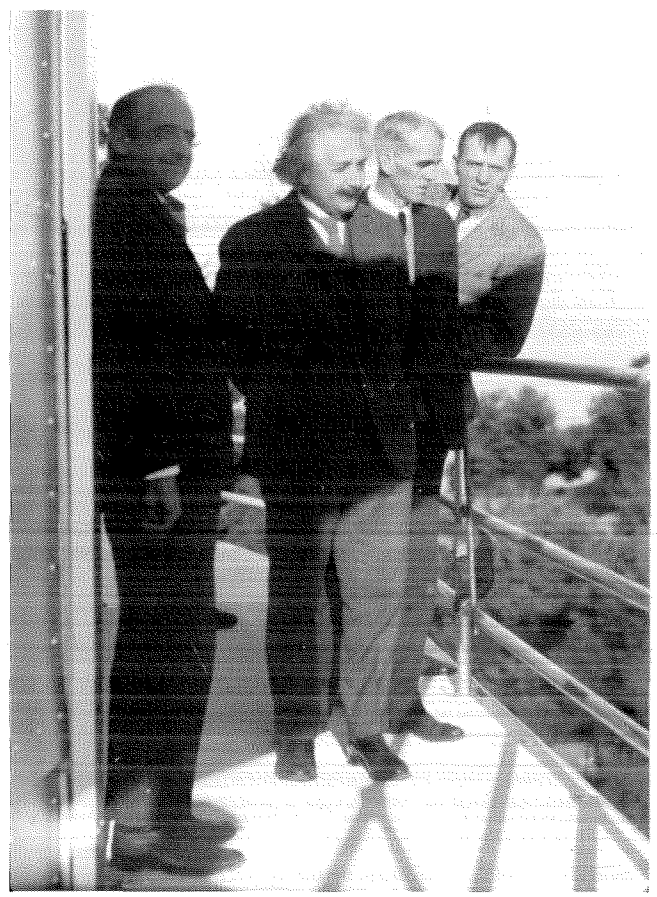
In the early 1930's he came to California specifically to consult with scientists at the California Institute of Technology. Few members of the general public understood the nature of his visits, but they idolized him all the same. From the moment his boat docked in San Diego on December 31, 1930, the reception accorded him by Californians was one part show business, one part hero worship, and one part genuine affection. Groups of children dressed in blue and white middies serenaded him and thrust wreaths of flowers into his hands, two bands struck up tunes, and in Los Angeles a theatrical group, the Yale Puppeteers, opened a play called *Mr. Noah* in which the ark landed on Mt. Wilson instead of on Mt. Ararat. After its landing, the script called for Mr. Einstein to come out of his office to see what was going on. Einstein himself agreed to attend a private performance of the play, and afterwards examined the puppet of himself, remarking that it was "good, but not fat enough." He then took from his pocket a letter addressed to "Lieber Albert," made a wad of it, and stuffed it up under the smock of the puppet.

Will Rogers, the noted humorist, really described the whole sideshow when he said just after Einstein returned to Berlin in March of 1931: "The radios, the banquet tables and the weeklies will never be the same. He came here for a rest and seclusion. He ate with everybody, talked with everybody, posed for everybody that had any film left, attended every luncheon, every dinner, every movie opening, every marriage and two-thirds of the divorces. In fact, he made himself such a good fellow that nobody had the nerve to ask him what his theory was."

"What his theory was" was very much the point of his visits to Caltech, however. As early as 1913, Einstein was looking for experimental verification for the correctness of his theory of general relativity, and he had been in correspondence with Caltech's George Ellery Hale, asking him to make an astronomical measurement. He was anxious to know if Hale could detect the influence of the sun's gravitation field upon a light ray. Hale replied that in order to try he needed a solar eclipse. The experiment was finally carried out in 1919 by two British expedition teams and again in 1922 by an American team of astronomers — and it did confirm the theory of general relativity.

There were cosmological implications in this theory, and they attracted a lot of attention in the 1920's and 1930's — nowhere more than at Caltech. Millikan had been urging Einstein to visit the campus for some time, and, in the fall of 1930, he agreed to spend the winter quarter in Pasadena. Not only would he be able to discuss his theory and its interpretation with distinguished scientists; he would also be meeting old friends again — Richard Tolman, the cosmologist; Paul Epstein, the theoretical physicist; and Theodore von Kármán, the aerodynamicist.

Tolman's scientific interests were varied, but the main thrust of his work at the Institute included statistical mechanics, relativistic thermodynamics, and cosmology. From its inception in 1905, Tolman followed closely the



In January 1931, Einstein and his mathematical assistant, Walther Mayer, with astronomers Walter Adams and Edwin Hubble at the top of Mount Wilson's solar tower.

development of relativity theory and its application to the problems of cosmology. Together with Gilbert N. Lewis, he published the first American account of the special theory of relativity (1909); and his introductory textbook about the theory appeared in 1917. This early interest in relativity theory, spurred on by Edwin Hubble's discovery that redshifts are proportional to distance, led to a series of studies at the Institute in the 1930's on the application of the general theory to the overall structure and evolution of the universe.

Epstein came to Caltech in 1921 from Holland, brought here by Hale and Millikan specifically to introduce the subject of quantum mechanics into the academic curriculum. Quantum mechanics was developed in two stages, and Epstein played a pivotal role in the first stage of its development. Equally important, Epstein's presence in Pasadena elevated theoretical physics to a place of prominence at the school.

Theodore von Kármán started out as a physicist and applied mathematician in Germany before embracing the field of aeronautics as well. He came to Caltech — the suggestion was Epstein's — in 1930 as director of the newly formed Guggenheim Aeronautical Laboratory.

The new Athenaeum at Caltech was the setting for many dinners to honor Einstein. At the first, on January 15, 1931, the guests included the physicist and Nobel Laureate A. A. Michelson and 200 members of the California Institute Associates. Several weeks later, a second dinner was held at which all the astronomers from the Institute and the Mt. Wilson Observatory were present. Edwin Hubble was there, as was Charles E. St. John, who verified the third prediction of the theory of general relativity. Colleagues came from Berkeley, including Tolman's close friend and co-author G. N. Lewis, who wrote to say he was coming with a friend — though not without some mildly humorous trepidation. As he put it in his letter to Tolman: "I have just accepted an invitation from Oppenheimer to drive me down. Do you think I should take out accident insurance?"

Einstein was not without a sense of humor himself. At a farewell luncheon in his honor on February 24, 1931, which was sponsored by the Pasadena Chamber of Commerce, he said: "I want to thank the extraordinary group of scholars in the fields of physics and astronomy who have afforded me glimpses of their work. They have conducted me not only into the world of atoms and crystals, but also to the surface of the sun and into the outermost depths of space. There I saw worlds which are flying away from us with incomprehensible rapidity, in spite of the fact that their inhabitants do not know us well enough to justify any such action."

To his relief, Einstein's visits to Caltech in 1932 and 1933 attracted less public attention. He and his wife, Elsa, moved into the Athenaeum for the duration of their stay, and he ventured off the campus less frequently. The purpose of his visits was, of course, the very serious one of discussing with his colleagues several scientific problems. Specifically, he was interested in the new astronomical findings concerning the redshift in distant nebulas. These observations indicated that the universe was expanding, not static, as Einstein had proposed.

How engrossing such discussions could be is indicated by a story about Einstein recently related by Charles Richter, professor emeritus of seismology. It concerned the Long Beach earthquake, which occurred at 5:54 on the evening of March 10, 1933. There had been a physics seminar that day, attended by Einstein and Beno Gutenberg, professor of seismology. The two walked back across the campus together talking mostly about Gutenberg's studies of earthquakes — and were so interested in what they were saying that they were oblivious to the fact that they were in the midst of one. When a colleague came up to them and asked, "Well, what did you think of the earthquake?" their response was, "What earthquake?"

Einstein was also deeply interested in problems of maintaining peace, particularly as they related to the rising power of Nazism in Germany. He participated in a student disarmament conference at the Pasadena Civic Auditorium, and a nationwide radio presentation on German-American relations. His first two visits to Caltech were sponsored by friends at Caltech, but his third visit, in 1933, was supported by the Oberlaender Trust of Philadelphia, in an effort to further understanding between Germany and the United States.

During this third visit, Einstein side-stepped as much and as long as possible the question of whether conditions in Germany might prevent his return to the country of his birth. After the January 30 announcement that Hitler had become Chancellor of Germany, the question could no longer be evaded. Scheduled to leave Pasadena at the end of February, he postponed his trip for a few weeks, and then went to Belgium for several months instead of to Berlin.

In the fall of 1933, Albert Einstein returned to the United States as an emigré, landing as so many had before him in New York City. From there, he went the short distance to Princeton, New Jersey, to become a charter member of Abraham Flexner's new Institute for Advanced Study and, eventually, a citizen of the United States. He died in 1955, never having returned to Germany or to Caltech. □

Engineering Education for a Rapidly Changing Technology

by Hans Liepmann

GALCIT, the Graduate Aeronautical Laboratories at the California Institute of Technology, is a system now 50 years old, with which I have been associated for nearly 40 years. Conceived by R. A. Millikan as part of his general scheme to construct a small, very high level technological school, GALCIT was built up by Theodore von Kármán (in the spirit of Felix Klein) to serve as a center for the fusion of science and technology. GALCIT has had an influence on engineering education in the U.S. out of proportion to its size and I will use the experience there as an example from which to extract some principles of engineering education for a rapidly changing technology.

SMALL SCHOOLS — PRO'S AND CON'S

In the 1920's and 1930's the Daniel Guggenheim Fund for the Promotion of Aeronautics made possible the establishment of a set of aeronautical schools in the U.S. The acronym GALCIT, which originally stood for Guggenheim Aeronautical Laboratory at the California Institute of Technology, reflects this origin. The aim of the Guggenheim Fund was clearly directed toward the schooling of engineers for the then rapidly developing aircraft industry. Quoting from C. B. Millikan's write-up in GALCIT's 25th Anniversary brochure of 1953:

> The program of instruction and research which was announced as the GALCIT began its life as outlined in the 1930 Catalogue of the California Institute:
>
> 1. A comprehensive series of theoretical courses in aerodynamics and elasticity with the underlying mathematics and mechanics.
> 2. A group of practical courses in airplane design.
> 3. Experimental and theoretical researches on
>   (a) The basic problems of flow in real fluids with regard to the scientific foundations of technical hydro- and aero-dynamics;
>   (b) practical problems in aerodynamics and structures, especially as applied to aeronautics.
>
> Far more important than the specific program outlined above was the fundamental concept of modern Applied Mechanics which Kármán brought to the new graduate school and which has ever since dominated its thinking and guided its activities.
>
> Modern Applied Mechanics was founded by the German mathematician, Felix Klein, late in the last century. Its aim is the application of methods of pure science to the treatment of engineering problems. Originally it involved the use of the most advanced mathematical techniques in the theoretical analysis of such problems and the application of the physicists' methods to their experimental study. More recently other scientific techniques, especially those of chemistry, have effectively been utilized.

For the times, GALCIT's surprisingly great emphasis on the basic sciences was, on the one hand, necessitated by the discipline: Aeronautical engineering, compared to other engineering disciplines, required far greater attention to fundamentals because ignorance could not be compensated for by large safety factors. On the other hand, these solid science-based foundations provided GALCIT with a marked flexibility, an ability to adjust easily to the rapidly changing technology.

Kármán was well aware of this fact and his insistence on the name "aeronautics" in preference to "aeronautical engineering," and his regret that it was impossible at the time to use the name "applied mechanics," clearly reflect this recognition. This flexibility has proved crucial for the continued success of GALCIT into the present, when standard aeronautical or aerospace engineering is but one part of a host of engineering and applied science problems encountered by its graduates.

Both the California Institute of Technology, with less than 2000 students, and GALCIT, with some 50 graduate students, are very small indeed. This fact presents both an unusual opportunity and unusual challenges. It is certainly far easier to keep a closer interchange between disciplines and between faculty and students in a small university than in a very large one, and it is easier to keep student levels up by selecting a small number from a large sample.

It is far more difficult to staff a small university, since mistakes in faculty appointments stand out, and it is far more difficult to decide on a research and instruction program, because a small set of directions has to be selected — complete coverage of any field being impossible. This selection has to be based, in turn, on a correct evaluation of the importance of developing new technology. This latter choice is obviously the most important and most difficult task in a time of rapidly changing technology. Again, this task is particularly difficult for a small institute, which cannot afford the luxury of safely covering all or most possibilities, a drawback that is fortunately somewhat counterbalanced by the greater flexibility of a small institute or school.

The correct anticipation of future needs is indeed the key to engineering education; it requires an awareness of both the new directions and results in the sciences, and an acquaintance with and understanding of the needs of industry. The necessary link with industry is not easily handled; *it requires a type of loose interaction sufficiently close to produce a mutual appreciation of problem areas, but not so close as to lead to oscillations in the school's program synchronous with the day-by-day crises in industrial production.*

Consequently, some problems found by engineering education in general are even more pronounced in a small school and some maxims derived from the experience with GALCIT should therefore have general validity.

A school the size of CIT and *a fortiore* GALCIT can never turn out the large number of line engineers required by industry. This has to be left to the large engineering schools with extensive undergraduate programs. GALCIT can only produce a small number of highly trained engineers to fill positions in which their broad background, the exposure to fundamental sciences, and the familiarity with modern tools is important. For the supply of this particular but essential subset of engineers the existence of small, high-level, versatile institutes or schools is, in my opinion and experience, crucial.

INPUTS

Faculty and Teaching. In any school facts and methods can be acquired from reading textbooks and only a minimum of guidance is required from a teacher. The development of an original style of approach to problems, a sort of basic philosophy in judging the importance of technological demands, and in particular access to the interconnections between disciplines, require first-rate instructors in the classroom and even more so in research education. Enthusiastic and forceful teachers sometimes reproduce students in their own image. This tendency, within limits, can be quite fruitful in pure scientific fields. In applied science and engineering, however, the vast majority of graduates should become practitioners of an art in surroundings that seldom resemble the environment of the faculty.

Selecting a faculty capable of remaining abreast of the fundamentals, coupled with an awareness of and interest in industrial problems, is probably the most demanding and difficult problem in engineering education. It is often advocated that teachers in engineering must come from a background in industry. In my opinion — clearly biased by my own upbringing — this is neither a necessary nor a sufficient condition. The background may be hopelessly outdated a few years after leaving industry, and the selection of industrial engineers who leave industry permanently for teaching is often biased toward unsuccessful members of industrial teams. I am *not* insinuating that engineers leaving industry for university appointments cannot become outstanding faculty members, but I do not believe that an industrial background guarantees success.

Often a practitioner of a specific important or fashionable analytical or computing technique appears as the ideal choice for an engineering faculty appointment because of his ability to solve "real" problems. If this competence in a specific technique is not grafted onto a broad interest and knowledge, success will be short-lived, industry will develop the same special capability rapidly, and the university will be left with an analytical technician of very limited use for research and teaching.

The awareness of industrial needs and problems by an engineering faculty, which is obviously a crucial prerequisite, can be brought in differently. Mutual consulting — faculty in industry and industrial engineers in schools — seems to me a necessary requirement. Service of faculty on national committees is another excellent source of inputs of real problems. Of course, the willingness of the faculty to be buffeted by the "real world" is the prime requisite for the success of any industrial contacts.

At GALCIT, two additional contact points with industry have proved important. The operation of a wind tunnel, and later of some water tunnels as well, used extensively by industry on a rental basis, has been a very important link with day-by-day industrial problems spanning a very wide variety of subjects from airplane performance to building aerodynamics and smog control. Indeed, the original GALCIT 10-foot tunnel of the Kármán days has had a beneficial influence on research and instruction that is difficult to overestimate.

The second most recent link with industrial problems that we have found particularly useful is a seminar-like course called "Case Studies in Engineering." This course is aimed at exposing students to the real and often not entirely technical problems in industrial production and consists of a presentation of the steps in the development of a finished product, presented by the engineers who made the decisions and did the actual work. One particular term's study covered the development of the DC-10. Other examples are the Mariner Spacecraft, a Hughes Communications Satellite, and a Lockheed Navy Plane.

In our opinion, such a course demonstrates to the students the intricacies, constraints, and compromises needed for the completion of a whole engineering system; something that is not learned by summer jobs in industry and similar experiences.

At the opposite end of the teaching, we rely on close cooperation with the applied mathematics and applied physics options to provide fundamentals in science. This cooperation includes joint faculty appointments. The importance of such cooperation increases with the increasing need for the exposure of engineering students to new developments in applied science: lasers, integrated electronics and optics, and cryogenics, for example, are rapidly becoming routine tools in many technologies. Industrial laser development as well as work on nuclear fusion have, in recent years, attracted a good fraction of our graduates. To be able to work in the ''advanced'' technology of today, and the unknown advanced technological problems of tomorrow, requires an exposure to fundamental science sufficient to at least permit an overlap with physicists, mathematicians, and chemists. For example, we strongly urge our graduates to take a course in quantum mechanics, as well as courses in solid state physics, modern optics, and, of course, digital electronics and computing. Contrary to public opinion the requirements for modern engineers are for a broad, rather than a narrow, highly specialized, background. *Consequently, the educational policy for a rapidly changing technology should aim for a graduate capable of specializing rapidly rather than being specialized.*

As an illustration from the past and present take, say, jet noise — a very relevant problem. Successful work on its reduction requires a combination of expertise in acoustics and turbulence. The reentry problem of spacecraft requires a combination of shock wave dynamics, and electromagnetic radiation, as well as convective heat transfer and thermodynamics. Chemical laser development leads to combined problems in turbulent mixing, reaction kinetics, and modern optics, coupled with at least rudimentary understanding of quantum mechanical radiation rules.

I may add that close contacts between applied mathematics and engineering is important in *both* directions. Contact with real problems is as important to applied mathematicians as access to new mathematical techniques is to engineers.

It is almost a definition of a real problem that it defies an analytical solution. Consequently, the principal ability that schooling should develop in an engineer or applied scientist is the ability to construct models. Stripping the nonessentials from a real problem to arrive at an approximate solvable model that retains the essential features of the original is the principal art in applied work. The existence of large computers shortens the distance between original and model but does not remove the need for model construction.

It is, of course, impossible to give a universal scheme or method for modeling valid for all cases; in this sense modeling is an art that can be developed fully only on a basis of broad and diversified knowledge coupled with a lot of common sense and intuition based on experience. Hence, modeling cannot be taught as a discipline with set rules but must be expounded by the discussion of examples.

What is surprising is the resistance of students to the use of educated guesses and to the lack of a systematic, foolproof scheme. This quite widespread reluctance to use an intuitive approach, in which not all the steps to the result are visible, is common in modeling, similarity considerations, and dimensional analysis — all of which are very important in solving engineering problems. This reluctance can be broken down only by developing confidence through repeated use which, with some help, leads to the realization that a scientific method need not be pedestrian and that engineering and applied science is an art as well as a trade.

Research. It is evidently easier to teach something you really understand. In a time of rapid changes such understanding, or teaching, requires a continuous education of the faculty. Research is usually the most effective way to keep a faculty competent and aware of recent — and future — problems. A really successful research program in an engineering school anticipates technology. For example, research in compressible fluid flow at GALCIT and elsewhere anticipated the need in the development of high-speed aircraft and jet engines. Research on two-phase fluid flow, which evolved from problems with rockets, proves now to be crucially important for work on reactor safety problems.

Instead of continuing with rows of examples in research, I would rather address two fashionable, and for me rather annoying, arguments faced in applied research.

It is sometimes stated that innovation in engineering requires less originality and ingenuity than innovation in basic science since all the fundamental laws governing engineering problems are known. This is an argument that, transferred to musical performance, would put a violinist at a much higher level than a pianist because the pianist "merely combines existing keys."

The second of the fashionable annoying statements encountered concerns the concept of relevance. I believe that practically every researcher aims at relevance and that research which leads to real understanding of a field is always relevant, if not today, then tomorrow. Wasted research efforts, in my experience, are usually the ones that pretend to be applied by clothing unreal problems in applied language — problems that are sometimes called "dry water."

In this context I cannot help but remember the time, 39 years ago, when I came to the U.S. The then relatively small effort on semiconductor research was considered of academic interest only. The transistor that a few years later resulted from the work is certainly the most important technological innovation of our time. It is almost funny today to read about the 1880 experiences of Werner von Siemens, whose simple theoretical equations leading to a rational way to lay undersea cables were called "scientific humbug" in some English engineering circles.

Students. The selection of the small number of entering students from a large sample is obviously a problem. Contrary to public opinion, to make this selection independent of incidentals like financial means, race, or sex is far easier than prejudging performance. Grades and tests measure the "voltage," but the requirement for performance is power — voltage times current; and the "current" is only partly evaluable from personal references. The history of past educational opportunities too can only partly be assessed and it is unavoidable that mistakes occur. The difficulties in selection are enhanced by the undergraduate background of the GALCIT students, which varies from civil and mechanical engineering to physics and mathematics, and by the variety in the universities and industrial positions from which they apply.

A small fraction of the incoming class has traditionally come from the military academies. I fully realize that the presence of officers on university campuses is considered a controversial subject in some quarters. To me, the contact between civilian and military engineering students is extremely helpful in developing mutual understanding and respect. In some curious ways, it contributes to the civilian education as well; for example, destroyer-trained engineering officers demonstrate an unbelievable ability to find and make do with scrap materials in their experiments!

For historical reasons the armed services in the U.S. have always played an important role in supporting research — indeed, often some very fundamental and not military oriented research. To have the technological interface between the military and civilian research establishment handled well requires, obviously, very competent officers who are aware of the sensibilities and idiosyncracies of the civilian research establishment.

Admissions to GALCIT are handled by the faculty, not by special administrators, and in borderline or particularly unusual cases we have arranged for personal interviews. A similar process is, of course, impossible for a large engineering school, which has to devise more formal schemes of admission to insure the best overall selection. A small school can handle fluctuations from the mean more easily and accommodate the occasional "oddball" who does not fit any established rules of admission.

In the vast field of engineering education, Caltech and GALCIT are of course singularities, but here — as in the theory of complex variables — the singularities determine the function.

Outputs

Graduates. Since its beginning GALCIT has produced some 1100 graduates, and detailed statistics have been kept of their careers. The most important results to be drawn from these statistics are:

1. Even during the depth of the crisis in the aerospace industry, graduates had no difficulty in finding industrial jobs. This is certainly due to their breadth in both training and outlook and it is reflected in the shift from employment in conventional aerospace to other industries. The dividing line between "aerospace" and other industry is today, of course, not sharply drawn but the diffusion of the graduates into very diversified industrial employment is evident.
2. The percentage of graduates who took academic positions has been nearly constant at between 16 and 18 percent except in the post-Sputnik years, when every university increased its space program and an unusually large fraction of graduates was seduced into academia.

One emerging technological field is doubtless energy engineering in all its forms, from fusion and fission reactors to coal combustion and the development of efficient power distribution, communication, and transportation systems. For these fascinating fields, the need for an engi-

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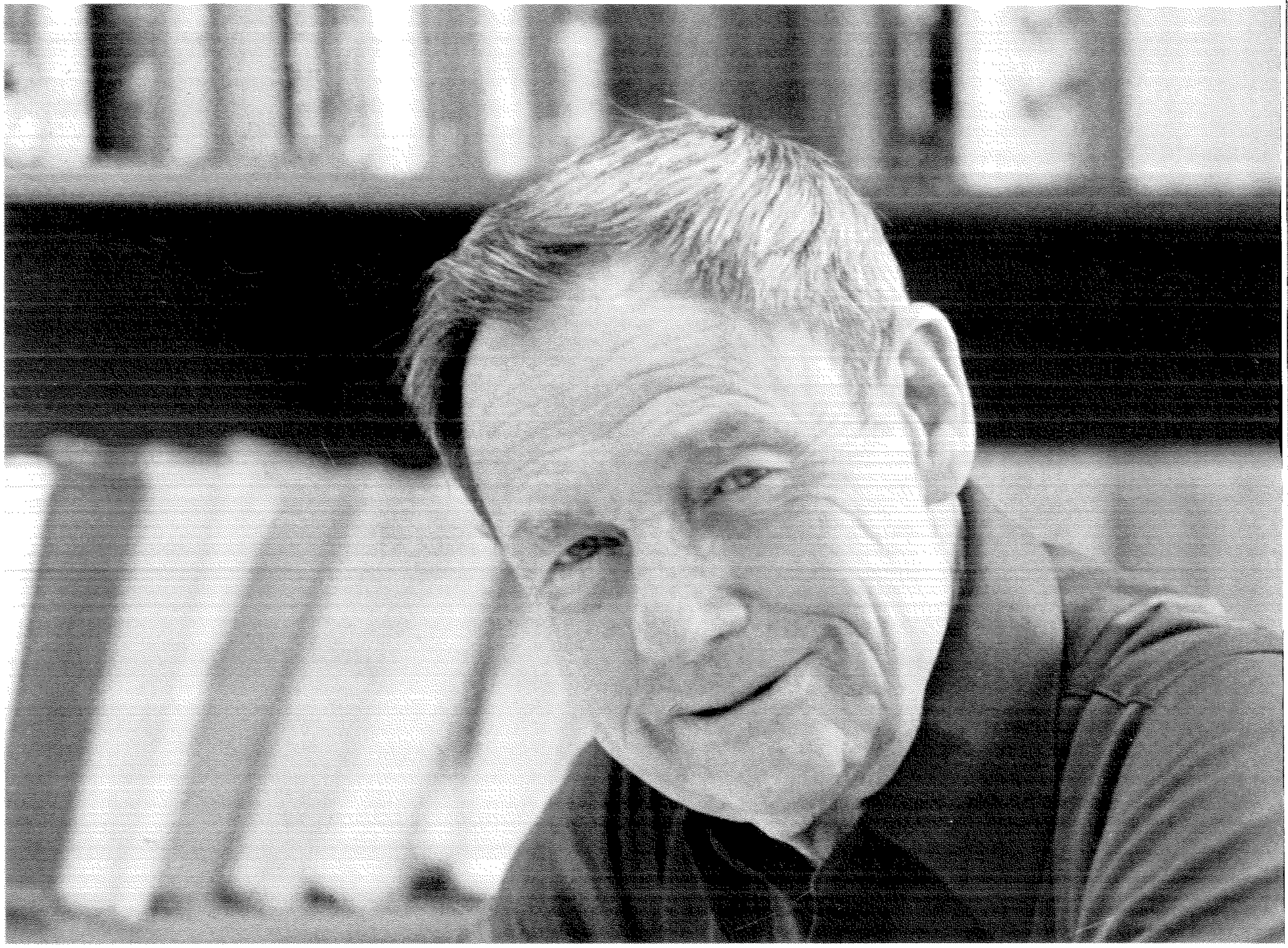
Retiring This Year

Robert D. Gray
Professor of Economics

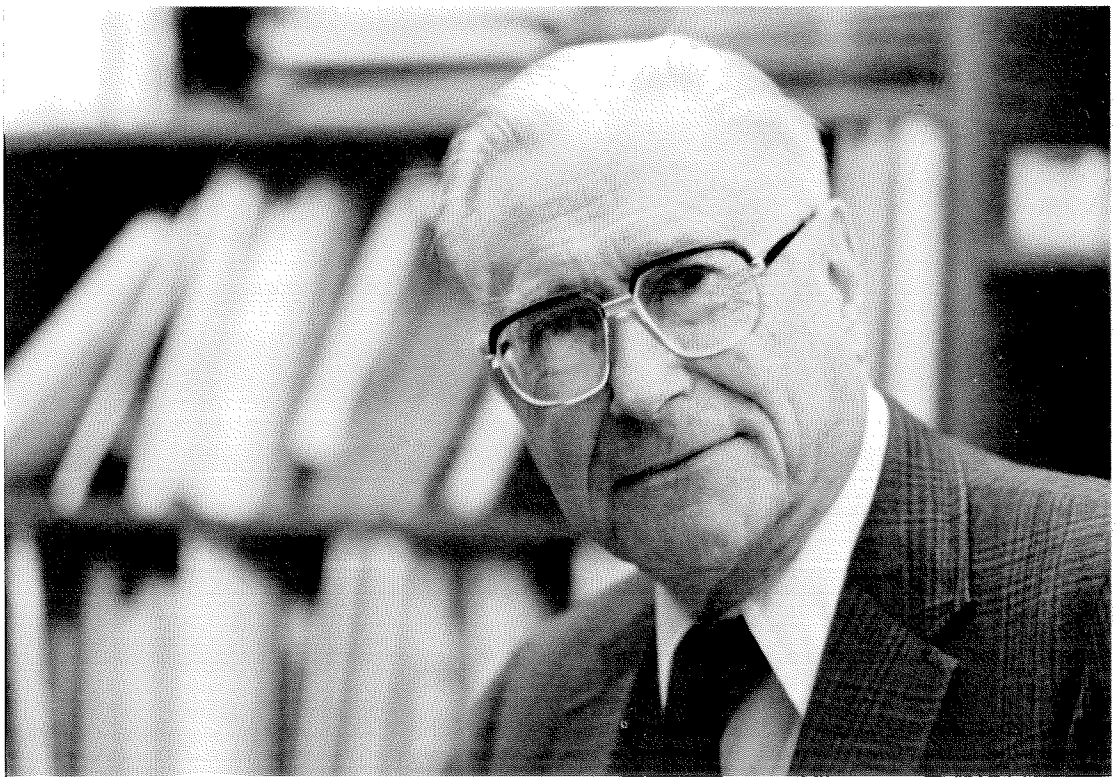
Robert D. Gray becomes professor emeritus this month after 39 years on the Caltech faculty. In 1930 Bob took his BS in economics at the Wharton School of Finance and Commerce, University of Pennsylvania, and remained on the faculty there until 1937. After three years at the University of Connecticut, he came to Caltech in 1940 as associate professor of economics and industrial relations, becoming professor in 1942. From 1941 to 1977 he was director of the Industrial Relations Section (which became the Industrial Relations Center in 1960), and he stayed most of another year as acting director while the Institute searched for a suitable successor. More than 300 friends honored him for his work at the Center at a dinner in December 1977. He has become widely recognized as an authority on wage and salary administration, managerial compensation, management development, surveys of employee opinions, and employee benefit plans. He has served on a number of Institute committees over the years, particularly those having to do with employee benefits. He has also served governmental agencies as a member or consultant. He was, for example, for almost 20 years a member of the California State Personnel Board and was twice its president. He is a member of several service and civic groups and professional societies and was made a life member of the Personnel and Industrial Relations Association of Los Angeles in 1955. Among his latest awards are the Thomas P. Pike Industry Award of the Alcoholism Council of Greater Los Angeles and the Phil Carroll Award of the Society for the Advancement of Management.



Robert P. Sharp
Robert P. Sharp Professor of Geology

After a career at Caltech that began when he enrolled as a freshman in the fall of 1930, Bob Sharp is about to become professor emeritus. During the 12 years between 1935 and 1947 he earned an AM and a PhD at Harvard, spent 3 years in the Air Force, and taught at the Universities of Illinois and Minnesota. He has spent the years since then back at the Institute — except, of course, for thousands of hours on geological field trips devoted to teaching, to research, and to sheer enjoyment of the out of doors. His research interests have been directed toward understanding the processes shaping the features of the earth's surface, and to that end he has hiked over and studied a lot of it, particularly the western United States and Alaska. He is the author of a number of papers and three books — one book on glaciers and two field guides to southern California. His knowledge of surface features made him a leader of those attempting to analyze photographs of the lunar and Martian surfaces in early space explorations. Under his chairmanship from 1952 to 1967 the Division of Geology grew in both scope and distinction. He was chairman of the presidential search committee, whose work led to the selection of Harold Brown, and a member of many other Institute committees. In 1950 *Life* magazine named him as one of the country's outstanding college teachers; and in 1958 he was winner of *Sports Illustrated*'s Silver Anniversary Award, presented to former college athletes — a unique distinction among Caltech football players. He has also been widely recognized professionally with membership in numerous professional societies, in 1964 by the Kirk Bryan Award of the Geological Society of America and in 1977 by its highest award — the Penrose Medal. In 1973 he was elected to the National Academy of Sciences; and in 1978 his colleagues at Caltech completed a three-year-long project (with his unwitting help) to raise money for the professorship that was named in his honor and of which he has been the first holder.

Retiring This Year



J. Harold Wayland
Professor of Engineering Science

J. Harold Wayland, who becomes professor emeritus on July 1, is a 1931 graduate of the University of Idaho. He then came to Caltech and earned his MS and PhD, working in mathematics and physics under Harry Bateman and Robert A. Millikan. For the past 20 years he has concentrated on bringing the methods of the physical and engineering sciences to bear on studies of biomedical problems. He has been particularly interested in studies of flow and exchange dynamics in microcirculatory beds, specializing in the use of intravital microscopy for such studies in experimental animals. Recently his work has involved the use of fluorescent tracers carried on biocompatible macromolecules and recorded using state-of-the-art closed circuit television techniques. He is past president of the Microcirculatory Society and past chairman of the Medical Sciences Division of the AAAS. He is very much involved in furthering international cooperation and collaboration in microcirculatory studies, and to that end he is currently chairman of the International Liaison Committee for the 2nd World Congress for Microcirculation, to be held in La Jolla this summer. He is also a member of the Commission on Microcirculation and Capillary Exchange of the International Union of Physiological Sciences. He has been a visiting professor at Shinshu University Medical School in Japan; visiting scientist at the Karolinska Institutet in Stockholm; academic guest, Institut für Biomedizinishe Technik of the University and ETH, Zürich; and in the fall of 1979 will be visiting professor in the Department of Physiology, University of Limburg, Maastricht, The Netherlands. The visit to Maastricht is just the start of a trip around the world for the Waylands, mixing science with pleasure and including a two-week trip on the Nile.

Engineering Education

. . . continued from page 23

neering education, broad rather than specialized in training and outlook, is obvious.

PhD's. A few words should be added concerning PhD's in engineering: The first rather common misconception on PhD's is that they must be highly specialized, very theoretical, and lacking in common sense. This prejudice probably stems from reading the titles of PhD theses, which almost always sound very specialized and which often sound (and sometimes are) silly. In this connection, I remember having been told that a quite famous paper by H. Bateman, "The decay of a simple eddy," gave the United States Congress a few happy minutes because its colloquial interpretation is indeed quite silly.

To realize the ability to penetrate a particular subject to the limit of the state of the art, the experience of both the frustration and exhilaration in trying for new understanding are (or should be) the factors of lasting value in PhD research. The ability to penetrate a new subject rapidly is, after all, one of the outstanding requirements for leading engineers today where fields, techniques and products are changing continuously.

The second misconception is the belief in the lack of appreciation of engineering PhD's in industry. In our experience, this is not true at all; in fact, we have not been able to supply the demand. In cases where I have found such a prejudice, it was based on experiences with narrow specialists who wanted to do their PhD research over and over again. Actually the years spent in the work toward the PhD degree can and should be used for broadening and not for specialization. Of course this presupposes students with a sufficient intellectual curiosity and a faculty that appreciates and actively stimulates the trend. Evidently a reasonable selection process should eliminate PhD candidates who do not live up to these standards. Since no foolproof selection process has ever been found, a few PhD candidates will slip through who act strictly according to the motto posted as a joke in some university offices: Take a PhD. It beats working anytime! □

Letters

Setting It Straight

Santa Barbara

Editor:

Thank you for the copies of *Engineering & Science*. You have done the same good job in putting some coherence into this second part of my reminiscences as you did with the first ("Henry Borsook — How It Was," *E&S,* January-February and March-April).

There are two errors that I shall be grateful to have corrected in the next issue.

Page 24, right column, 21 lines down: "vitamins A and D were added to milk." Actually, vitamin D had been added to milk for some years before, and I had nothing to do with it. Flour and bread were enriched with vitamins and iron.

Page 29, left column, 25 lines down: "I think I'm the only one of the original group who's still alive." Ernest Chamberlain, who was a co-founder of Meals for Millions, is still alive. Mrs. Clinton and the children are also still alive.

Again, many thanks.

HENRY BORSOOK

Sorry About That

Corning, N.Y.

Editor:

Caltech would be outraged if some eastern publication located its campus somewhere in western Utah. Your article on the Hale Telescope ("A Giant's Birthday," *E&S,* March-April) locating the casting of the Pyrex blank at "Corning Glass Works in Pennsylvania" needs appropriate emendation. The disc was cast in CGW's "A Factory" in *Corning, New York,* at least 10^{10} microns *north* of the New York-Pennsylvania border.

Faithfully,

WILLIAM W. WRIGHT

Wright is right; we misplaced Corning.

How's That Again?

Pasadena

Editor:

Since your March-April issue carried a lively account of the Caltech student celebration of Einstein's 100th birthday, you may also want to record another campus activity in this regard – in the form of a letter sent to all members of the Caltech physics faculty:

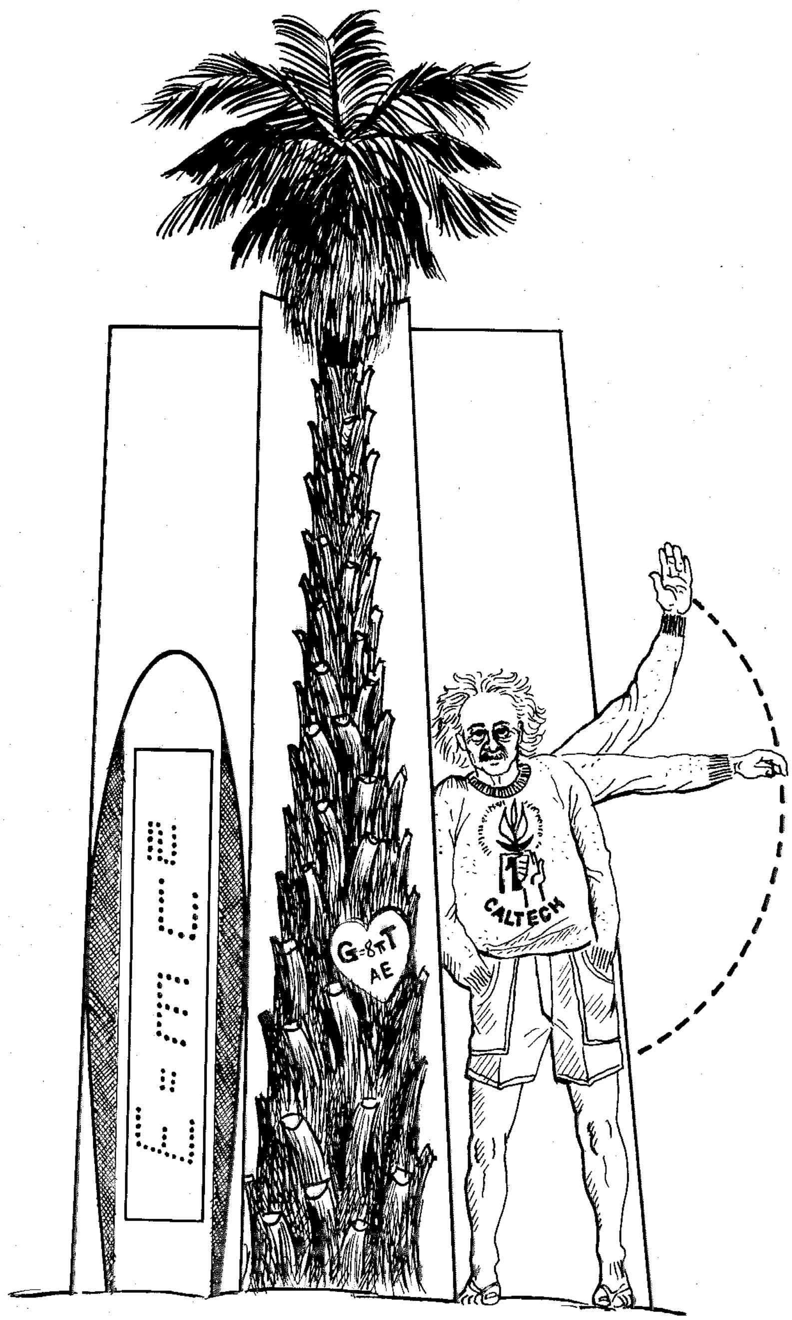
Dear Colleague:

The relativity community here at Caltech has been particularly concerned that Einstein's special relationship with Caltech (and southern California) be appropriately commemorated. Einstein spent the first three winters of the 1930's in Pasadena. He conferred with colleagues at Caltech and the Mount Wilson Observatory, and he enjoyed the peculiar pleasures of the southern California life style. Of course, it was at Mount Wilson that Hubble verified the greatest prediction of Einstein's general relativity — the expansion of the Universe.

To plan an appropriate memorial, a group of concerned physicists here at Caltech has formed an *ad hoc* committee — the Einstein Memorial Committee at Caltech (EMC^2). After considering and rejecting numerous ideas for a memorial, the committee has now reached unanimous agreement on a specific proposal: a memorial mosaic to be constructed on the east face of Caltech's Robert Andrews Millikan Memorial Library, a building justly celebrated for its architectural excellence.

The east face of Millikan Library offers enticing advantages: Its nine stories provide ample space for a memorial of suitable grandeur, and it affords a superb view of the San Gabriel Valley and Mount Wilson (on those few days when the smog allows sufficient visibility). At the same time the east face poses a great challenge: A ridge running up its center splits the face into three parts with which any memorial must harmonize.

To meet this great challenge the committee has commissioned the renowned southern California artist, Burke Roberts. Mr. Roberts is the foremost modern exponent of the ancient art of mosaic; his unique style employs tiny shards of glass from broken beer bottles to build up a vast, multicolored mosaic. Mr. Roberts' mosaics grace many buildings in the Los Angeles area.



For the benefit of any reader who has difficulty in grasping the full sweep of the concept by reading about it, the Einstein Memorial Committee at Caltech is happy to offer this artist's rendition of the east face of Millikan Library as modified to display the Burke Roberts Einstein Memorial.

Mr. Roberts has met the challenge of Millikan's east face with an eclectic design that brings together various themes from Einstein's life in southern California. The main theme is drawn from Einstein's surfing experiences in southern California. A mosaic of Einstein will occupy the right third of the face. Einstein will be wearing his familiar surfing outfit, a Caltech sweatshirt (with its inspiring motto, "The truth shall make you free") and jogging shorts. Using the advanced technology developed for Rose Parade floats, Einstein's left arm will wave slowly and majestically and, on the hour, will point toward Mount Wilson. The ridge occupying the middle third of the face will be sculpted into a palm trunk, topped with plastic palm fronds. On the trunk will be carved the field equations of general relativity, $\mathbf{G}=8\pi\mathbf{T}$. The left third of the face will be a mosaic of Einstein's surfboard, leaning against the palm tree. Running lengthwise along the surfboard will be a lighted "traveling sign," which can be programmed to display any desired material. Current plans call for a short biography of Einstein, with emphasis on the development of his famous equation, $E=mc^2$. The entire mosaic will tower above Millikan Pond, which will seem to invite Einstein to enjoy a cool swim in its sparkling waters.

This magnificent memorial promises to become the centerpiece of the Caltech campus. For the tens of people who take the campus tour daily, it will surely become a highlight, rivaling even the world's smallest motor exhibited in Bridge Laboratory.

The Einstein Memorial Mosaic must be paid for entirely by private funds. I am writing to ask you to give generously to this worthy project. Mr. Roberts estimates that the entire project will cost approximately $1.6 million. An enormous amount of labor will be required in the tedious construction of the mosaic. In addition, the beer bottles will be a substantial expense. Only the finest imported beer will be used, and Mr. Roberts estimates that 10^5 bottles will be required. (The beer will be donated to deserving graduate students at Caltech.)

The committee realizes that this great undertaking will not be universally admired. Einstein was a humble man, and some critics will insist that he would not have wanted a memorial such as we are proposing. Fortunately, Einstein is dead, so we need not worry about what he would think. As Burke Roberts has so aptly put it, "Einstein was never rich in material possessions — all the more reason someone should get rich off his memory."

Please send your checks directly to EMC^2, Caltech 130-33, Pasadena, California 91125.

Sincerely,

HELMAR SCIEITE, JR.
Honorary Chairman
Einstein Memorial Committee at Caltech

We're looking for engineers who can't wait to get to work.

We're looking for people who are looking for a real job. One that offers challenging work. Responsible work.

That's what you can expect at General Electric.

At GE, you'll be handed important assignments right from the start. You can do as much of the job as you're capable of doing. If you need help, it's there. If not, nobody butts in.

Here's the kind of thing we're talking about; some recent examples of jobs handled by new GE engineers:

1. *Charles P.* Aerospace systems manufacturing. Develop and document a direct numerical control system.
2. *Steve O.* Design engineering. Design test equipment for attitude control system of new communications satellite.
3. *Norma L.* Steam-turbine manufacturing. Investigate, analyze and obtain funds for solution of shop problems.
4. *Stephanie B.* Medical systems service engineering. Installation and test of new hospital radiographic and fluoroscopic x-ray system.
5. *Mel D.* Field engineering. Appraisal load testing of low and medium-voltage switchgear and power transformers for utility and industrial applications.

There's a good reason GE hands people like that – like you – real work assignments. It's the best way to develop the skills you will need throughout your career. You develop initiative and creativity. And responsibility. And GE also knows there's little to match the glow you feel when you make an important contribution.

You can make your contribution in just about any field of engineering at GE. We're that diversified in disciplines.

If you like the kind of challenge and responsibility that GE offers, we'd like to hear from you. Send for our free careers booklet. Just write:
General Electric, Educational Communications, WID, Fairfield, Connecticut 06431.

Progress for People

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