

SCIENTIFIC AMERICAN

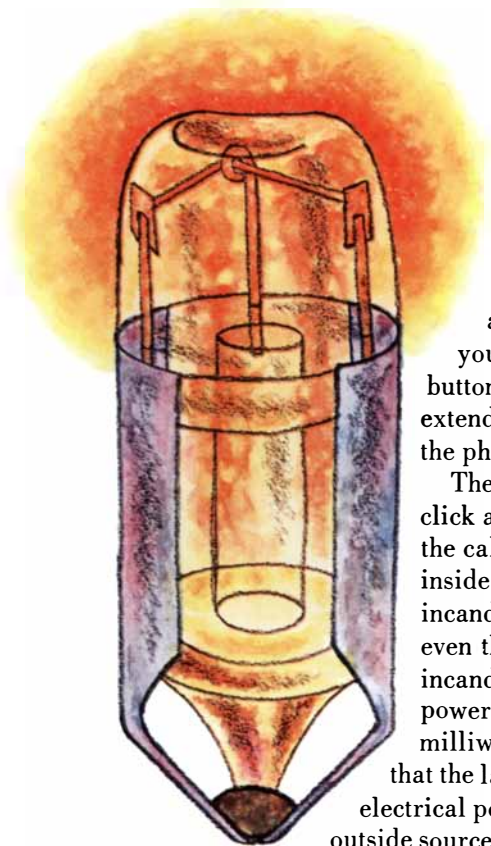


PINE FARM

ONE DOLLAR

November 1971

The Evolution of

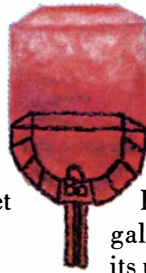
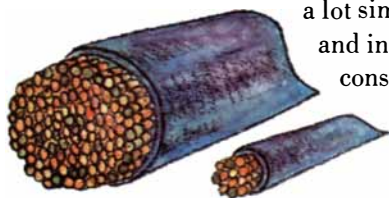


If you've ever used a telephone with buttons that let you switch from one line to another, you probably noticed a decided "click" when you pressed one of the buttons—and a thick cable extending from the back of the phone's base.

The reason for both the click and the thickness of the cable is that the lamps inside the buttons are incandescent bulbs, and even the smallest incandescent bulb requires power in the order of 400 milliwatts. This means that the lamps have to get electrical power from an outside source; that all the switching has to be done *inside* the phone (hence the clicks); so we need 50 wires coming out of it.

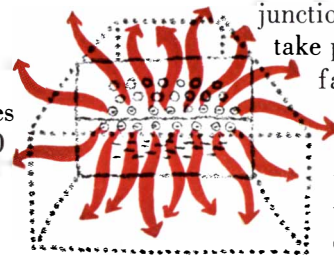
What would happen, however, if that light source required no more power than normally required to operate the phone itself, and if this light source were *also* compatible with integrated circuitry?

It would mean, first, that the switching could be done electronically; a light touch of the button would activate it; and the phone would need only 6 pairs of wires. Furthermore, the phone would be a lot simpler, hence less costly to make and install; much copper could be conserved; and power consumption would be reduced.



Well, such a light source is in late stages of development at Bell Laboratories and Western Electric. It's the gallium phosphide, light-emitting diode, and its ultimate significance goes far beyond even what we've already described.

Like all solid-state diodes, the light-emitting variety is made up of an "n"-type layer doped with an impurity which produces an excess of electrons in the conduction band, and a "p"-type layer doped with an impurity which produces an excess of holes in the valence band. When voltage is applied (negative to the "n" layer, positive to the "p"), the electrons and holes drift toward the junction, where recombinations take place. Under certain



favorable conditions, the energy emitted in such a recombination can take the form of a photon of visible light, a virtually direct conversion of electric current to light.

This phenomenon has been long recognized; the problem was finding a material to make an efficient light source.

In the early 1960's it was discovered that gallium arsenide phosphide was such a material.



But for various reasons Bell Labs scientists were not quite satisfied with GaAsP. Among other things it was not efficient enough at visible wave-lengths. Furthermore, it was not sufficiently transparent: many of the photons that *are*

a Solid New Light

produced get reabsorbed before they can break loose from the diode.

Meanwhile the Bell Labs scientists were studying the basic physics and chemistry of these matters in another material—gallium phosphide. As knowledge of this sort was gained, it began to appear to them that gallium phosphide would make a better light source.

It would take development time for gallium phosphide lamps to surpass those of gallium arsenide phosphide.

But in the Bell System, the unique working relationship between Bell Labs and Western Electric makes it possible to telescope the later stages of development with the early stages of production technology.

Thus, once the research had reached a point where it seemed possible to produce efficient diodes on a larger scale, part of the development effort was moved to Western Electric's plant in Reading, Pa. Here, Western Electric and Bell Labs engineers worked together, setting up pilot production facilities, and producing the diodes to be used in a field trial of experimental key telephones.

But even while all this was going on, Western Electric engineers were developing ways of turning Bell Labs experiments into mass production methods. Producing GaP crystals, doping them, mounting them, laser-testing them and getting them on line involved virtually a

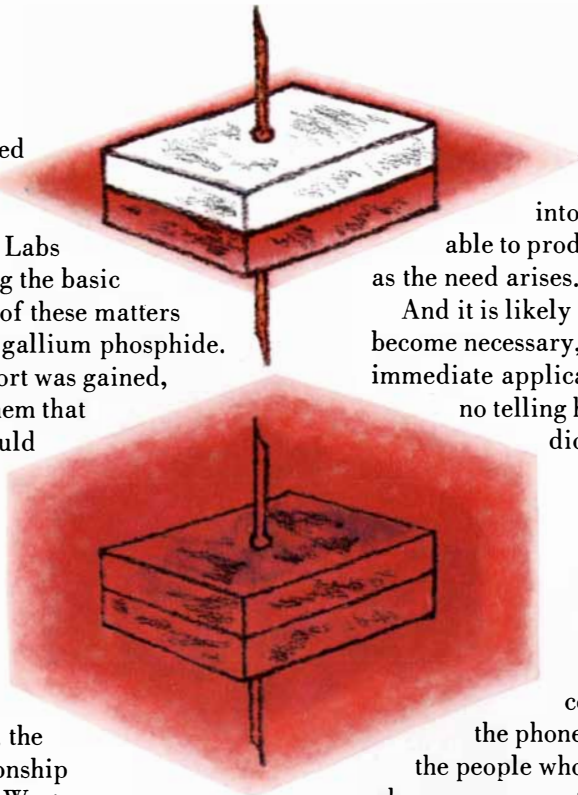
brand new technology. Because Western Electric engineers got into the job so early, they will be able to produce GaP diodes in vast quantity as the need arises.

And it is likely that mass production will become necessary, because looking beyond immediate application in key telephones, there's no telling how many uses for light-emitting diodes the Bell System will discover.

Their use would simplify the design and reduce the power consumption of telephone switchboards. And it's possible that some day your home telephone may have a readout panel that will allow you to dial a code when you come home, and see

the phone numbers of the people who called when you were out; dial your bank and see your balance or dial a computer, put in a problem and see the answer immediately.

New, improved light-emitting diodes and all the advances they can mean are the kinds of things that happen because Bell Laboratories and Western Electric work together.



 **Bell Labs**
Western Electric

Crystal-clear bottle with more class than glass.

The Marlex® Marketing Team created it.

The packaging industry needed it. A bottle that feels soft and satiny, has sparkling clarity plus the unbreakability, light weight and economy of plastic.

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Using Marlex polypropylene resins, the team developed our patented Orbet process—a sophisticated fabricating technique for producing crystal-clear bottles with all the best features of plastic. They can be used for practically everything from dishwashing liquids and detergents to syrup and juices.

But it took years of research and development by our Marlex Marketing Team. And years of working with packaging experts. Testing for clarity, impact strength, moisture vapor transmission, environmental stress cracking.

The point is: whatever your product, if you have any reason to

work with plastics, you have every reason to work with Phillips, inventors of genuine Marlex polyethylene and polypropylene resins. The resins that are worth more to you.

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*Robert F. Lynch, Fairfield, N.J. 201 227-6600.
Bill Shriver, Southfield, Mich. 313 353-6666.
Ralph Porter, Villa Park, Ill. 312 834-6600.
Harry House, Memphis, Tenn. 901 682-8317.
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THE COVER

The painting on the cover depicts a stand of slash pine (*Pinus elliottii*) on a plantation of the International Paper Company in Georgia. As a result of genetic improvements applied by selecting parent trees characterized by rapid growth, the trees mature in 25 years instead of 40 (see "The Genetic Improvement of Southern Pines," page 94). A number of other improvements have been similarly bred into various species of Southern pine, which constitute the major source of the wood pulp and paper manufactured in the U.S. The brown cast of the ground around the trees results from fallen pine needles. The absence of undergrowth is attributable to the fact that the tree farms are subjected to controlled burning periodically in order to remove growth that competes with the pine trees for nutrients and also could fuel a wildfire that had started in the plantation.

THE ILLUSTRATIONS

Cover illustration by Lorelle A. Raboni

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Emory University got Supercomputer to take on their Chemistry Department for under \$10 an hour.

It's an amazing sight.

In one of the labs you can watch a grad student analyzing complicated NMR spectra. Like Carbon 13. Or polymer structures. Checking this. Comparing that. Modifying experiments while they happen.

In another room, a group of students is learning how to work with computers. But there's no instructor. They're teaching themselves.

In yet another room, a post-

doctorate fellow is performing molecular orbital calculations. Watching how a slight change in molecular structure affects the energy surface.

But the really incredible thing is that they're all working directly with one computer. All at the same time. With no computer staff.

Emory's Chemistry Department has a DECsystem-10. Super-computer.

They figure their DECsystem-10

is as powerful as the computers most comp centers have.

But it cost half as much.

Now stop and think about that for a minute.

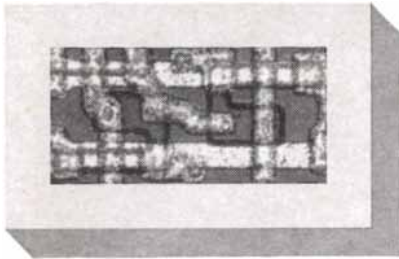
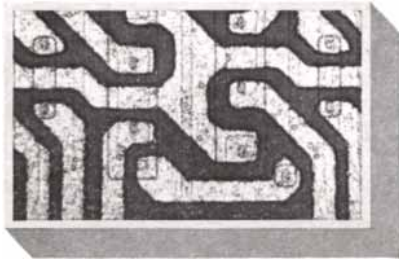
If Emory's Chemistry Department can get a computer that big for under \$10. an hour, maybe you can afford one after all.

Look into it. Write for DEC-system-10 literature, Digital Equipment Corporation, 146 Main Street, Maynard, Massachusetts 01754.

digital

**“ISOPLANAR
IS HERE, AND
IT WORKS”**

For openers, a 256-bit TTL RAM that's dense as MOS but fast as bipolar. Debugged and deliverable now.



Comparison of one bit of memory in conventional bi-polar design (top) and new isoplanar technique (bottom).

There Were Times We Had Doubts.

In March, when we announced the isoplanar process, we also announced that we weren't really sure it was commercially feasible.

We had had a lot of experience in production LSI bipolar memory components and systems (last year we shipped more than 8 million bits to Illiac IV alone). So we went ahead—antsy but optimistic.

We selected a fully-decoded 256-bit RAM to prove we could produce a device of that complexity quickly, efficiently, and profitably, using the isoplanar process.

We could. And did.

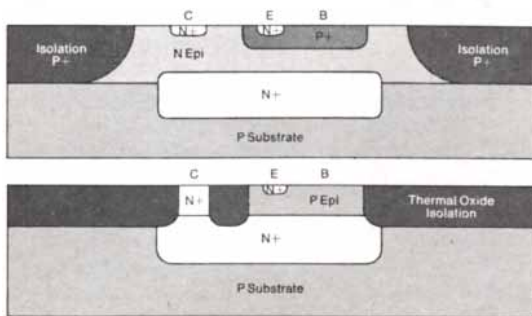
Presenting—debugged and deliverable—our new isoplanar 93410 256-bit RAM. Fast, small, dense.

As Les Hogan, our President, said: "Isoplanar is here, and it works." Beyond our expectations.

And, looking ahead, isoplanar is where it is going to happen.

Isoplanar Technology. Briefly.

The old-fashioned planar process required a large region for p+ isolation and isolation-to-base clearance. The isoplanar process shrinks



No space is required between base and collector regions and isolation in isoplanar bi-polar (bottom) compared to conventional planar bi-polar (top).

this region and fills it with thick insulating silicon oxide that needs no separation from base and collector regions.

Selective etching of silicon nitride, without harming the oxide, provides simpler masking rules and a self-aligning base. Transistor geometries are smaller and parasitic capacitance is reduced. The structures are less sensitive to defects in manufacturing (reduction of the active isolation area, for example, eliminates failures due to oxide pinholes). The surface of the chip is flat, so the traditional metal-over-oxide step problems are eliminated; metallization is simpler and more reliable.

We got smaller, denser, more reliable products with higher yield. At a low cost to our customers. Plus a reasonable profit for us.

What we hoped for, we got.

Isoplanar Is Good for You.

What do you get?

- More electronics for your dollar.
- MOS density.
- Speed of bipolar.
- Higher reliability from an essentially coplanar structure.
- Devices that are compatible with voltage and logic levels of standard ECL and TTL families.
- Wider choice of speed / power trade-offs— isoplanar design uses energy more efficiently.
- Smaller chip real estate, which reduces costs no matter how you look at it.
- Low-cost advantages from our higher yields.
- Devices that are available now.

The First Isoplanar Production IC in the World.

The 93410 high-speed TTL RAM is designed for scratchpad memory, buffer, and distributed main memory application.

- Operates from 0 to 75°C.
- Three chip select lines.
- Uncommitted collector outputs.
- Chip select access time: 20 Nsec.
- Read access time: 50 Nsec.
- Power dissipation: 2 mW/bit.

The 93410 is built on a 96 x 126 mil chip. It uses conventional, high-volume, reproducible metal widths and clearances. (For comparison, our own 256-bit 93400 bipolar memory for Illiac IV occupies a 110 x 140 mil chip, has only partial decoding, and typical access time of 50 Nsec.) It is available now in sample quantities (100-up) at \$21.50 each in 16-pin ceramic DIP.

The 93410 is a superior product, per se. More important, it proves the economic feasibility of the isoplanar process. Today, for production of low cost TTL or ECL read / write memories. Soon, hopefully, for a host of other semiconductor devices.

Tomorrow's Memories.

With the 256-bit isoplanar RAM a current reality, let's look at what isoplanar holds for tomorrow's memories.

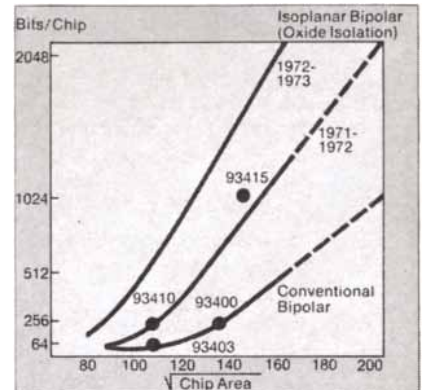
We have in the works a temperature-compensated 9500 Series ECL-compatible 256-bit RAM.

We are in the development cycle of a 1024-bit fully-decoded TTL bipolar memory chip (93415)

that's only slightly larger than our 256-bit isoplanar chip. The great potential in the isoplanar process will begin to be realized in this device. The 93415 is designed for high-speed buffer and main frame applications.

- Address access time: less than 100 Nsec.
- Chip select access time: less than 50 Nsec.
- Uncommitted collector outputs.
- Power dissipation: 0.5 mW/bit.
- 16-pin hermetic ceramic DIP package.

Both the ECL 256-bit RAM and the 1024-bit RAM will be available early in 1972.



The graph gives you some idea of where we've been and where we're going with bipolar memories and isoplanar. It indicates the feasibility of 2048 and 4096-bit read / write memories for 1973. By then we fully expect isoplanar to dominate memories in high-performance and small systems. Memory designers please note that our estimates of packing density and time scale are at least as conservative as our original announcement of the process.

Beyond Memory.

But isoplanar doesn't stop with memories.



The process, we feel, will profoundly effect the architecture of future generations of computers. Ultimately isoplanar technology will be used to fabricate together, on the same chip, combinations of logic and memory of

much greater complexity than have been considered to date. Examples are content-addressable memories and multi-port registers. What we have learned thus far indicates that, in the long run, isoplanar will prove valuable in all complex bipolar circuits.

The process will also bring about significant improvements in high-frequency low-noise transistors, diodes, linear devices, in low-cost realization of monolithic complementary MOS devices, in radiation-resistant circuits—in the universe of semiconductor devices.

For More Information.

We've put together a package of information about the isoplanar process, products and prognosis. It's available for the asking.

Fairchild makes advanced products to uniform standards throughout the world.



LETTERS

Sirs:

I should like to congratulate Drs. Hirschhorn and Greenough for their interesting and timely article on cholera [SCIENTIFIC AMERICAN, August].

I would, however, take issue with one of the authors' statements that "as is so often true in medical science, the intensive investigation of a particular disease has once more in this case provided new insights into normal physiological and biochemical processes." Although this may be a valid prognostication, it does not do justice to history. Indeed, cholera is a superb example of an instance in which our understanding of a disease was arrested for more than a century awaiting advances in basic physiology and biochemistry. These advances range from the development of the experimental chamber (illustrated in the article) developed by Hans Ussing of Copenhagen for the study of sodium transport across frog skin through the discovery of cyclic AMP and its intracellular regulation by Earl W. Sutherland, Jr., and his co-workers in the course of their studies on the mechanisms of hormonal action.

STANLEY G. SCHULTZ, M.D.

School of Medicine
University of Pittsburgh
Pittsburgh, Pa.

Sirs:

I was intrigued by Lynn Arthur Steen's article "New Models of the Real-Number Line" in the August issue.

The article suggested to me the possibility that alternative models exist also for other systems, in particular the set of whole numbers. Peano's axioms, or modern equivalents thereof, which are supposed to define all the properties of the integers, may be satisfied not only by the familiar integers but also by some unfamiliar mathematical objects that we may call hyperintegers. Gödel's theorem almost guarantees that this is the case.

The existence of such hyperintegers would explain why certain statements of number theory, such as Fermat's last theorem or Goldbach's conjecture, appear to be true even though no proof of them has been found. The solution to one of these problems might work as follows: A model is found in which a counterexample, to Fermat's last theorem,

say, is found among the hyperintegers. This would demonstrate that no conventional proof of the theorem could be found in number theory, since any such proof would apply equally well to the hyperintegers. One might still be able to establish, however, that the *assumption* of Fermat's last theorem, as a new axiom, is not inconsistent with the other axioms of the theory. This would in itself be a demonstration that the theorem holds for the familiar integers, since they must be included in every model of number theory, including those models in which the theorem holds.

GILBERT SHAPIRO

University of California
Berkeley, Calif.

Sirs:

Gödel's theorem does indeed guarantee the existence of alternative models for Peano's axioms. The earliest explicit construction of such a model was given by Skolem in 1934. More recent contributions by Tarski, Scott and Robinson have established "nonstandard arithmetic" as a small but significant branch of mathematical logic.

Nonstandard models of arithmetic, like nonstandard models of the real-number line, exist because one of Peano's axioms—the so-called induction postulate—cannot be adequately expressed in first-order logic since it involves quantification over sets. But the existence of nonstandard models will not make it any easier to prove Fermat's last theorem, because to prove that this theorem is not inconsistent with the other axioms requires the discovery of some model for which Fermat's last theorem is true. But since every model must contain the natural numbers, the task of verifying the truth of Fermat's last theorem in one of the new models is no easier than is the original objective of proving it true for the natural numbers themselves.

LYNN A. STEEN

St. Olaf College
Northfield, Minn.

Sirs:

Lynn Margulis' article "Symbiosis and Evolution" [SCIENTIFIC AMERICAN, August] struck a familiar chord. On reading the article I found the name of one of my mentors, Ivan E. Wallin. Incidentally, his initials were I. E., not J. E., and he was not a physician; he was pro-

fessor of anatomy at the University of Colorado Medical School.

It may be of interest to Dr. Margulis and your readers that Dr. Wallin completed the experimental work on which his book *Symbiogenesis and the Origin of the Species* was based while the medical school was located on the university campus in Boulder, Colo. At about the time the book received severe criticism from his histological and bacteriological colleagues, the medical school was moved to its present location in Denver. In order to bolster the new and unusual concepts stated in the book, Dr. Wallin attempted to replicate his experiments but failed. Being a meticulous researcher, he even returned to Boulder and brought back his media ingredients, sterile water and certain other laboratory items to make another attempt at replication. He failed again. This disillusioned him, and from that time on he never turned a hand to research of any kind again. We, his students, never regretted this decision, since he devoted full time to teaching.

L. C. MASSOPUST, JR.

Cleveland Psychiatric Institute
Cleveland, Ohio

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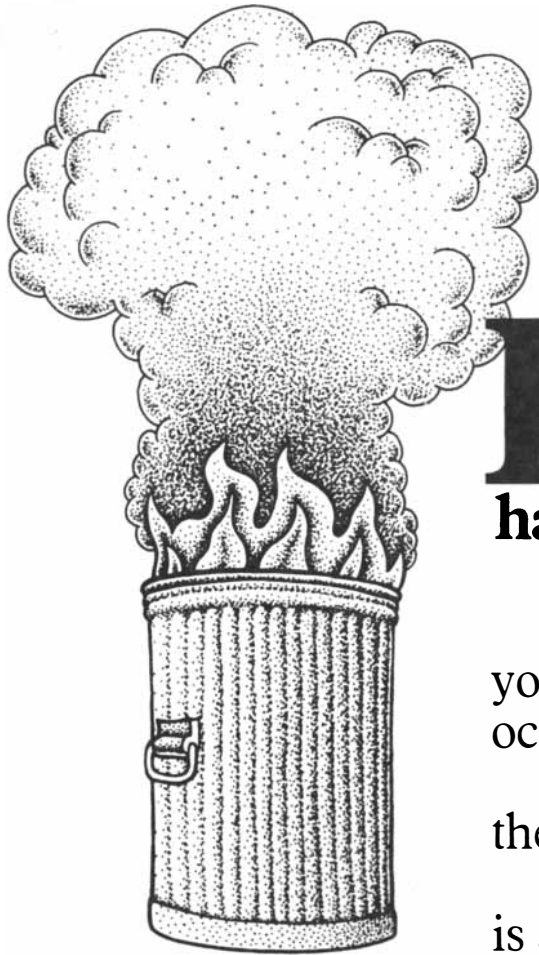
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NAME

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50 AND 100 YEARS AGO



NOVEMBER, 1921: "The subject of atomic energy was well to the fore in the recent convention of chemists in New York, where some of the best papers were devoted to the study of the ever-recurring question these days as to how and whence the coming generations will secure the needed energy for light, heat, transportation and the thousand-and-one other requirements of human life. In this search we have at one time or another considered (with more or less doubt as to their filling the huge demand) coal and oil, natural gas, the energy of the earth's rotation and that of the wind, the tides and the waves. Water power, of course, is included, and we are told that the solar heat that beats on the Sahara desert represents in energy the daily equivalent of some six billion tons of coal. But none of these possibilities is so attractive as that of atomic energy. It was Rutherford who said, "The race may date its development from the day of the discovery of a method of utilizing atomic energy." So enormous is this energy that it will confer on the man or the nation that learns to release and control it a power only less than that of the Omnipotent. Before that day arrives let us hope that a way will have been found to put more of the human into what we are pleased to call human nature."

"From Berlin we learn that Krupp's is resuming the manufacture of munitions, and that machine section No. 2 has three howitzers under construction."

"The admirable researches carried out in recent years at the Kaiser Wilhelm Institute of Chemistry by Prof. Alfred Stock and his fellow workers has resulted in the discovery of a wonderful variety of boron and silicon compounds showing a close analogy with those of organic chemistry, the apparent inertia of boron and silicon being due to the extremely volatile and ephemeral nature of most of these compounds. These somewhat unexpected results were reached by a special and most refined

method of experimenting, which enables such volatile substances in minimal quantities (some tenths of a gram) to be handled, cleansed, analyzed, their physical constants ascertained and their chemical behavior studied under perfect seclusion of any air, fat or moisture. According to Stock, boron and carbon show a close analogy in their power of aggregating large numbers of their own atoms into stable molecular complexes: 'chains,' 'rings' and so forth. Also like carbon, silicon possesses the faculty of polymerizing small molecules into large, nonvolatile ones. This much can be asserted on the strength of Stock's experiments, that the chemical character of carbon is only quantitatively, not in principle, different from that of other elements."

"Is air travel already wearying us and becoming like an old song? At the Chicago Pageant of Progress the 11-passenger hydroplane 'Santa Maria' carried a projector and an operator to beguile the tedium of flying with motion pictures while the hydroplane and the audience were hurtling through the air at 80 miles per hour."



NOVEMBER, 1871: "We have received from England the news of the death of Charles Babbage. This gentleman gained considerable celebrity by inventing a calculating machine, which excited great public curiosity for a time but was found to be valueless for general use. It was subsequently improved and is now in use in England for indicating logarithms in one of the statistical departments of the government service. The deceased was for many years the holder of the mathematical professorship at Cambridge, a position once held by Sir Isaac Newton. Babbage's writings on the economy of manufactures and cognate subjects are numerous and valuable. In 1832 he was a candidate for Parliament, but he was defeated at the election. He died in his 79th year."

"One of the most important expeditions ever fitted out in the U.S. is now being organized in Charlestown Naval Yard under the control of the U.S. Coast Survey. The *Hassler*, a vessel 165 feet long, well fitted and of ample power, is to convey a corps of scientific men, her officers and crew being selected espe-

cially with a view to their fitness for such service. The object of the voyage may be briefly described as the investigation of the greatest depths of the Atlantic and Pacific oceans, of the origin of the deep-sea currents, of the varied character of the water as to temperature, weight and chemical properties, as well as of the fish and other animal life inhabiting the depths of the sea. The scientific members of the party will be led by Professor Agassiz, and the dredging operations will be conducted by the Count de Pourtalés."

"What with the immense drafts made on the store of valuable timber possessed by this country and the destructive fires that almost annually visit some portion of our wooded regions, we are fast reducing our supply, and raising the value, of industrial woods in the market. Still we seem to regard the end as something remote and to imagine that something will turn up before our timber is exhausted. At the present rate of consumption, however, we may fix an early date for the total denudation of our forests, the annual drain on which now far exceeds the natural growth and is constantly increasing. We have more than once endeavored to awaken a realization of this fact in the public mind, which, however, contents itself with the present plenty and puts away the thought of anticipated evil. There are vast tracts of country where scarcely anything except timber can be properly cultivated, and by proper attention of the Government the oftentimes worthless, or comparatively worthless, timber now growing on them might easily be replaced by timber of great value in the arts. There is no more reason why we should not cultivate oak or hickory or pine than corn or wheat. Surely our timber is as worthy of the attention of the Government as our mineral wealth."

"Some particulars of Commander Selfridge's exploration of the Isthmus of Panama have been communicated to the public, although the report has not yet been published. The route recommended for a canal between the Atlantic and the Pacific is along the course of the river Atrato and thence to Cupica Bay on the Pacific. The work is calculated to cost more than \$100 million, the obstacles to rapid engineering progress being formidable. One of the difficulties is the construction of a tunnel four miles long, 70 feet wide and 170 feet high. The canal will require 22 locks, nine rising from the Atlantic coast to the highest point and 13 descending to the Pacific."

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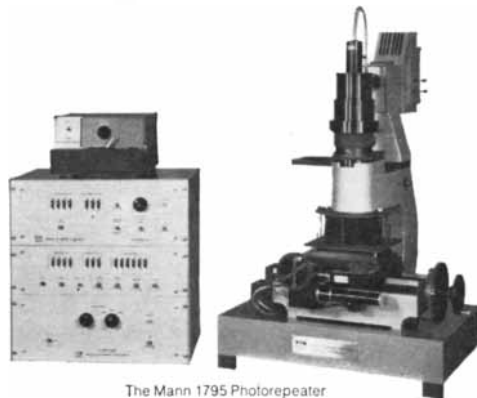
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THE AUTHORS

W. HALDER FISHER ("The Anatomy of Inflation: 1953-1975") is a fellow of the Battelle Memorial Institute working in business economics and applied econometrics. He is also in charge of the institute's program "Aids to Corporate Thinking." Born in Virginia, he was graduated from Richmond College in 1934 with a degree in chemistry but then switched to economics, receiving his master's degree at the University of Virginia in 1943 and his Ph.D. there in 1945. From 1946 to 1952 he taught at the University of Delaware. He then spent 15 years in Washington as successively an economist for the Federal Trade Commission, an economic consultant with Robert R. Nathan Associates, head of his own firm of economic consultants, research economist for the U.S. Chamber of Commerce and member of the Battelle Institute's Washington office. Since 1967 he has been at the Columbus Laboratories of the institute. "My main noneconomic interests," he writes, "involve reading (primarily science fiction), wines (especially the whites and sherries) and cooking, and fishing (both fly-fishing and the use of ultralight spinning tackle) all over the world. While in college I wrote poetry and wrestled but have done neither of them for many years."

T. H. GEBALLE ("New Superconductors") is professor of applied physics at Stanford University and a part-time member of the technical staff of the Bell Telephone Laboratories. As a result he commutes frequently between Palo Alto and Murray Hill "with briefcase and tennis racket always in hand." Geballe did his undergraduate work at the University of California at Berkeley and returned there, after military service in World War II, for his Ph.D., which he received in 1950. From 1952 to 1968, when he went to Stanford, he was a full-time member of the technical staff of Bell Laboratories. He writes that as the father of five children, ranging in age from five to 24, he observes "no discernible generation gap but rather an ongoing generational flow."

THEODORE FRIEDMANN ("Prenatal Diagnosis of Genetic Disease") is assistant professor in the department of pediatrics at the School of Medicine of the University of California at San Diego and is also associated with the

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DON L. ANDERSON ("The San Andreas Fault") is professor of geophysics at the California Institute of Technology and director of the Cal Tech Seismological Laboratory. After receiving his bachelor's degree in geology and geophysics at Rensselaer Polytechnic Institute in 1955, he spent a year with an oil company, followed by two years of geophysical research with the Air Force Cambridge Research Center and the Arctic Institute of North America. He received his Ph.D. in geophysics and mathematics from Cal Tech in 1962. His current research activities include seismological investigations of the earth's interior, the physics of the interiors of the moon and terrestrial planets, volcanology, theoretical seismology and studies pertaining to the evolution of the earth and the solar system. In addition he is principal investigator of the Viking seismology experiment that will be landed on Mars in 1976.

SHEMARYAHU TALMON ("The New Covenanters of Qumran") is visiting professor in the department of Near Eastern and Judaic studies at Brandeis University. Educated through high school in Germany, he emigrated to Israel in 1939 and obtained his master's degree at Hebrew University in 1945 and his Ph.D. there in 1958. He taught at Hebrew University for a number of years, becoming associate professor and chairman of the department of Bible studies in 1966. In 1968 he became head of Haifa University College. In the academic year 1970-1971 he was visiting professor in the department of Near Eastern languages at Harvard University, giving lectures at several other American universities also. "My interests include current literature and traveling," he writes. "I also dabble in sociology."

JOHN E. PIKE ("Prostaglandins") is research head in the experimental chem-

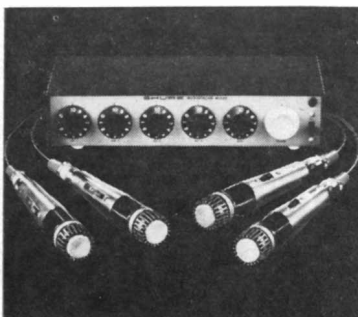
istry division of the Upjohn Company. Born in England, he received his master's and doctor's degrees at the University of Oxford. After two years (1954-1956) as a postdoctoral fellow at the University of Wisconsin he spent a year with the United Kingdom Atomic Energy Authority, going to Upjohn in 1958. His early research interests were in the synthesis of steroids; later he turned to working on their development as therapeutic agents. He notes that his work on prostaglandins "has broadened my field of interest from chemistry to biology." Pike writes that his nonprofessional activities include "travel, squash, tennis and a serious (if recently somewhat neglected) interest in tournament chess."

BRUCE J. ZOBEL ("The Genetic Improvement of Southern Pines") is E. F. Conger Distinguished Professor of Forestry at North Carolina State University and director of the industrial forest-tree improvement program involving the university and a number of other organizations. His degrees are from the University of California at Berkeley, beginning with a bachelor's degree in 1943 and ending with a Ph.D. in 1951. For several years before going to North Carolina State in 1957 he was a silviculturist at Texas A&M University. Zobel has served as consultant to government and industry in a number of countries. He is a member of the Food and Agriculture Organization's Panel on Gene Resources.

JAMES H. BROWN ("The Desert Pupfish") is assistant professor of biology at the University of Utah. "I love the Southwest," he writes, "although I was born and raised in upstate New York, and I think the simple desert and mountain ecosystems present exceptional opportunities for ecological research." Brown obtained his bachelor's degree at Cornell University in 1963 and his Ph.D. at the University of Michigan in 1967. From 1967 until this year he was successively a postdoctoral fellow and assistant professor of zoology at the University of California at Los Angeles. "I am pretty much just a biologist," he writes, "but two other things come to mind. Recently I have been involved in what has become a rather sizable campaign to preserve the remaining pupfish populations and their natural habitats. My wife, who is also a biologist, working for her Ph.D. at the University of Southern California, helps me with much of my work and shares my main nonbiological hobby: the arts and crafts of the Indians of the Southwest."



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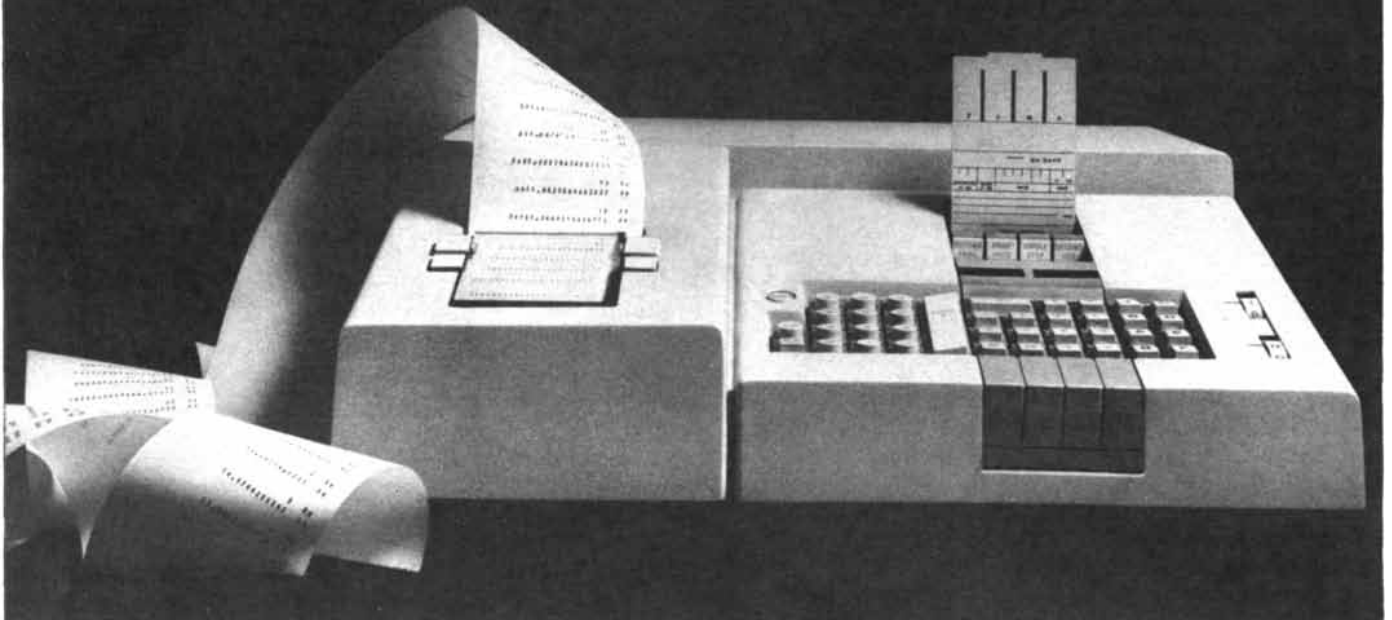
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The Anatomy of Inflation: 1953-1975

An input-output analysis of the process in the U.S. shows that not all prices have been increasing. It is also possible to distinguish the effects of "demand-pull" inflation and "cost-push" inflation

by W. Halder Fisher

In a time when the trend of prices and wages is consistently upward one tends to label the trend "inflation" and to regard it as a homogeneous process in which everything goes up except the purchasing power of the dollar. A detailed examination of the anatomy of inflation, however, shows a richer pattern. Analyzing the trend of prices in the U.S. since 1953 and projecting them to 1975, as my colleagues and I at the Battelle Memorial Institute have been doing, one sees that many prices have in fact declined, relatively if not absolutely. It also becomes apparent that the main contribution to the upward thrust of recent years is the inflation of costs in the service sectors of the economy. In making these observations we have employed the sensitive instrument of input-output analysis.

The inflation of prices is more like the weaving of a tapestry than like the ascent of a ski lift. The net movement of prices rising at different rates and some prices declining is nonetheless upward. In a typical postwar situation, as exemplified by the years after World War II in the U.S., the process begins with a period of abnormal demand. The shortage of civilian goods during the war created a classic inflation-breeding cycle: more dollars were pursuing fewer goods in comparison with an earlier point in time. Then the cycle was intensified by more war, first in Korea and then in Vietnam. These conflicts have led the Federal Government to increase

its purchases not only of armaments but also of a wide range of other products. Many of the things the Government buys are the things that everybody else buys: food, clothing, vehicles, medical supplies and so on. In addition both the arms race and the space race increased Federal outlays well above tax revenues, thereby leading (by way of deficit financing) to an outpouring of new Federal dollars for goods and services.

The recipients of Federal dollars naturally spent them for the usual things people buy. Increased demand for these goods and services, in relation to their supply, forced their prices to move upward, slowly at first but with increased speed as demand continued to build up. The result was what has become known as "demand-pull" inflation.

Another kind of inflation arises from the spiraling process that tends to accompany demand-pull inflation. It begins because individuals have to give up more dollars for the things they need or want. As is well known, this erosion of individual purchasing power eventually leads labor, usually acting through the more powerful unions, to press for higher wages. As one union succeeds in improving its wage position, others have both an incentive to demand more and a precedent to exploit at the bargaining table. Rising wages are felt throughout the economy as increases in the cost of producing raw materials, semifinished components and finished goods of all

kinds. The companies producing these goods try to pass the costs on to the purchasers of their output. The result is what has become known as "cost-push" inflation.

It should also be noted that many companies faced with rising labor costs will try to substitute new capital, embodying labor-saving technologies, for labor. This stratagem transfers the demand-pull from consumer goods to capital goods and, operating through higher interest and depreciation costs, adds to the cost-push.

Given sufficient time and a banking system that has both reserves to lend and a willingness to lend them to buyers of industrial or consumption goods, thereby putting more money in the hands of purchasers, a round of cost-push inflation leads to a second round of demand-pull inflation, which leads to still another round of cost-push. Demand-pull and cost-push follow each other and also propel each other. Thus the spiral continues.

Although this general explanation of inflation is correct in that it provides a clear indication of causes and effects, it does not adequately convey what happens to the prices of particular parcels of goods and services. In order to follow such processes one needs more detailed information. My purpose here is to provide the required detail within the context of an input-output model of the U.S. economy.

The model, which is the one em-

ployed by the Office of Business Economics of the U.S. Department of Commerce, partitions the economy into 87 sectors. Each sector can be regarded as an industrial process that creates a particular parcel of goods and services. For example, a sector commonly used at this level of detail is "Primary iron and steel." It encompasses the process that begins with the blast furnace and ends with the production of iron and steel pigs, rods, strips and sheets of various specifications for use as the raw materials of industry. Another sector is "Motor vehicles and equipment," which produces automobiles, trucks, buses and repair parts. If the sectors are plotted against one another at right angles in a chart, one can readily perceive what each sector buys from and sells to every other sector.

Price indexes for the years 1929 to 1968 have been published by the Department of Commerce. The indexes apply directly to most of the 87 sectors of the department's input-output model. In other cases the indexes can be combined to fit the sectors. At Battelle we have projected these price observations to 1975 with a newly devised hierarchical forecasting program. By means of this program we derive a family of curves to depict the price trend in each sector. Typical curves appear in the illustrations accompanying this article.

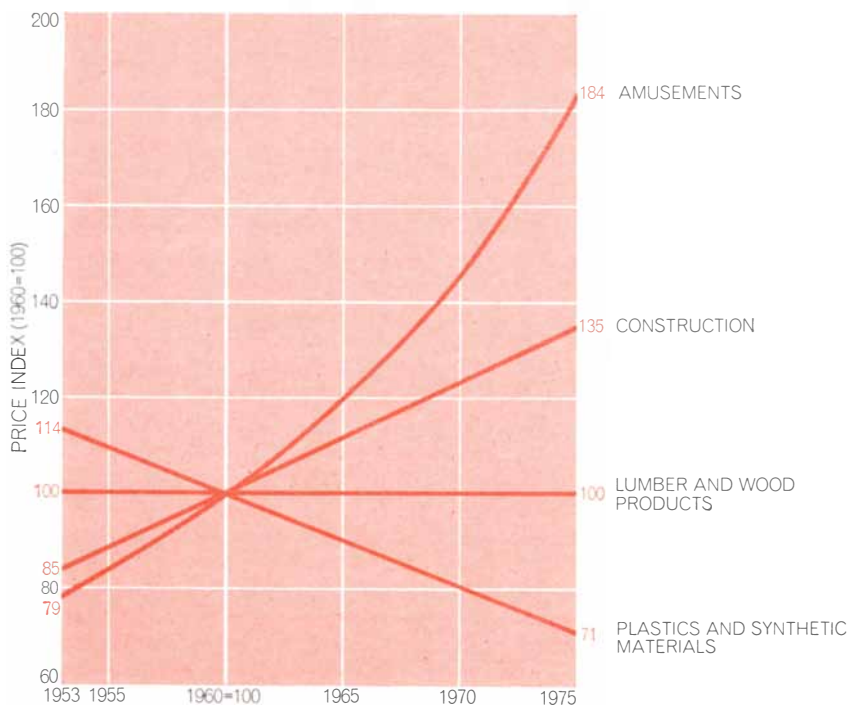
A distinction should be made in discussions of inflation between absolute price changes and relative price changes. Although absolute changes affect the value of money for anyone who buys goods and services, relative changes have the greatest impact on the profitability of business enterprises. In order to measure relative price trends, absolute price changes for each separate sector must be expressed in terms of changes in the average of all prices. If the average price is to be meaningful, it must be calculated as the weighted average of all transactions, that is, each separate price must be allowed to affect the average in proportion to the importance of that particular product or service to the entire economy. For 1975 we achieve the weighting in terms of the expected composition in 1975 of the gross national product. The weighting for 1960, which is our base year, reflects the actual composition of the G.N.P. at that time.

It is generally agreed by economists and statisticians that the price disturbances following World War II ended about 1953. There was a period of post-war adjustment from the end of the war in 1945 until about 1950. Then the Korean war set off an intense round of inflation that lasted until at least 1953. Although there has been no period since

1953 when prices in general have stopped rising, most prices seemed to settle down to more moderate behavior patterns at about that time.

Between 1953 and 1960 average prices (the "G.N.P. deflator series" published by the Office of Business Economics) rose from 88.3 percent of the 1958 average to 103.3 percent, that is, by almost 17 percent. (If one rebases the series to 1960, as we have done, the rise is from 85.7 to 100.) Between 1960 and the middle of 1970 the rise in average prices was more than 30 percent. The rise projected for 1970 to 1975 is about 9 percent. When the increases are expressed in terms of average annual rates (compounded), the rise from 1953 to 1960 was at a rate of 2.2 percent per year. During the 1960's the rate was 2.7 percent per year, and for 1970 to 1975 the rate foreseen is 1.8 percent per year. Taking the period from 1960 to 1975 as a whole, the rate of inflation will average out to about 2.4 percent per year.

If one thinks of each individual price series (each sector) as a colored thread, with each thread having a color different from all other threads, the behavior of prices from 1953 to 1975 can be visualized as a multicolored band of variable width that rises from a 1953 point (85.7 percent of 1960) to a 1975 point (142.5 percent of 1960). Individual threads, however, move up and down within the band. A thread that was near the upper edge of the band in 1953 or 1960 might appear at the lower edge by 1975. Nonetheless, this particular thread may still be higher in 1975 than it was in 1960 or in 1953 because the entire band is inclined so sharply upward.



SAMPLE PRICE TRENDS are plotted for four sectors of the U.S. economy for the period from 1953 to 1975. All follow a linear trend except amusements. Approximately the same ratio holds throughout the economy. Of 82 productive sectors, 26 have nonlinear trends.

price is expressed as 100, the 1975 prices in the four sectors we are examining will be: amusements, 184 absolute and 130 relative to average; new construction, 135 and 95; lumber and wood products, 100 and 70, and plastics and synthetics, 71 and 50.

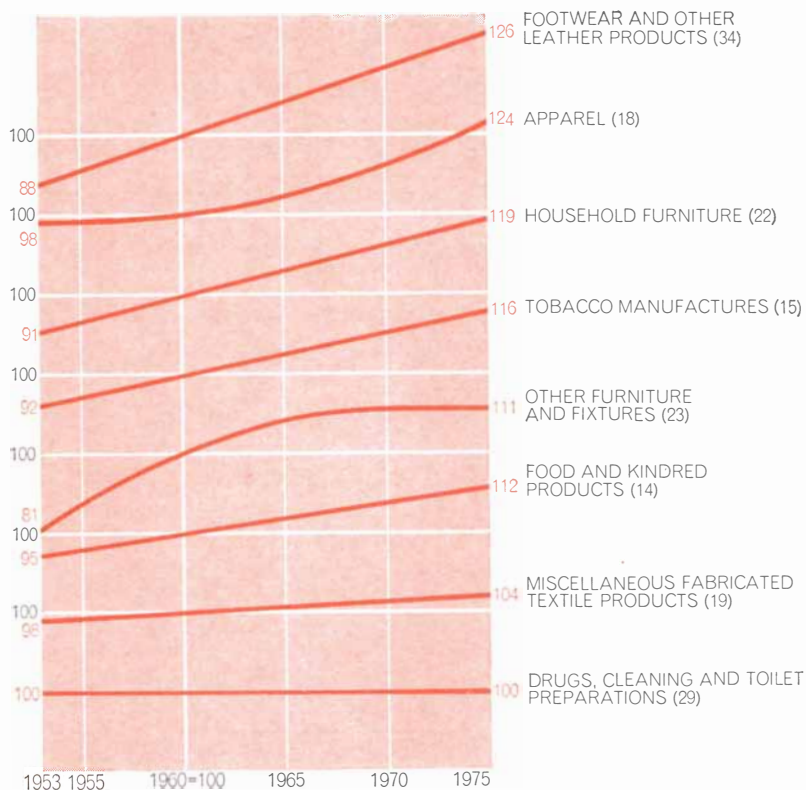
It is a property of price indexes that their relations with one another are obscured in the base year, since every price in that year is assigned a value of 100. These relations can be clarified in another way. For example, in 1960, according to the U.S. Forest Service, the average wholesale price of Douglas fir lumber was \$75 per 1,000 board feet. The U.S. Bureau of the Census reports that in the same year the average price for new, privately owned, single-family housing units was \$13,725. Therefore the base-year price relation between these two items was such that the price of a house would, on the average, buy 183,000 board feet of Douglas fir lumber.

During the period 1960 to 1975, apart from short-term fluctuations, Douglas fir lumber is projected to follow a no-change trend. In contrast the level of house prices is projected to be 35 percent higher in 1975 than it was in 1960. The projections indicate that 1,000 board feet of lumber will still cost about \$75 but that a new house will cost about \$18,500. In other words, because of the relative price change the price of a new house will buy 247,000 board feet of lumber in 1975 instead of the 183,000 board feet it bought in 1960.

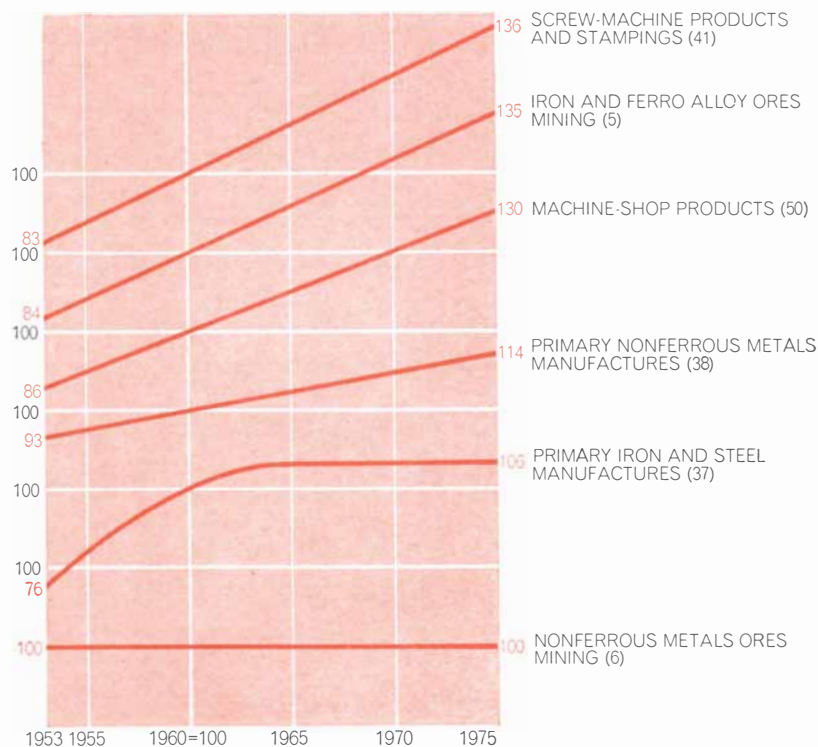
Another point about relative prices emerges here. The figures show that the relative cost of a house will have risen significantly from 1960 to 1975. If one takes into account the behavior of all prices, however, both house prices and lumber prices will fall in relation to the average, although construction prices will fall comparatively less than lumber prices.

Let us now examine the price trends in six broad groupings of the input-output model. Each grouping encompasses a number of sectors. The groupings are nonmetal final goods; metal final goods; basic metals and their intermediate manufactures; basic nonmetals and their intermediate manufactures; energy; services and miscellaneous sectors.

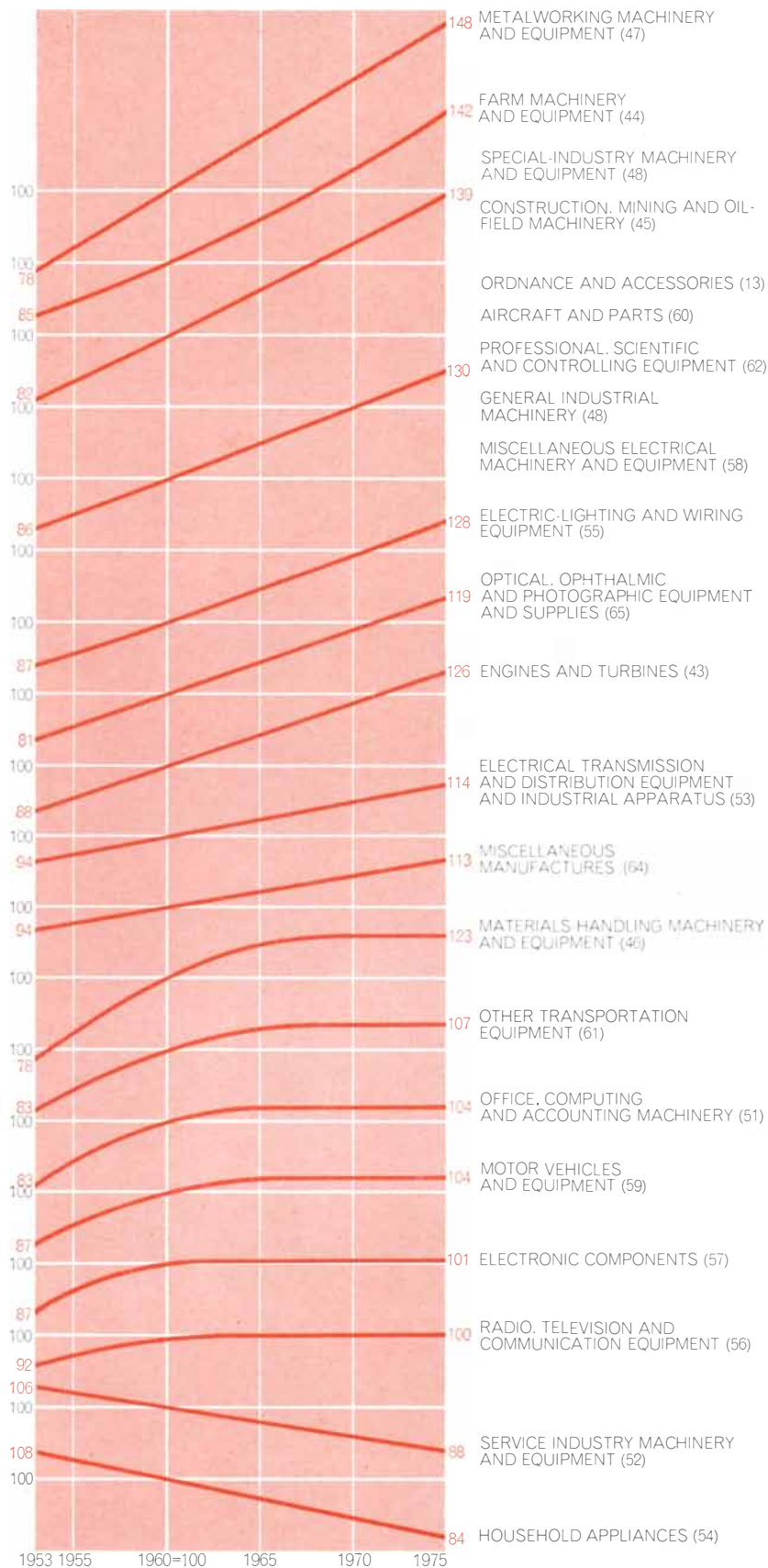
The eight sectors grouped in the category of nonmetal final goods are devoted primarily to the production of consumer goods and certain forms of consumer capital. Taken as a class the prices in these sectors have tended to rise mod-



RELATIVE PRICE TRENDS of the sectors of the economy grouped under the heading of "Nonmetal final goods" are plotted for 22 years. Following the name of each sector is the number assigned to that sector by the Department of Commerce. In each case the lower number at left shows the relation of the sector's prices in 1953 to the base of 100 in 1960, and the number at right shows the level of prices projected for the sector in 1975.



METAL PRICES are grouped under the heading of "Basic metals and their intermediate manufactures." Curves for metal containers and other fabricated metal products are omitted as being similar to Sector 50, curve for structural products as being similar to Sector 38.



TWENTY-TWO-YEAR PICTURE of prices grouped under "Metal final goods" shows several curves, such as the one for Sector 56, with a distinctive shape. In this and other graphs such curves represent prices that were projected to turn downward before 1975 but have been continued at peak because in modern times prices tend to move downward sluggishly.

erately, but none has risen as much as the average of all prices (which is projected to be 142 in 1975 on a 1960 base of 100). Hence one can say that non-metal final goods prices have shown a relative decline.

In 1953 these prices stood well below their 1960 levels [see top illustration on preceding page]. Indeed, they may have risen somewhat faster before 1960 than they have since. Their levels in 1953 ranged from 80 to 100 (on a 1960 base of 100), and their levels in 1975 are projected to range from 100 (drugs, cleaning and toilet preparations) to 126 (footwear and other leather products). Thus their dispersion has widened slightly along with the rise. Only two of the sectors—apparel and nonhousehold furniture and fixtures—have not followed essentially linear trends.

The grouping under metal final goods consists of 22 sectors, which is the largest number of sectors in the six broad classifications. The grouping includes certain consumer products, such as household appliances, but all sectors produce capital, either for producers or for consumers. Because of their number and variety, these sector prices probably are more widely dispersed than the ones in the nonmetal grouping, both in 1953, when they ranged from 78 to 108 percent of 1960, and as projected to 1975, when the range will be from 84 to 148 [see illustration at left]. Two series (service-industry machinery and household appliances) decline over the period, and several series, following markedly nonlinear paths, are projected not to rise much above their 1960 levels.

Seven of the 22 sectors follow nonlinear trends. They do not seem to have any other obvious characteristics in common, however, that would account for the similarity in their price trends. Only two of the 22 sectors are projected to rise relatively. Farm machinery is projected to rise with the all-price average and metalworking machinery is projected to rise somewhat faster. All other prices in this grouping will decline in relative price positions.

Nine sectors are included in the category of basic metals and their intermediate manufactures. Only one of them—primary iron and steel—has followed a strongly nonlinear price trend [see bottom illustration on preceding page]. Another sector, nonferrous-metals mining, is projected to have an essentially unchanged price level throughout the period, although there have been year-to-year fluctuations, and such fluctuations will probably continue.

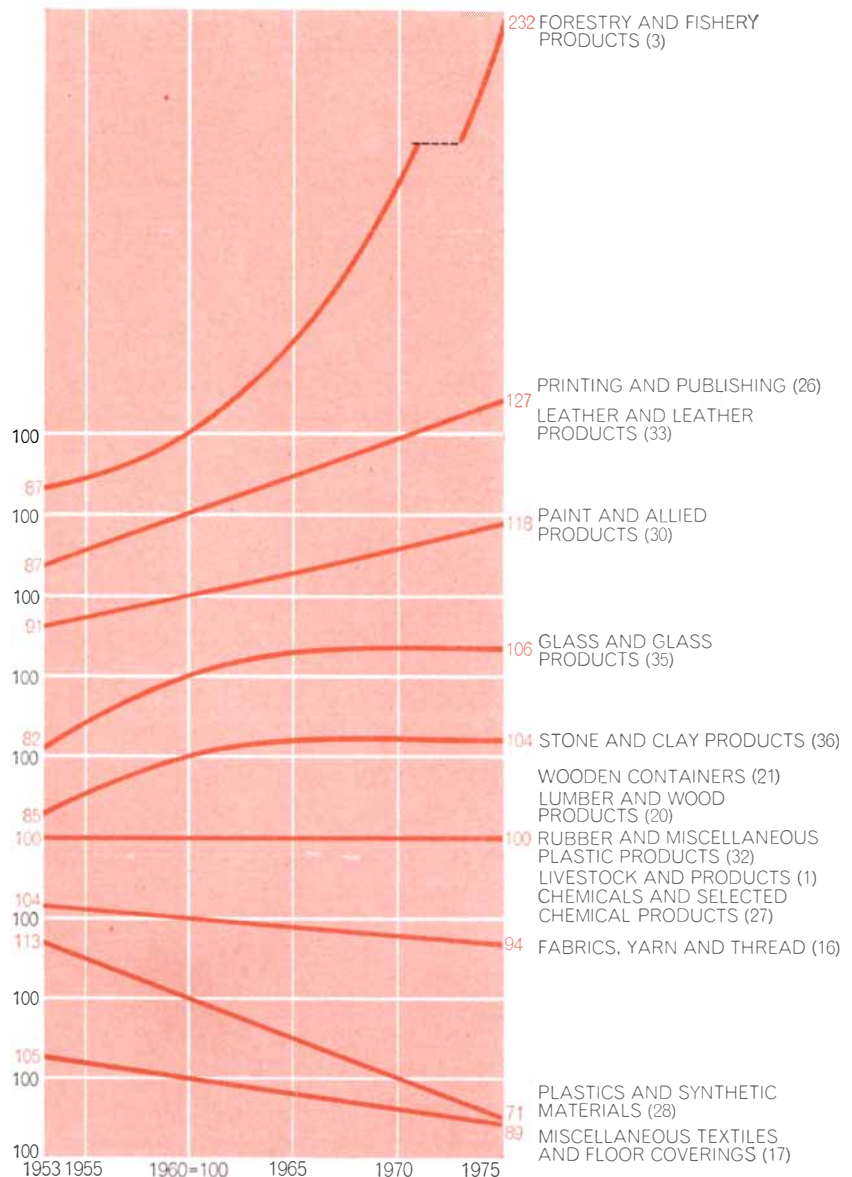
These sectors produce primarily for other producers rather than for final demand. Thus their prices directly affect production costs rather than final markets, although they can have strong indirect effects on final markets. None of these prices is projected to rise as rapidly as the average price, so that all the prices in the group follow paths of relative decline. It appears that a modest increase in their range of dispersion is also likely to occur.

The grouping of basic nonmetals and their intermediate manufactures is larger than its metals counterpart and also brings together more diverse price behavior. The two extreme sectors in the entire economy are in this group, namely forestry and fishery products and plastics and synthetic materials. The plastics sector, which produces resins and man-made fibers for other manufacturers, is projected to decline by 1975 from 113 percent of 1960 to 71 percent [see top illustration at right]. Two other sectors—fabrics, yarn and thread and miscellaneous textiles and floor coverings—also display declining price trends now and as projected.

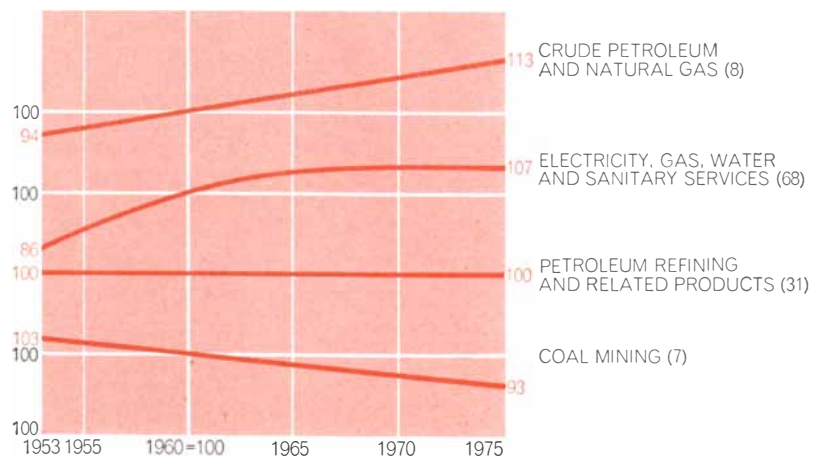
At the other extreme forestry and fishery products are projected to rise from 87 percent of 1960 to 232 percent. This steep rise reflects several contributory influences. One major cause is the accelerating increase in stumpage values (the prices bid for standing trees) as a result of large demands for logs for lumber, plywood, wood pulp and export. Another factor is the sharp increase in shellfish prices as water pollution and overfishing reduce the supply of shellfish. Part of this rise also reflects changes in the composition of imported fishery products.

In addition to forestry and fishery products, only two other price series in the group (glass and glass products and stone and clay products) follow non-linear trends. Neither rose much after 1960. Indeed, if one ignores the two extremes of the basic nonmetals group, the other sectors follow fairly diverse paths but do not greatly increase their range of dispersion. Two sectors are projected to decline, five to remain essentially unchanged and 11 to rise moderately.

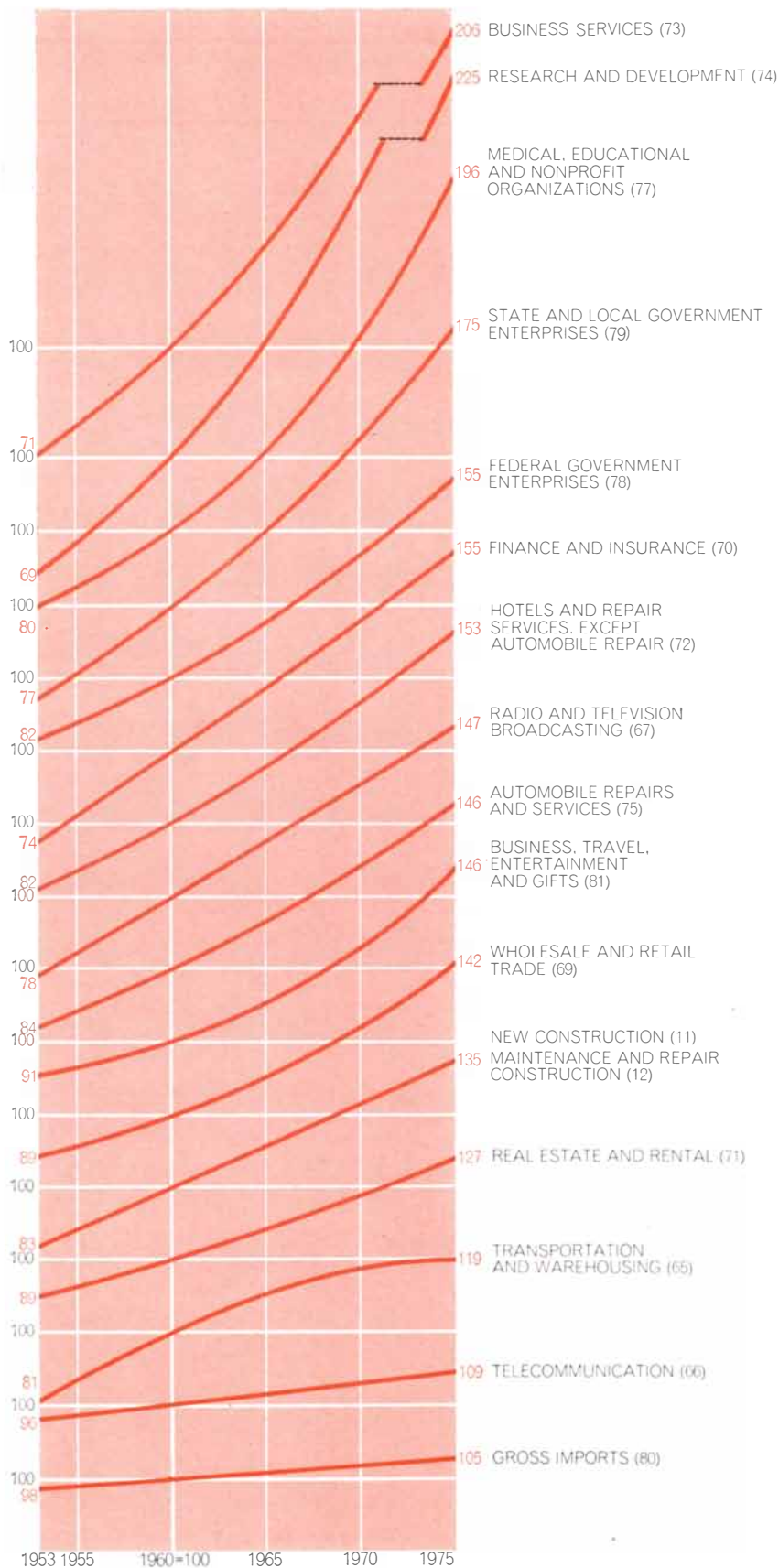
The energy grouping has only four sectors at this level of detail. One of them (coal mining) is projected to display a mildly declining price trend and another (petroleum refining) is projected to show no change in price level. The other two sectors are projected to follow rising price trends: crude petroleum and natural gas a linear trend and electricity,



EXTREME SECTORS of the entire economy are in the grouping "Basic nonmetals and their intermediate manufactures." Extremes are sectors 3 and 28. Several curves relating to paper products, agriculture, forestry and fishery services, chemical and fertilizer mining and stone and clay mining have been omitted as being similar to the curve for Sector 30.



ENERGY GROUPING has only four sectors. The data for coal mining (Sector 7) do not reflect recent price increases in that sector. They are thought to be short-run trends.



MAJOR UPWARD THRUST in the economy comes from sectors grouped under the heading of "Services and miscellaneous sectors." They are mainly labor-intensive activities, and the cost of labor is expected to continue rising. Curve for amusements is omitted as being similar to Sector 77 and curve for office supplies as being similar to curve for Sector 71.

gas, water and sanitary services a non-linear trend [see bottom illustration on preceding page]. All four sets of prices are projected to decline with respect to the average.

Recent increases in coal prices were not reflected in the data underlying the computed trends. It is still too early to determine if these increases will persist to the point of altering the overall trend. In view of the comparatively large supplies of available petroleum and natural gas and the possibility that concern over pollution by sulfur dioxide may further reduce the domestic consumption of coal, a continued downtrend remains quite likely.

The grouping of services and miscellaneous sectors contains 19 sectors, none of which have prices that are expected to decline. Indeed, 12 sectors display price trends that rise faster than average [see illustration at left]. That is why the upward trend that characterizes the average gets most of its thrust from the service-related sectors.

The reasons for the push from these sectors emerge readily on analysis. The service sectors have in common the fact that they are disproportionately labor-intensive rather than capital-intensive, even though some sectors (particularly transportation and communication) have extremely high ratios of capital to output. The distinctive factor about service sectors is that in them capital cannot be easily substituted for labor, so that increases in their output imply increasing amounts of labor input, and the cost of that labor is expected to continue going up.

It is also noteworthy that 11 of the service sectors display nonlinear price trends. For 10 of them the price increase is expected to accelerate. Thus in every respect this class of industries is a source of price dynamics for the entire economy.

All the price trends I have been discussing can be summarized in terms of their relation to the average of all prices by means of the following procedure. First, one makes the simplifying assumption that the average price in 1960 and 1975 is the unit of reference. In that way we take as given the relation that existed in 1960, when by definition every price (and therefore the average) had a value of 100. In the second step one deflates every 1975 price by the 1975 average (142 percent of 1960), thereby giving the 1975 average the value of 100. Deviations of the deflated 1975 sector prices from 100 therefore measure the degree that their trends from 1960 to 1975 will

have carried them away from the position they had in 1960 with respect to the average of all prices [see illustration at right].

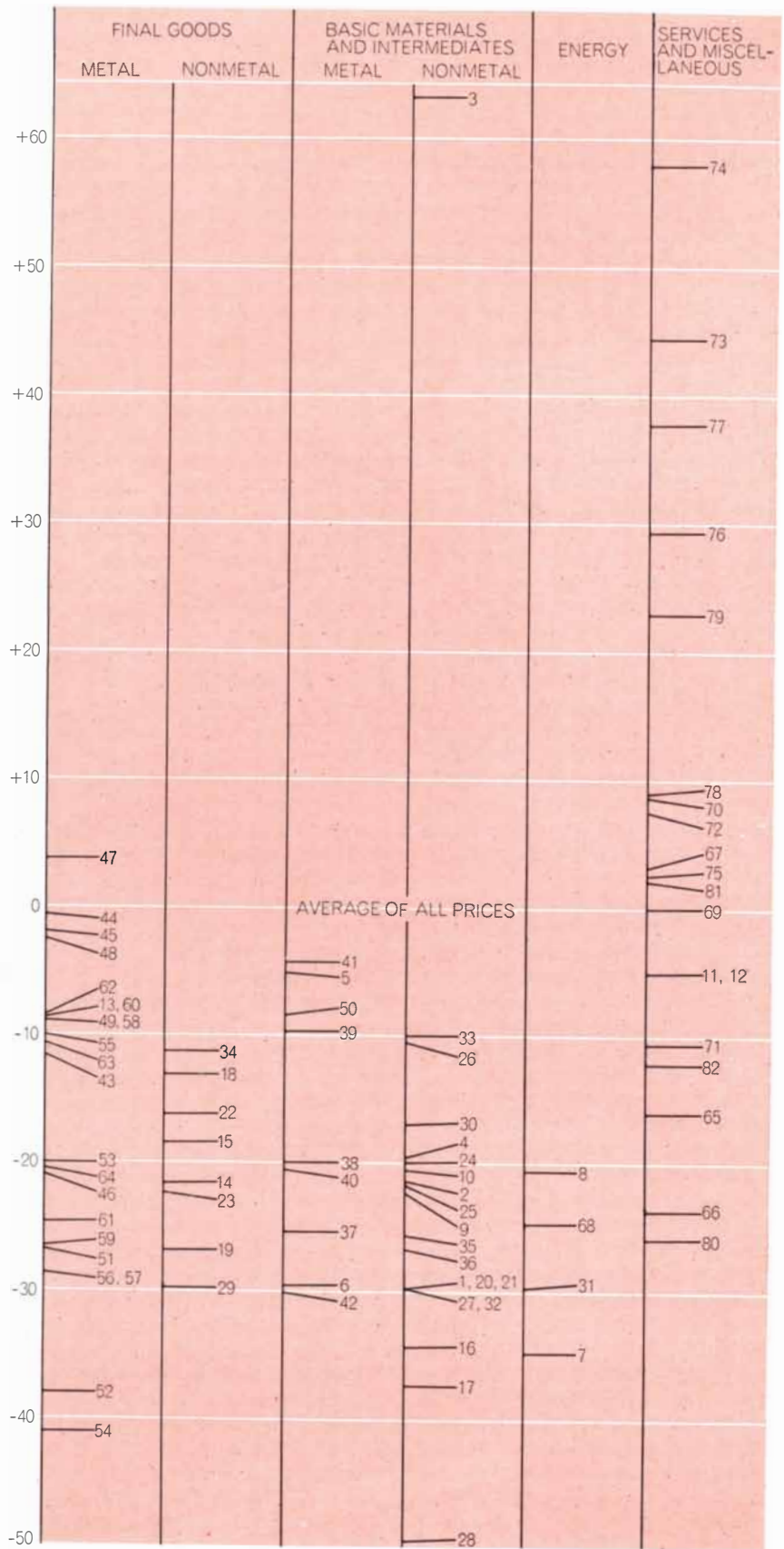
The comparisons that emerge from the illustration make obvious the implications for 1975 that were inherent in the price trends discussed above: all final goods prices except those of machine tools (metalworking machinery) declined relatively from 1960 to 1975. Similarly, all basic and intermediate goods prices declined except those of forestry and fishery products. All energy prices declined, and most service and miscellaneous sector prices rose.

Taking each grouping as a whole, we can now obtain a visual impression of their relative price behavior. Energy prices are projected to decline most, followed by prices of nonmetal final goods. Service and miscellaneous prices are projected to rise substantially. All three of the remaining price groupings will decline moderately.

In general the cost of labor tends to be the most inflationary element in the economy, which is why prices in the service sector are rising comparatively more rapidly than other prices. In view of the relative declines that are projected for the prices of most finished goods, the employed labor force will benefit from the trend. People on fixed incomes will not enjoy such benefits, since most prices will tend to rise in absolute terms, even when they are falling with respect to the average of all prices.

Inferences that can be drawn about the profits of business are less clear. Even though the cost of raw materials and intermediate products is projected to decline in relation to the average, the trend does not imply that business profits will increase. For example, the prices charged by food processors are projected to fall less than prices in the energy sector and the prices of livestock, but they will fall distinctly more than the prices of metal containers. The profits of a particular food processor might rise or fall, depending on the input structure of his business.

What does seem clear is that the future looks promising for companies that buy things and sell services. A case in point would be a landscape gardening company, which buys such items as seed and fertilizer and sells the service of exterior decoration. Since the prices of things are on a relative downward trend and the prices of services are on a relative upward trend, such companies will tend to become increasingly profitable as these trends continue.



CHANGES IN RELATIVE PRICE STANDING from 1960 to 1975 are plotted for all sectors, identified by sector numbers. The numbers at left show deviations of 1975 prices from 100, which is the average of all 1975 prices, and so measure the extent to which trends of 1960 to 1975 will have carried sectors from positions they had relative to 1960 price average.

NEW SUPERCONDUCTORS

Recent experiments have led to the discovery of alloys that are superconducting at the highest temperatures yet recorded. Other new superconductors incorporate alloys and organic substances

by T. H. Geballe

After 60 years as little more than a laboratory curiosity the phenomenon of superconductivity is finally on the threshold of large-scale technological application. Why, one might reasonably ask, has it taken so long? Part of the answer is perhaps to be found in the fact that for most of this period physicists characteristically tended to concentrate their attention on the problem of trying to understand superconductivity in the simplest possible systems: the handful of pure metallic elements in which the phenomenon was first observed. It has been only in the past two decades that certain investigators, starting with John K. Hulm and B. T. Matthias in this country and N. E. Alekseevskii in the U.S.S.R., have broadened the study of superconductors to include intermetallic compounds, or alloys, in a systematic way. And it has been only in the past decade, largely through the work of J. E. Kunzler at the Bell Telephone Laboratories, that some of these compounds have been found to be capable of carrying very large electric currents without loss in the presence of strong magnetic fields.

The superior performance of these materials has already been exploited in the construction of large-volume, high-field superconducting solenoid magnets for various research projects; even larger magnets of this type will someday be used for confining the plasmas in fusion-power reactors. In the near future large superconducting motors and generators will be built that are likely to be competitive with conventional units in special situations. The Japanese National Railroad is developing a train that is to be levitated with superconducting magnets. Somewhat further in the future there may be lossless superconducting power-transmission lines, particularly if superconductors can be found that will

operate at even higher temperatures than is possible at present.

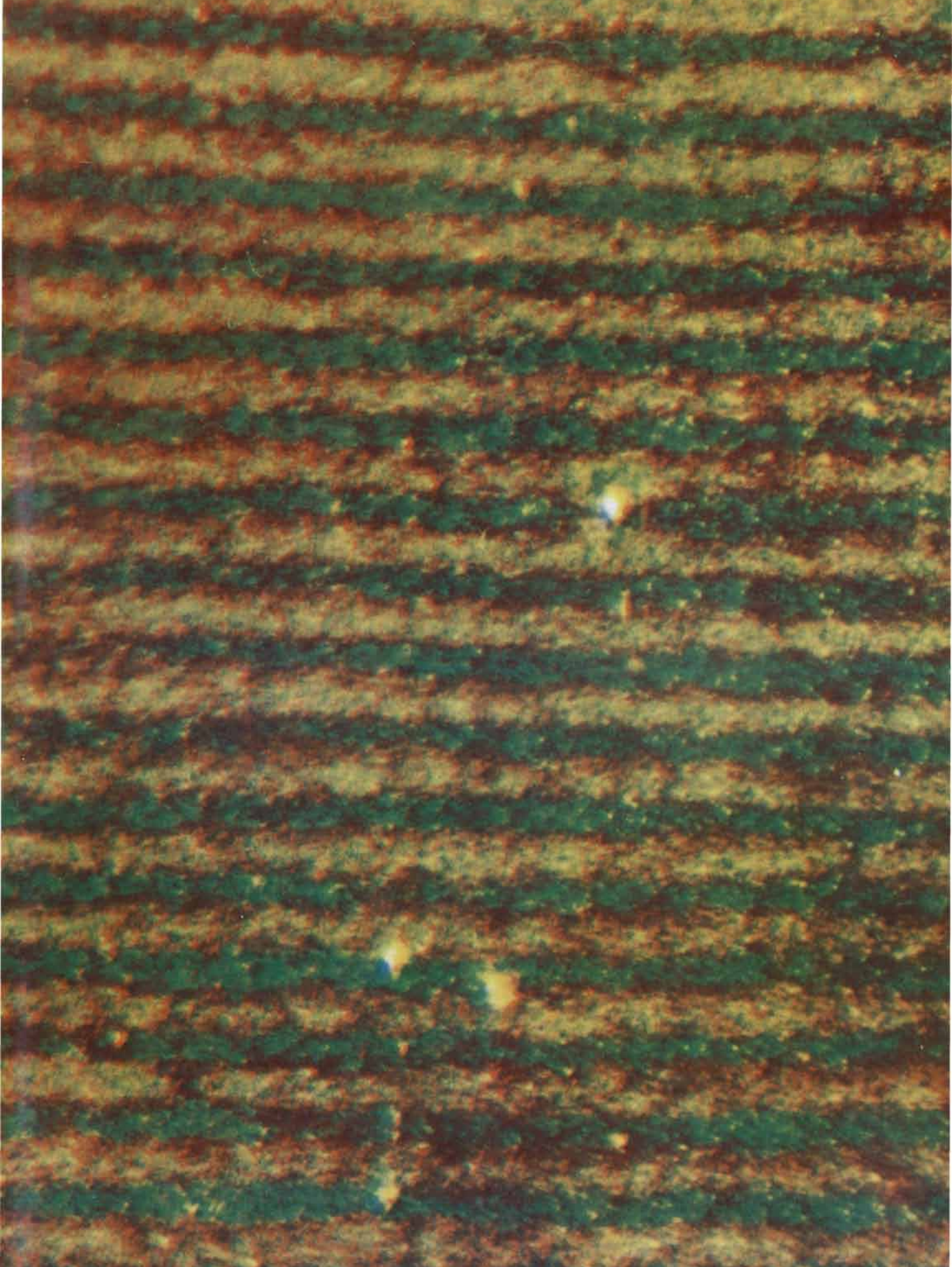
The purpose of this article is to describe some recent research that has led to the discovery of a number of promising new superconductors. These materials include an alloy that remains superconducting at temperatures higher than any previously recorded; its superconducting transition temperature is above 20 degrees Kelvin (degrees Celsius above absolute zero). In addition a new class of layered materials incorporating intermetallic compounds and organic molecules have been found to be the most anisotropic, or directional, superconductors produced to date. The largely empirical approach employed to make these discoveries has in turn yielded new insights into the basic structural and chemical conditions that are favorable for the occurrence of superconductivity and in particular for the attainment of high superconducting transition temperatures.

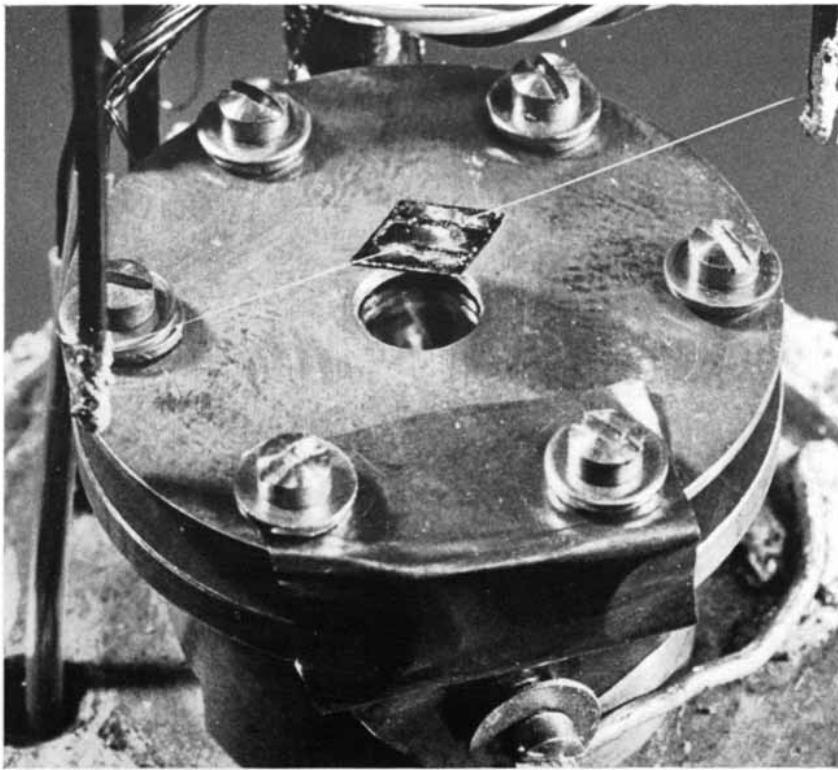
The discovery of superconductivity, like many other new findings in basic research, was completely unanticipated. Heike Kamerlingh Onnes was engaged in studying the properties of the rare gas helium in his laboratory at the University of Leiden when in 1908 he succeeded in liquefying the gas for the first time. Sud-

denly he had available for experimentation a range of temperatures only a few degrees above the absolute zero of temperature (-273 degrees C.); this was roughly 10 times lower than anyone had achieved before. Among the many new experiments he performed over the next few years was one in which the electrical resistance of frozen mercury was measured. He observed to his surprise that instead of diminishing gradually as absolute zero was approached the resistance disappeared abruptly and completely at 4.15 degrees K.

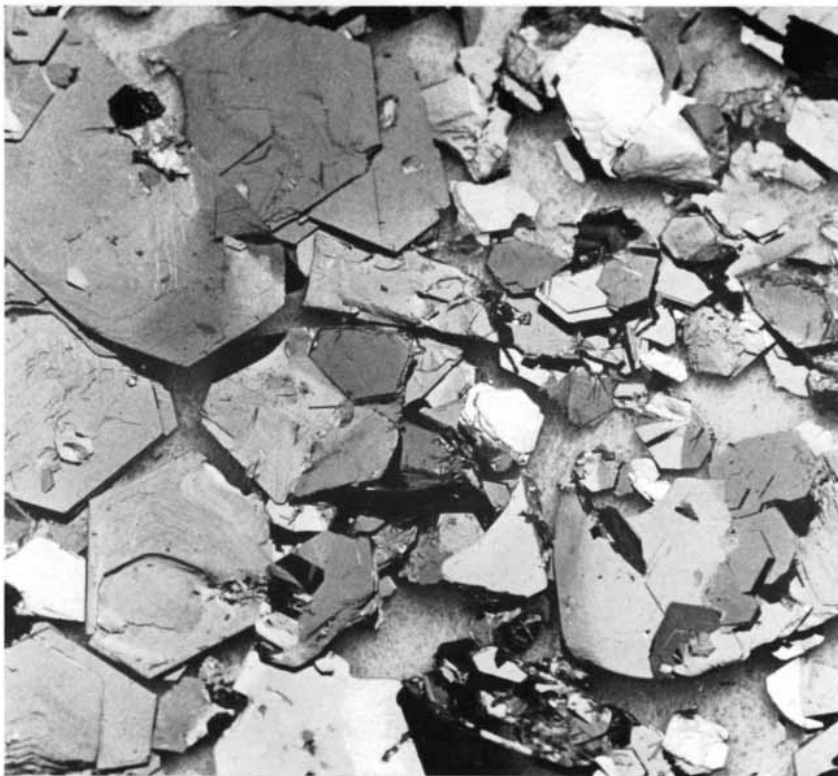
The superconducting state of matter discovered by Kamerlingh Onnes in this experiment has since been found to possess many other wonderful physical properties in addition to the resistanceless flow of electric current. One of the most important of these properties is the Meissner effect, named after the German physicist W. Meissner, who with his colleague R. Ochsenfeld discovered in 1933 that under certain circumstances a superconductor can be perfectly diamagnetic, that is, a magnetic field can be completely expelled from inside a sample when it becomes superconducting. More recently physicists in this country and in Germany have found that the magnetic flux inside a superconducting tube can take on only certain discrete, or

LAYERED SUPERCONDUCTOR shown greatly enlarged in the high-resolution color electron micrograph on the opposite page is one of a newly discovered class of superconducting intermetallic compounds. The layered structure consists of three-atom-thick sheets of the intermetallic compound tantalum disulfide (TaS_2) alternating with one- or two-molecule-thick sheets of pyridine (C_5H_5N), an organic compound that is "intercalated" between the TaS_2 layers to form the compound $TaS_2(\text{pyridine})_{1/2}$. The periodicity of the structure is 12 angstroms; the magnification is greater than four million diameters. The superconductivity of such intercalated crystals is highly anisotropic, or directional, being much more readily attained for electrons flowing along the planes than for those flowing across the planes. The color electron micrograph was made by Humberto Fernández-Morán, Mitsuo Ohtsuki, Akemi Hibino and Charles Hough of the University of Chicago's Pritzker School of Medicine. The image was produced on a new type of photosensitive film that records interference colors as a function of variations in the thickness of the organic layers.





HEAT-CAPACITY APPARATUS consisting of a sample mounted on a silicon-chip calorimeter suspended by wires .0015 inch thick is used to obtain important information about the superconducting properties of experimental samples by measuring their heat capacity, the ratio between the heat added to the sample and the resultant rise in temperature.



TYPICAL SAMPLE of a new layered superconductor studied by the author's group appears in this photograph. The crystalline flakes, shown approximately actual size, are composed of the intermetallic compound niobium diselenide (NbSe_2). The crystals were grown in the author's laboratory at Stanford University by means of the vapor-transport method.

quantized, values; indeed, if it were not for the fact that superconductivity occurs only at uncommonly low temperatures, we in the everyday world might have become familiar with the quantum world long before it had to be invented in the 1920's to explain the far more subtle interactions of light and matter. In the words of the theorist Fritz London, superconductivity is "a quantum state on a macroscopic scale." Below the superconducting transition temperature all the conduction electrons in a superconducting sample organize themselves in a coherent fashion and behave as if they were part of a single atom, no matter how large the superconductor is.

Although a highly successful theory has been worked out to describe the superconducting state, there exists no precise theoretical limit to the temperature range within which superconductivity might occur, nor is there any theorem that requires superconductivity to be caused by only one kind of mechanism. General considerations, based solely on the fact that all interactions in a solid are electrostatic, have recently been invoked by some theorists to argue that no compound can be a superconductor at temperatures anywhere near as high as room temperature. Apart from such general arguments, however, little guidance on this point is available from theory. In such a situation there is a natural challenge to try to find out by experimentation.

At least two possible approaches exist. One is to develop theoretical models based on the assumption that a particular type of interaction—one favorable for superconductivity—might operate as the result of a particular environment. If the interaction were to operate, the model calculations indicate that superconductivity would occur at unprecedentedly high temperatures, contrary of course to the very general arguments mentioned above. Room-temperature superconductivity is easily within the reach of such models. For example, W. A. Little of Stanford University has proposed a hypothetical "one-dimensional" metal—an organic molecule with special side chains—that could have such properties [see "Superconductivity at Room Temperature," by W. A. Little; *SCIENTIFIC AMERICAN*, February, 1965]. Similarly, the Russian physicist V. L. Ginzburg has proposed a two-dimensional system of conducting planes only a few atoms thick sandwiched between dielectric layers that can be polarized by the conduction electrons in a way that favors superconductivity. Although the Little

H																			He
Li	Be											B	C	N	O	F	Ne		
Na	Mg											Al 1.19	Si	P	S	Cl	Ar		
K	Ca	Sc	Ti 4	V 5.03	Cr	Mn	Fe	Co	Ni	Cu	Zn 56	Ga 1.09	Ge	As	Se	Br	Kr		
Rb	Sr	Y 67	Zr 54	Nb 9.2	Mo 46	Tc 8.2	Ru 49	Rh	Pd	Ag	Cd 52	In 3.41	Sn 3.72	Sb	Te	I	Xe		
Cs	Ba	Lu	Hf 16	Ta 4.4	W 01	Re 1.7	Os 65	Ir 14	Pt	Au	Hg 4.15	Tl 2.38	Pb 7.2	Bi	Po	At	Rn		
Fr	Ra	Ac	Th 1.37	Pa 1.4	U 2	Np	Pu	Am	Cm	Bk	Cf	E	Fm	Md	No	Lw			

LANTHANIDES (RARE EARTHES)		La 4.9 6.3	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
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TRANSITION ELEMENTS

 NONTRANSITION ELEMENTS

POSITION IN PERIODIC TABLE of the elements can be used to predict superconductivity. The simple metals (*black and gray*) have conduction electrons that spread uniformly throughout most of the ion lattice of the metal. The transition metals (*dark color and light color*) have conduction electrons that are much more localized around individual lattice-ion positions. Elements that

are superconducting at standard temperatures and pressures are accompanied by numbers giving the temperature (in degrees Kelvin) at which each makes the transition from the nonsuperconducting to the superconducting state. The superconductors with the highest transition temperatures have been found among compounds that combine transition metals and nontransition metals.

and Ginzburg models are highly controversial and a number of serious objections have been raised by other theorists, there are no widely accepted counterproofs.

The way to test a model is to try to find or make an example. One may succeed in synthesizing such a new model system, however, only to find that it is not superconducting at all—that some other unanticipated interaction among the electrons has dominated the hoped-for superconducting one.

The approach favored by our group, which includes workers from both Bell Laboratories and Stanford, is a much more empirical one. It is basically to work with intermetallic compounds that exist naturally. Hunting for new superconductors from among the thousands of intermetallic compounds that can be made by simple chemical reactions turns out to be a fairly easy task; hundreds have already been found to be superconducting. Once the superconductor has been found, experiments are designed to follow the response of the transition temperature to well-defined chemical and physical changes, and new understanding frequently emerges.

These new materials and interactions will be discussed here, but first it will be

useful to outline some of the basic concepts of the physics of metals for the benefit of readers who may not be familiar with the general properties of electrons in metals.

Many electrical properties of metals are surprisingly well described by a very simple model first proposed by Paul K. L. Drude and Hendrik A. Lorentz in 1900, shortly after the discovery of the electron. According to the Drude-Lorentz model, each valence electron is detached from its parent atom and is free to roam throughout the metal, confined only by the boundaries at the surfaces of the metal, just as a gas molecule is free to be anywhere inside its containing vessel. During its wanderings the detached electron will drift in response to an applied electric field and thus will conduct electricity by virtue of the fact that it carries a negative charge. While drifting toward the positive side of the electric field, the electron is frequently scattered by the positively charged ions that are the nuclei of the metal's atoms. Those ions are fixed in space and form a regular crystalline lattice.

Quantization was introduced into the Drude-Lorentz model some 40 years ago, shortly after the discovery of the

wave-mechanical nature of matter. The quantum theory of metals is capable of explaining and predicting many properties, for example the fact that as the temperature decreases, the conductivity increases. The positive ions vibrate less vigorously as the temperature decreases and scatter the wandering electrons less effectively. The electrons therefore drift more easily under the influence of the applied electric field. On the basis of such a model one expects the conductivity for a crystal with a perfect lattice (which of course is not attainable) gradually to become infinite as the temperature approaches absolute zero.

In spite of the many successes of the "nearly free electron gas" concept, as the Drude-Lorentz model refined by quantum mechanics has come to be known, it is completely incapable of explaining superconductivity. Paradoxically those metals that are the best conductors at room temperature are not superconducting even at the lowest attainable temperatures. Copper is not superconducting even when it is cooled to within a few millidegrees of absolute zero. Meissner discovered in 1929, however, that the metallic compound copper sulfide (CuS), made simply by heating copper wire in an atmosphere of sulfur,

becomes superconducting at a temperature of 1.5 degrees K. That discovery might have encouraged a broad search for superconductivity in unusual compounds, including those with a room-temperature conductivity thousands of times poorer than the conductivity of copper. Yet even though the following year Meissner found superconductivity in niobium carbide (NbC) just above 10 degrees K., most studies of superconductivity continued to be confined to a select few elements such as tin, lead and mercury.

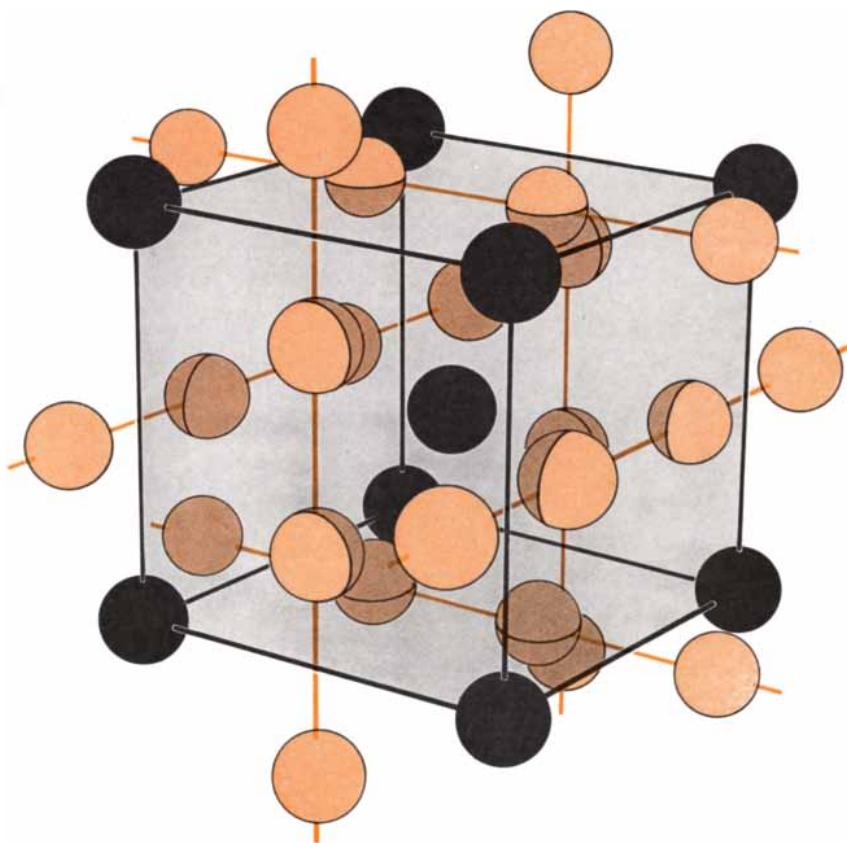
In 1927 Kamerlingh Onnes and his colleague W. Tuyn came within .01 degree K. (their experimental limit of error) of discovering a major clue: the involvement of the ionic lattice in the interaction giving rise to superconductivity. They just missed detecting a difference (which I now estimate to have been .01 degree K.) between the superconducting transition temperature of "radium-lead," as the newly discovered isotope of lead derived from the decay of radium

was then called, and ordinary lead. With more and purer isotopes available after World War II, workers at Rutgers University and the National Bureau of Standards discovered that the superconducting transition temperature was inversely proportional to the square root of the mass of some isotopes of mercury and also of lead. The lattice of ions has characteristic vibrational frequencies that also depend on the square root of the isotopic mass. This key result—the participation of the ions in the superconducting interaction—was independently suggested at about the same time by the theorist Herbert Fröhlich. It was followed in a relatively few years by the highly successful microscopic theory of superconductivity of John Bardeen, Leon N. Cooper and J. Robert Schrieffer, who were then working at the University of Illinois.

Through an interaction involving the lattice of positive ions, electrons of equal and opposite momentum and spin attract each other and form pairs (called Cooper

pairs). The Bardeen-Cooper-Schrieffer (BCS) theory shows that electrons "condense" from the nearly free electron gas into the paired superconducting state. One does not usually associate the pairing of electric charges of the same sign with a lowering of energy, but when the lattice is included, the pairing idea becomes reasonable. The positive ions, vibrating around their equilibrium position, are momentarily attracted by an electron. The electron moves some 100 times faster than the ions, so that by the time the ions have responded to its presence and moved slightly together, it is far away. The Cooper-paired partner, however, arrives to take advantage of the accumulation of positive charge: an energetically favorable situation. Already it can be seen why not-so-good ordinary electrical conductors can make good superconductors. The same lattice-electron interaction that leads to the scattering of a normal electron and hence to electrical resistance can, at low temperatures where there is not too much thermal agitation, lead to electron-pairing and superconductivity. Furthermore, a theorem put forward by Philip W. Anderson shows that the superconducting interaction will persist in full force even in very imperfect crystals, provided that the imperfections are nonmagnetic in character.

The BCS theory successfully describes much of superconductivity. It shows how the unusual features such as zero resistance and the Meissner effect follow from the lattice-electron interaction. In its refined form the theory can even be used for calculating the spectrum of lattice vibrations purely on the basis of superconducting data. So far, however, it has had no success in predicting the effects of atomic constituents, crystal structure and chemical bonds on the occurrence of superconductivity. Empirically we know that these considerations are important factors in determining not only whether a substance is superconducting or not but also whether the transition occurs at a higher temperature or a lower one. For example, the element niobium has been found to be particularly favorable to superconductivity. Among the elements in their normal state niobium has the highest temperature of transition from the nonsuperconducting state to the superconducting state, and among those compounds with the highest transition temperatures it is always present. If a series of related superconductors are compared, those incorporating niobium usually have the highest transitions.

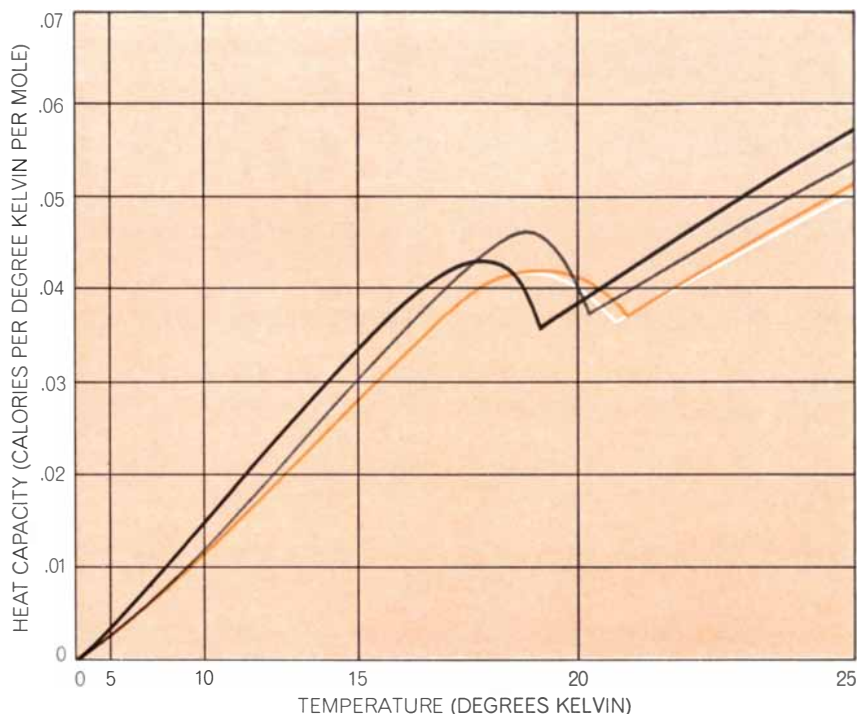


BETA-TUNGSTEN STRUCTURE stands out as the crystal most favorable to superconductivity. The ideal structure is an intermetallic compound with the formula A_3B where the atoms of element *A* (color) are placed so as to form close-packed linear chains of atoms running along the three cubic directions. Three conditions appear to be necessary to obtain high transition temperatures in the beta-tungsten structure: (1) the chains of *A* atoms must be long and unbroken and must consist of the transition atoms niobium or vanadium, whereas the *B* atoms must be a nontransition element; (2) the compound must be well ordered; (3) the compound should be formed at the ideal three-to-one chemical ratio.

When liquid helium became more plentiful as a research refrigerant after World War II, many new superconducting compounds began to turn up. Soon empirical criteria for superconductors emerged. A useful formulation was advanced by Matthias in 1957; in it he used only position in the periodic table of the elements to predict superconductivity [see "Superconductivity," by B. T. Matthias; *SCIENTIFIC AMERICAN*, November, 1957]. Matthias distinguishes between the "simple" metals (such as zinc and lead), almost all of which are superconducting if they have enough valence electrons per atom, and the transition metals, where superconductivity is an oscillating function of the average number of valence electrons per atom. For example, the superconducting transition temperature of titanium, which has four valence electrons per atom, is invariably increased by combining it with transition-metal elements to its right on the periodic table, that is, elements with more than four valence electrons per atom. The maximum transition temperature is reached when the alloy has close to 4.7 valence electrons per atom. Alloys of niobium (which has five electrons per atom) with titanium are used in large superconducting magnets and will be the "workhorse" material for the forthcoming large superconducting motors and generators.

Compounds consisting entirely of transition metals and compounds consisting entirely of nontransition metals are predictable in their superconducting behavior. Compounds combining transition metals and nontransition metals are surprisingly unpredictable. It is in this latter class of compounds that the highest-temperature superconductors are found. These compounds have only a few different crystal structures.

The crystal structure that stands out as being most favorable to superconductivity is the beta-tungsten structure [see illustration on opposite page]. In this structure the spatial arrangement is evidently favorable to superconductivity. The structure usually has the form of a compound A_3B where the atoms of element A are placed so as to form linear chains of transition-metal atoms running along the three cubic directions. An unusual feature is that along the chain directions the atoms come about 10 percent closer to one another than they do in their elemental forms. At least 20 superconductors have been found in this system since Hulm and G. Hardy discovered superconductivity in the vanadium-silicon compound V_3Si at 17 degrees K. in 1952. If the A atoms are of the transi-



HIGHEST TRANSITION TEMPERATURES observed by means of heat-capacity measurements were attained in 1967 by the author and his colleagues at the Bell Telephone Laboratories in alloys of niobium, aluminum and germanium with the general chemical formula $Nb_3(AlGe)$. The transition to the superconducting state in each case shown here corresponds to the sharp angle in the sample's heat-capacity curve. The black curve represents the data for a pure niobium-aluminum compound (Nb_3Al). The other curves show the effect of substituting an increasing amount of germanium for the aluminum atoms in the compound. The formulas of these samples are $Nb_3(Al_{.8}Ge_{.2})$ (gray curve); $Nb_3(Al_{1.75}Ge_{.25})$ (colored curve); $Nb_3(Al_{1.67}Ge_{.33})$ (white curve). Highest transition temperature measured in this experiment was 20.4 degrees Kelvin for the compound represented by colored curve.

tion metals niobium or vanadium and the B atoms are of aluminum, gallium, silicon, germanium or tin, and if the metals are reacted in the proper ratio, a compound with a beta-tungsten structure and a high transition temperature is likely to form. Thus niobium-aluminum (Nb_3Al) and niobium-tin (Nb_3Sn) both have a transition temperature above 18 degrees K. One would also expect the niobium-germanium compound Nb_3Ge to have a high transition temperature, but as it usually forms it has a transition temperature of only six degrees K. It is also found to contain more niobium with respect to germanium than the ideal three-to-one ratio of the chemical formula. If Nb_3Ge is formed by quenching it rapidly from a melt, its transition temperature can be as high as 17 degrees K. (although under various conditions the transition is spread all the way down to six degrees). The rise in the transition temperature is believed to be due to a closer approach to the ideal ratio and the breadth of the transition to be due to atomic disorder, both of which result from the rapid quenching.

The results of a wide variety of ex-

periments by many workers in different laboratories show that three conditions are necessary to obtain high transition temperatures in the beta-tungsten structure: (1) the chains of A atoms must be long and unbroken and must consist of either niobium or vanadium, and the B atoms must be a nontransition element; (2) the compound must be well ordered; (3) the compound should be formed at the ideal three-to-one chemical ratio.

If the B atom is a transition metal, the beta-tungsten structure has no favorable effect. For example, iridium, a transition metal, forms superconducting compounds with molybdenum, Mo_3Ir , in both the beta-tungsten and the hexagonal structure. Each structure has a transition temperature near eight degrees K., corresponding to an average of seven electrons per atom. No special effect of the beta-tungsten structure is apparent. On the other hand, gold, a nontransition metal, forms a beta-tungsten structure with niobium, Nb_3Au , which has a transition temperature of 11 degrees K. If Nb_3Au is mildly quenched from a melt, however, it forms a body-centered-cubic structure with the same electron-to-atom

ratio as the beta-tungsten phase but with a much lower transition temperature: near one degree K. Similarly, Nb_3Al , which has the highest known transition temperature of any binary compound so far reported when it has the beta-tungsten structure (18.8 degrees K.), can be quenched into the body-centered-cubic phase where the transition is near four degrees K. There is evidently something special about the structure that favors

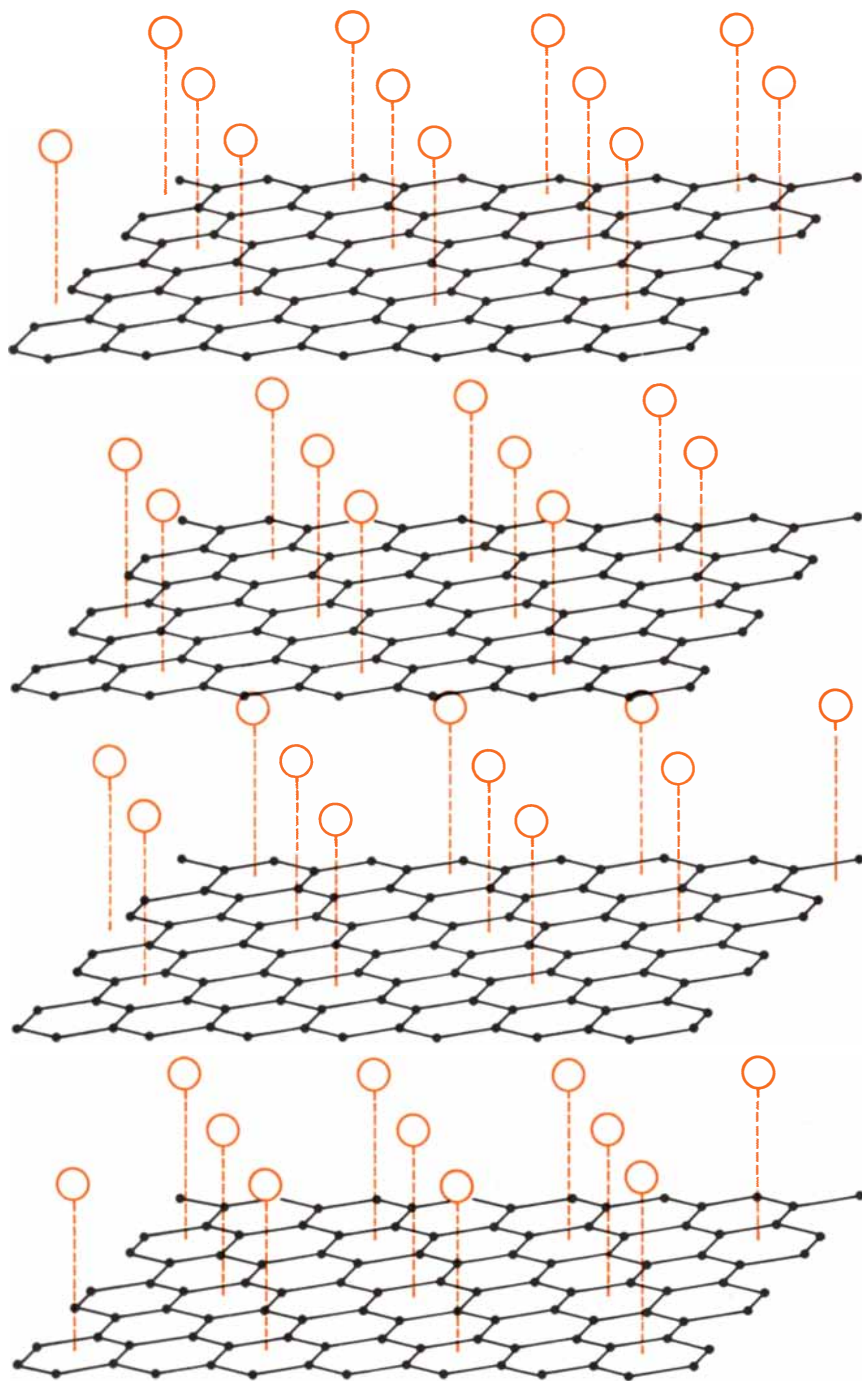
superconductivity in the beta-tungsten alloys where the *B* atom is a nontransition element.

Can the transition temperature ever be raised by combining two compounds such as Nb_3Al and Nb_3Sn ? The experimental answer has almost always been no. Adding a third component increases the chance of introducing disorder into the system. The observed transition temperature is almost always even less than

interpolation between the values for the two compounds would indicate. A small exception that surprised me at the time was found by Thomas B. Reed and his co-workers at the Massachusetts Institute of Technology in the early 1960's on adding Nb_3Al to Nb_3Sn .

The dramatic effect of rapid quenching on the transition of Nb_3Ge discussed above subsequently led me to ask the following question. If Nb_3Al could enhance the superconductivity of Nb_3Sn even slightly, what effect would it have on quenched Nb_3Ge ? A group of us at Bell Laboratories including Matthias, L. D. Longinotti, E. Corenzwit, G. W. Hull, R. H. Willens, J. P. Maita and myself started investigating $\text{Nb}_3\text{Al-Nb}_3\text{Ge}$ compounds early in 1967. We soon discovered superconductors that were stable at the highest temperatures and magnetic fields known so far. The details of just how this was done illustrate the advantages of empiricism when it is combined with some alertness and some good luck.

The initial results were not promising; the first samples (containing more germanium than aluminum) quenched by Willens were found to have a transition temperature not significantly different from that of Nb_3Ge . Matthias suggested quenching a compound consisting of 80 percent Nb_3Al and 20 percent Nb_3Ge . Russian workers had just reported a good transition temperature for that composition (although the transition was still below that of our best Nb_3Al). A small pellet Longinotti made by arc-melting the elements niobium, aluminum and germanium directly together had a surprisingly high transition temperature near 18 degrees K. With the poor results of the initial rapid quench in mind we decided to divide the pellet and save some for future use. Our caution was justified because the ensuing rapid quench actually lowered and broadened the transition temperature so that it was like that of the earlier quench. Apparently the disorder introduced dominated the compositional change. Following a suggestion by Corenzwit, we then annealed the remaining half of the melt. An annealing temperature of 900 degrees C., which we now know was somewhat on the high side, was chosen, but fortunately it was low enough to produce a small amount of material that had a transition temperature close to 19 degrees K. The transition was detected by Hull by observing the superconducting shielding currents induced in the sample as it was slowly cooled in an alternating magnetic field. This clue quickly led to annealing at lower temperatures, which produced more atomic order and higher transition tem-



INTERCALATION of potassium atoms (color) between the tightly bonded sheets of carbon atoms in a graphite crystal (black) raises the concentration of electrons in the graphite, converting it from a nonsuperconducting semimetal to a fair superconductor. The compound is the first of a large class of layered crystals investigated by the author's group.

peratures. In a few days 20 degrees K. was reached; it was the first substantial increase in transition temperature since the 18 degrees K. found in Nb_3Sn some 13 years earlier.

These $Nb_3(AlGe)$ alloys always contained other crystalline phases. Nevertheless, the heat-capacity curves produced by Maita [see illustration on page 27] showed that the onset of the transition was due to the bulk beta-tungsten compound. The transition onset was as high as 20.4 degrees K. when the ratio of aluminum to germanium was properly adjusted. Much work has since been done in a number of laboratories toward optimizing the time and temperature of the heat treatments. For example, if one tries to reduce the disorder by annealing below 650 degrees K., the time needed for the establishment of equilibrium becomes inconveniently long, and deleterious effects such as the precipitation of other phases and the loss of aluminum become significant. Many laboratories in this country, in Europe and in Japan have prepared $Nb_3(AlGe)$ samples following roughly the same procedures and have obtained materials with transitions near 20 degrees K. Curves of transitions up to 21 degrees K. have recently been published by Jiri Ruzicki of the University of Karlsruhe. All these materials are apparently multiphase, that is, they consist of more than one crystal form. This means that one must be most careful in interpreting the superconducting data.

In order to amplify the last remark I must digress briefly. In a multiphase sample it is possible for as little as .1 percent of a superconducting phase dispersed in the form of connected filaments (at the boundaries of the grains of the metal, for instance) to produce shielding currents that cause the entire sample to exclude magnetic flux and appear to be superconducting. I was saved from finding the compound $PdAs_2$ to be a semiconductor-superconductor many years ago by a chance encounter with the theorist Conyers Herring. Herring has an instinct for evaluating experiments critically and in that encounter he quickly recognized that the topology of a small second phase—which was in too small a concentration to appear in the X-ray diffraction patterns—could easily falsify the signal and make the entire volume appear superconducting. His thesis was easily proved by simply reducing the sample to a fine powder, thereby destroying the connectivity of the small amount of a superconducting phase dispersed at the grain boundaries of the semiconductor $PdAs_2$. The procedure of powdering the sample has

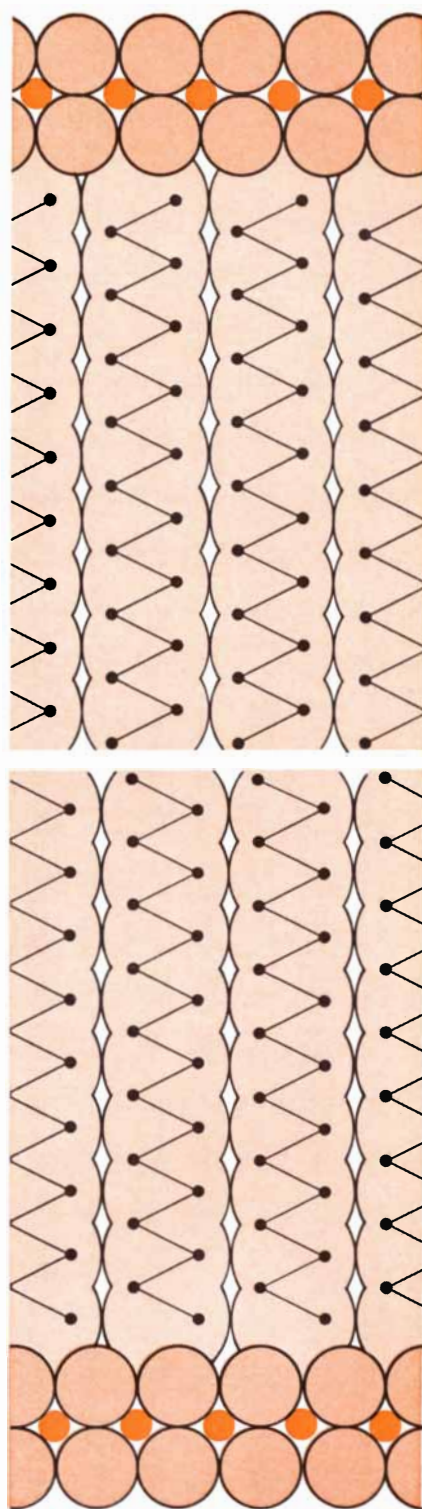
been instituted as a standard practice by an increasing number of workers. It is only a guide, however, since sometimes the connectivity of a small amount of second phase is not destroyed. In other cases the superconductor itself (which may be the principal phase) may be disordered, oxidized or somehow destroyed by the powdering.

When a small amount of heat is added to an isolated metallic sample, the temperature increases by a definite amount that depends on the vibrational frequencies of the lattice and the energy states available to the electrons. The ratio between the heat added and the temperature rise, which is called the heat capacity, gives important information about superconductivity. Both the characteristic lattice frequency and the density of the energy states available to the electrons are parameters that enter into the BCS theory, and they can be determined from heat-capacity measurements. Moreover, there is an additional contribution to the heat capacity associated with the transition to the superconducting state that is proportional to the number of superconducting atoms. This contribution cannot be misrepresented by a small amount of a second phase; if only a small fraction of the sample is superconducting, only a small additional heat capacity will be measured when the sample becomes superconducting.

Heat-capacity measurements are perhaps the best method available for investigating new superconducting materials. The students in my group at Stanford have developed a new silicon thermometer-calorimeter capable of measuring samples consisting of as little as a milligram of metal. It is thus possible to investigate the bulk superconducting properties of films and small crystals.

One can now appreciate the significance of the data obtained for $Nb_3(AlGe)$. By X-ray analysis we had identified minor amounts of two phases other than the primary beta-tungsten one. Fortunately the Nb_3Al sample that was run as a control was almost single-phase beta-tungsten. The similarity of its heat capacity to the more multiphase germanium-containing samples led us to the pleasant conclusion that in the latter samples not only was the main beta-tungsten phase the superconducting one but also the other phases were not making major contributions to the observed heat capacity.

The heat capacity associated with the electrons that emerges from the data for all the samples of $Nb_3(AlGe)$ is surpris-



TWO-DIMENSIONAL VIEW of a layered intermetallic compound intercalated with long-chain organic molecules is shown here. The metal layers, composed of the transition-metal compound tantalum disulfide (TaS_2), are separated by two lengths of 18-carbon-atom-long organic molecules stacked at right angles to the TaS_2 sheets. The structure is roughly similar to that responsible for the electron micrograph on page 23, with the exception that the spacing of the layers in this case is approximately 10 times greater.

ingly low in comparison with other high-transition-temperature beta-tungsten superconductors. On a per-atom basis it is about the same as elemental niobium, and a factor of two smaller than had previously been associated with high-temperature superconductivity in the beta-tungsten structure. This puzzling result was not at all expected from available theory, but it did lead to the hope that in strong magnetic fields there might be some weakening of internal magnetic effects that are inimical to superconductivity. Simon Foner of the National Magnet Laboratory, who worked with the direct-current magnetic facility available there, found that Nb₃(AlGe) samples indeed remain superconducting up to 200,000 oersteds at 14 degrees K. The samples were subsequently found to remain superconducting up to 400,000 oersteds in the lower temperatures of the liquid-helium range; this was determined in a pulsed-field arrangement. Although the maximum current-carrying capacity in these materials has not been ascertained, they maintain their superconductivity in stronger fields than any other known material.

The features of the beta-tungsten

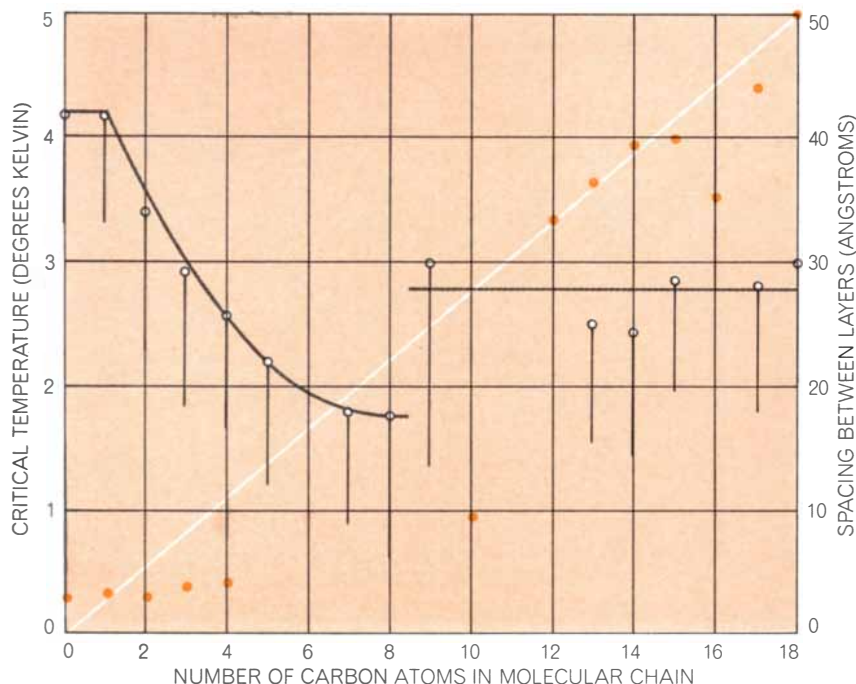
structure that make it favorable to superconductivity are subtle. Workers in this country and France have focused with some success on the distribution of energy levels available to the conduction electrons. It has been pointed out by Meier Weger of Hebrew University in Israel that the one-dimensional aspect of the linear chains of niobium atoms will be manifested in the energy-level distribution in spite of the fact that the overall symmetry is cubic. Although there are many clues (such as the softening of the lattice) and a number of detailed theories, the explicit mechanism that enhances the superconducting interaction in the beta-tungsten structure is still not clearly understood. If it were, it might suggest ways to proceed in achieving still higher transition temperatures.

Let us now turn to some crystals where the role of structure in determining physical properties is more apparent. Graphite is such a crystal. In its tight bonding within layers one atom thick and weak bonding between the layers give rise to the anisotropic mechanical properties that make graphite a good lubricant. The anisotropic bonds give

the lattice vibrations of graphite a two-dimensional character at low temperature. Because pure graphite has very few free conduction electrons it is called a semimetal. It has been known for a long time that it is possible to introduce electrons into graphite by "intercalating" its crystals with atoms of an alkali metal such as potassium. The atoms are inserted between the graphite layers by a rapid, reversible chemical reaction that proceeds at moderate temperatures. The alkali metal donates an electron to the graphite. By such means the concentration of electrons can be varied over a wide range and an excellent opportunity to explore for superconductivity is offered. At the suggestion of N. Bruce Hannay in 1965 we examined a number of crystals of graphite intercalated with alkali-metal atoms and found some to be superconducting. Unfortunately they became so only at temperatures well below one degree K. Moreover, they were the crystals that had the maximum alkali-metal content, so that they had lost most of their two-dimensionality.

There are many other compounds that form layered crystals with properties similar to those of graphite, including some 40 dichalcogenides such as niobium diselenide (NbSe₂) and tantalum disulfide (TaS₂). These are molecular crystals in which the covalently bonded molecular unit is an infinite two-dimensional sheet. In the third direction—perpendicular to the layers—identical sheets are stacked parallel to one another. Molybdenum disulfide (MoS₂) is another such crystal. In it each molecular sheet is three atoms thick and consists of a plane of molybdenum atoms covalently bonded on each side to a plane of sulfur atoms. The sulfur plane of one sheet thus faces a sulfur plane of the next sheet. The facing sulfur planes are bonded not covalently but by weak van der Waals forces.

MoS₂ is a good lubricant for the same structural reason that graphite is. Walter Rudorff of the University of Tübingen discovered several years ago that it also had chemical properties similar to graphite. He found that it and other transition-metal dichalcogenides could be intercalated with alkali metals and with alkali-metal-ammonia complexes. Working with Melvin B. Robin at Bell Laboratories, we found that when MoS₂ was treated with potassium from ammonia solution as Rudorff prescribed, a small fraction of the sample became superconducting at a temperature as high as five degrees K. We were unable, however, to obtain well-defined bulk superconductivity. (Workers at the California



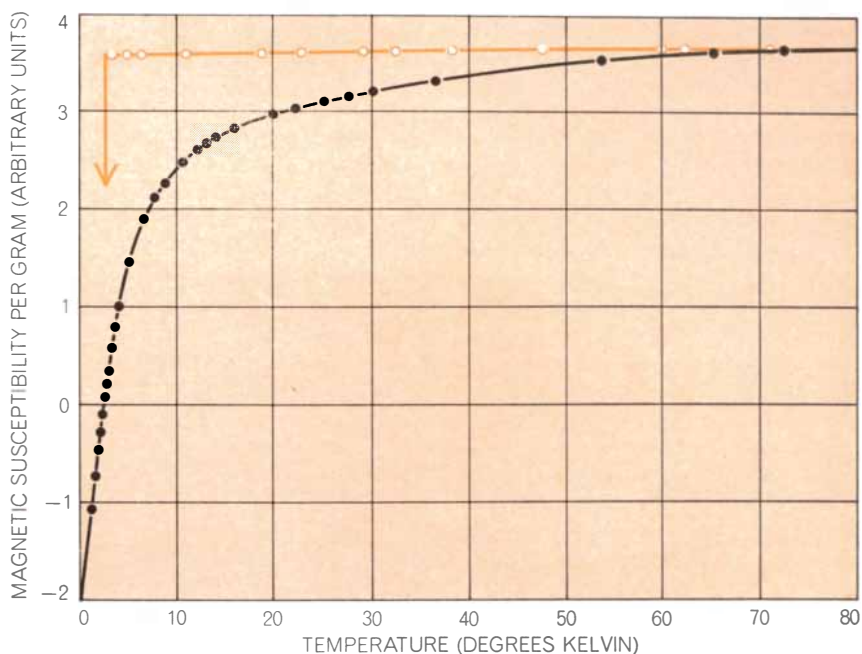
SUPERCONDUCTING TRANSITIONS of the intercalated crystals were found by F. R. Gamble, J. H. Osiecki, M. Cais and R. Pisharody of the Syva Research Institute and by F. J. DiSalvo and the author at Stanford to be characterized by a gradual onset whose width and shape are independent of the spacing of the layers. In this graph, which summarizes the data for a number of TaS₂ complexes intercalated with various organic amines, 90 percent of the superconducting transition takes place in the interval represented by the vertical black line below each transition-temperature onset, denoted by open circles. The colored dots give the predominant interlayer spacing for each complex; they indicate that the organic chains are parallel to the planes when the number of carbon atoms is four or less and are perpendicular to the planes when the number of carbon atoms is greater than 10.

Institute of Technology have recently reported superconductivity in alkali-metal-MoS₂ compounds with some supporting X-ray data.)

At about that time I joined the faculty at Stanford and continued the work there with Fred R. Gamble, a postdoctoral fellow, and Francis J. DiSalvo, a beginning graduate student. Gamble had been studying the interactions between organic molecules and thin superconducting films with Harden M. McConnell and brought this interest to the layered-compound research. He subsequently joined the Syva Research Institute in Palo Alto and continued to work with us. We decided to look into the layered structures more generally, hoping to find a large superconducting anisotropy. The results were negative for quite some time and would have been discouraging except for the enthusiasm of youth and one result that demonstrated the power of the chemistry involved. NbSe₂ is a layered dichalcogenide that is metallic and can be grown in nice single-crystal flakes that become superconducting at seven degrees K. We found that when alkali metal was intercalated, the transition temperature disappeared below our temperature-measuring range. When we simply dropped the intercalated metal flakes in water, however, hydrogen was evolved and in a matter of seconds the original NbSe₂ was restored, as was indicated both by structure and by superconductivity. Evidently the intercalation reaction is rapid and reversible; the intraplane bonds are strong enough for the planes to retain their integrity even when they are subjected to the turmoil of a rather violent chemical reaction.

In the fall of 1969 Armin Weiss and R. Rutherford of the University of Munich reported that titanium disulfide (TiS₂), which is a semiconductor, could be intercalated with various acid amides and hydrazine. When Richard Klemm, a Stanford graduate temporarily employed at Syva en route to graduate school, brought their article to our attention, we were all stimulated to test its applicability to the superconducting dichalcogenides. DiSalvo prepared fresh TaS₂ and Gamble almost immediately discovered its beautiful reactions not only with straight-chain acid amides but also with pyridine (C₅H₅N) and aniline (C₆H₅NH₂). The reactions manifested themselves by a dramatic swelling of the crystal and a moderate increase in the superconducting transition temperature.

An entire new class of superconduct-



PRECURSOR SUPERCONDUCTING EFFECTS above 35 degrees K. were discovered by A. Menth of Bell Laboratories in the course of an investigation of the magnetic susceptibility of certain intercalation complexes. The anisotropy of these complexes' response to the applied magnetic field is apparent in the difference between the two curves. The measurements represented by the open circles were made with the field parallel to the layers; those represented by the black dots were made with the field perpendicular to the layers.

tors was thus discovered whose properties are by far the most anisotropic known. Their two-dimensional character is only beginning to be understood, but among the almost 100 new superconducting crystals that have been synthesized so far certain trends are apparent. For example, if the chalcogenide from which a crystal complex is formed is superconducting, so is the complex. Furthermore, the superconducting transition temperature depends on the nature and concentration of the intercalated material more than on the separation of the metallic layers.

The pyridine-TaS₂ complex was found to crystallize with one pyridine molecule for every two TaS₂ molecules. A chemical bond is formed that evidently involves the lone pair of electrons on the nitrogen and the narrow, half-filled conduction band of the TaS₂ layers. When the conduction band is filled, as in the semiconductors tungsten disulfide (WS₂) and molybdenum disulfide (MoS₂), the intercalation reaction will not proceed, presumably because there are no empty states to accept the extra electrons. The synthesis of these compounds and the study of their properties offer a new meeting ground between organic chemistry and metal physics. Such an interdisciplinary overlap is likely to be valuable to the understanding of the first group of metals that are largely organ-

ic in content and also superconducting.

In these substances the molecular sheets remain intact, but their stacking sequence along the perpendicular axis frequently changes and their separation varies (depending on the particular organic material intercalated) from three angstroms to 57 angstroms. Presumably it will be possible to extend the range as even more intercalations are made. When the intercalation reactions are carried to completion, the ratio of intercalated molecules to TaS₂ molecules varies from 1 : 1 all the way to 1 : 6. Such ratios indicate site specificity and explain why order along the perpendicular axis is maintained. If pyridine is reacted with TaS₂ in the ratio of 1 : 4 instead of 1 : 2, which is the fully intercalated ratio, it intercalates between every other TaS₂ layer. This structure has been confirmed by Humberto Fernández-Morán, Mitsuo Ohtsuki and Akemi Hibino of the University of Chicago with the electron microscope [see illustration on page 23].

Gamble, Jean H. Osiecki and DiSalvo have made a rather thorough study of TaS₂ intercalated with a series of pyridine molecules with different side groups. Because the layer spacing is almost independent of the particular pyridine employed they conclude that the plane of the pyridine molecule lies parallel, or almost parallel, to the TaS₂ layers. Both 2-amino-pyridine and 4-phenyl-

pyridine open the layer spacing by about six angstroms. In the presence of excess organic molecules the reaction proceeds until there is one 2-amino-pyridine molecule for every two TaS₂ molecules or one 4-phenyl-pyridine molecule for every four TaS₂ molecules. The difference is undoubtedly due to the size of the respective organic molecules.

There is both chemical and physical evidence that the intercalation process involves a partial transfer of electrons to the metallic layer. The chemical evidence rests on the fact that there is a correlation between the strength of the organic molecule as an electron donor and its ability to intercalate. Gamble, Osiecki and DiSalvo found a rough correlation between the number of intercalated molecules and the superconducting transition temperature. Such evidence is also found in a recent study of the complexes of TaS₂ with *n*-alkyl amines whose chain length varies from zero (NH₃) to 18 (octadecylamine, C₁₈H₃₇NH₂). The layer spacing is always constant for the shorter chains of the series, indicating that the chains are lying parallel to the planes. The transition temperature decreases from about 4.2 degrees K. to 1.8 degrees as the chain length increases to eight carbon atoms.

The longer-chain amines, on the other hand, stand on end at right angles to the planes. The number of nitrogen bonds per tantalum atom remains constant, and so does the transition temperature (near three degrees K.). The layer spacing opens to 57 angstroms, corresponding to two chains end to end between each layer [see illustration on page 29].

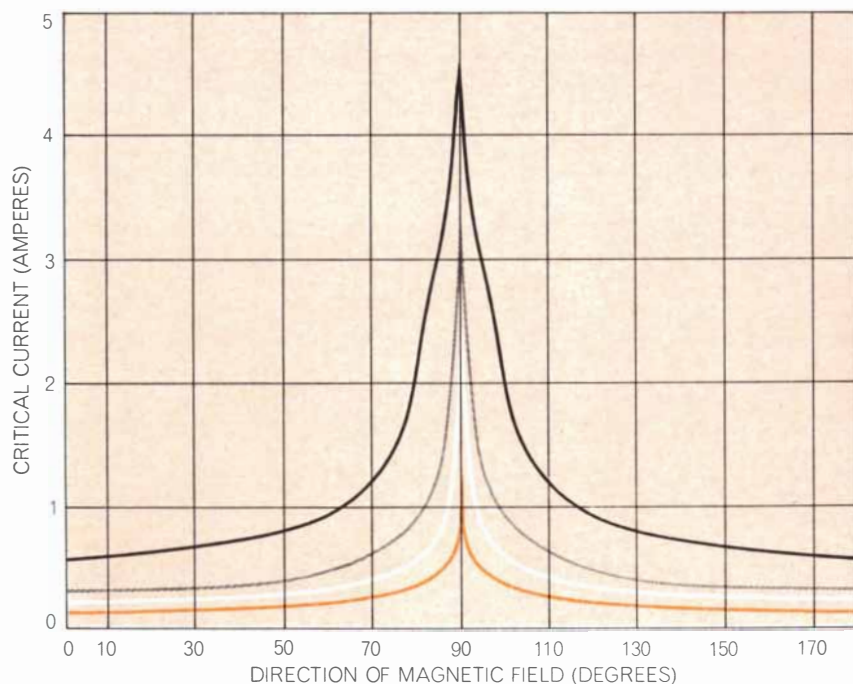
The superconducting properties of the intercalated crystals again reflect their strong anisotropy. We have found, however, that this sometimes emerges in unexpected ways. The heat capacity of a series of complexes whose layer spacing varies from three angstroms to 30 angstroms was measured by DiSalvo and R. Schwall at Stanford. They found that the heat-capacity anomaly associated with the superconducting transition shows a gradual onset whose width and shape are independent of layer spacing. The gradual onset is quite unlike the abrupt discontinuity in the heat capacity of the more familiar superconducting crystals. This behavior leads to the conclusion that a substantial amount of the disorder associated with the transition arises from two-dimensional intralayer ordering.

The existence of fluctuating, short-lived Cooper-paired electrons has recently been deduced from their effect on

electrical resistance above the superconducting transition temperature, following the discovery by Rolfe E. Glover III of the University of Maryland of a decrease of the resistance of quenched bismuth films above the transition temperature. The decrease quantitatively fits a theory proposed by the Russian theorists L. G. Aslamazov and A. I. Larkin. Their theory is based on the existence of such fluctuating pairs, which even for the short time they exist can lower the resistance. More recently workers at Harvard University have seen effects of fluctuating pairs on the magnetic susceptibility of lead by making very precise measurements above the transition temperature.

In order to see if the two-dimensional ordering indicated by the heat-capacity data could also be due to fluctuating Cooper pairs, A. Menth at Bell Laboratories investigated the magnetic susceptibility of some intercalation complexes. His results [see illustration on preceding page] show what we believe are precursor superconducting effects that are apparent above 35 degrees K., or 10 times the transition temperature. There is no theory that is applicable so far above the transition temperature. Additional quantitative experiments may suggest how present theory should be modified and perhaps extended.

In addition to the fluctuation effects seen above the transition temperature, we still have remaining the question of how far, if at all, one can hope to raise the transition temperature itself in intercalation complexes. These complexes conform closely to the "model" system of surface-induced superconductivity independently proposed by Ginzburg and McConnell several years ago and elaborated by Ginzburg over the past few years. These models demand that the conduction electrons be in contact with dielectric layers that can be polarized. The electron-pairing interaction operates by one metal electron's responding to the polarization induced in the dielectric by its partner. Our complexes show no evidence for any such polarization enhancement of superconductivity. So far, however, no easily polarizable molecules have been intercalated. The mild conditions under which many intercalation reactions proceed and the large number of substances that can be intercalated suggest that it will be possible to intercalate quite polarizable molecules in the not too distant future. One will then be able to use such precursor phenomena to monitor the effects of intercalation on the superconducting interaction at tem-



STRONG DEPENDENCE of the critical current (the current that destroys the superconductivity) on the orientation of a single crystal of niobium diselenide (NbSe₂) in a varying magnetic field at 4.2 degrees K. was observed by workers at the Lebedev Physics Institute in the U.S.S.R. The strength of the applied field increases from top curve to bottom curve. The field was always perpendicular to the current but varied from being perpendicular to the layers (0 degrees, 180 degrees on scale at bottom) to being parallel to them (90 degrees).

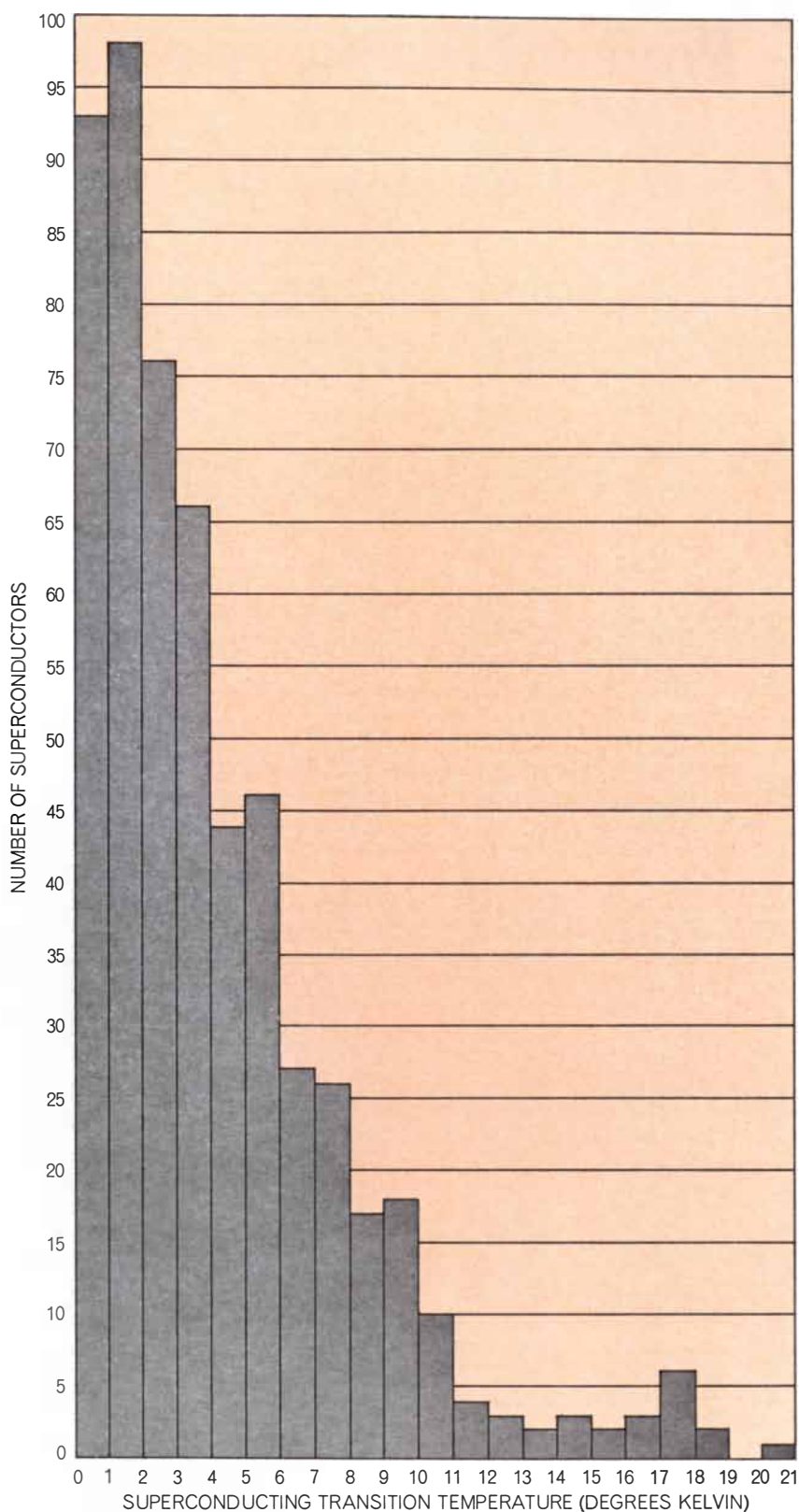
peratures well above the transition temperature.

The magnetic field necessary to suppress superconductivity in the layered complexes is more anisotropic than in any other system. Rough measurements indicate a ratio of at least 100 to one for the upper critical fields, with the field in the direction perpendicular to the planes being the smaller. The decrease in transition temperature with magnetic field is less than it is for any other known superconductor; 60,000 oersteds lowers the transition by some .5 degree K. in pyridine-intercalated TaS₂.

Many other properties of the complexes remain to be explored. They include the transport of current both parallel and perpendicular to the layers. Such experiments require rather perfect single crystals because crystal dislocations and other imperfections tend to "short out" the intrinsic electric anisotropy. A. R. Thompson of Syva has found that the resistance anisotropy increases from the situation where the resistance is about 10 times greater perpendicular to the planes than parallel to them to one where it is at least 100,000 times greater for intercalated compounds.

Experiments on the superconducting properties of unintercalated NbSe₂ have been conducted by E. A. Antonova, S. A. Medvedev and I. Yu. Shebalin at the Lebedev Physics Institute in the U.S.S.R. They find that the critical current (the current that destroys the superconductivity), when it is measured parallel to the layers, is strongly dependent on the direction of an applied magnetic field. The applied field is always perpendicular to the current but is rotated from being perpendicular to the layers to being parallel [see illustration on opposite page]. The observed anisotropy can be understood in terms of the crystal structure resisting the magnetic forces acting on the electron-transport current.

I have given here only those details that are necessary to provide a map of this field of exploratory research. Much interesting work done by other investigators, particularly on the beta-tungsten structure, has been omitted. The beautiful generalizations and concepts that emerge as a scientific field matures have been forthcoming in superconductivity since the advent of the BCS theory, but the results are still limited to relatively simple systems. How new concepts will be developed to encompass results of the kind discussed here, and how significant they may be, are questions that remain for the future.



KNOWN SUPERCONDUCTORS are compiled in this bar chart as a function of their superconducting transition temperature. The number of superconductors increases roughly exponentially below 12 degrees K., as one might expect from the prevailing quantum-mechanical theory of superconductivity. In the author's view there would be no superconductors above 14 degrees K. were it not for particularly favorable structural or chemical effects that are not yet well understood. With a few minor exceptions all the entries with transition temperatures above 12 degrees K. are compounds made by combining transition metals with nontransition metals. The single entry above 20 degrees K. is Nb₃(AlGe).

Prenatal Diagnosis of Genetic Disease

New techniques are making it possible to detect hereditary diseases early in pregnancy. To what extent is the control of such births justified on biological and social grounds?

by Theodore Friedmann

More than 1,600 human diseases caused by defects in the content or the expression of the genetic information in DNA have been identified. Some of these diseases are very rare; others, such as cystic fibrosis and sickle-cell anemia, are relatively common and are responsible for much illness and death. It has been estimated that more than 25 percent of the hospitalizations of children are for illnesses with a major genetic component. Thanks to new techniques of biochemistry and cell biology, we are learning a great deal about the biochemical mechanisms that lead from a genetic defect to clinical disease. Particularly important has been the discovery that cells from patients can be grown and studied in tissue culture in artificial nutrient media, and that these cells often continue to express the abnormal function of a mutant gene. As a result genetic manipulative techniques are being developed through which man may acquire the ability to control aspects of his own evolution, to eliminate disease and even to improve his genetic makeup. Another application of these techniques is prenatal genetic diagnosis.

The ability to establish the diagnosis of genetic disease prior to birth came through studies of the fluid that bathes the developing fetus within the amniotic cavity: a sac surrounding the fetus that is lined by two layers of cells (the chorion and the amnion) and is filled with fluid derived mainly from fetal urine and fetal respiratory secretions. Suspended in the fluid are viable cells shed from the fetal skin and respiratory tract, and perhaps from the fetally derived lining of the cavity itself. Amniocentesis, the removal of fluid from the amniotic cavity by needle puncture, became useful and important in the early 1960's for the detection of unborn infants who ran the risk of Rh incompatibility. When an

Rh-negative mother carries an Rh-positive fetus, the mother may become sensitized to the "foreign" red blood cells from the fetus, and the antibodies that develop may in later pregnancies cross the placenta, cleave to the fetus's red blood cells and cause the destruction of red cells, severe anemia, brain damage and even death [see "The Prevention of 'Rhesus Babies,'" by C. A. Clarke; SCIENTIFIC AMERICAN, November, 1968]. Obstetricians discovered that they could estimate the degree of blood destruction by measuring the concentration of hemoglobin breakdown products in the amniotic fluid.

During amniocentesis for Rh disease it became clear that much useful information could be obtained by examining cells in the amniotic fluid. In 1949 Murray Barr of Canada had discovered that nerve cells from female cats were distinguishable from those of the male by the presence in the female cells of a darkly staining piece of chromosomal material on the nuclear membrane. These "Barr bodies" were then found to characterize female cells in many other mammals, including human females. Mary Lyon of England subsequently found that early in mammalian embryogenesis one of the two X chromosomes in female cells (male cells have only one X chromosome and a Y chromosome) randomly becomes condensed and inactive. In the unusual instances where cells have more than two X chromosomes all except one are condensed. In male cells condensation does not take place. The altered physical properties of these condensed chromosomes give rise to their staining characteristics.

Since amniotic-fluid cells are mostly fetal in origin, investigators turned to them as an unprecedentedly valuable material for detecting the kinds of ge-

netic disease that are caused by mutations on the X chromosome and that therefore affect only males. The best-known of the "X-linked" diseases is the bleeding disorder hemophilia. In this disease a deficiency of one of the protein factors required for clotting results in prolonged and intractable bleeding, particularly at sites of traumatic injury.

An ovum from a female carrier of hemophilia will have either a normal X chromosome or a defective one. After fertilization half of all the resulting males will receive as their only X chromosome the one carrying the mutant gene. Since there is no normal copy of the gene from the father such males will express the defect fully. (The father must pass his Y chromosome in order for the fetus to be male.) The other males will be normal, since they have by chance received the normal X chromosome from the mother. Therefore detection of a female fetus *in utero* by the presence of Barr bodies in a pregnancy in which there is a risk of hemophilia rules out the possibility of disease, although 50 percent of the females will be carriers. A male fetus, however, may be either affected or normal.

Predictions can also be made on the genetic constitution of the fetus in the case of diseases associated with an abnormal number of chromosomes or arrangement of chromosomes. In 1959 the French geneticist Jérôme Lejeune discovered that patients with mongolism (now usually called Down's syndrome) have no mutant or defective gene but rather carry an extra chromosome that in itself is probably normal. We now know that most cases of Down's syndrome are caused by a defect in the separation of chromosomes, called nondisjunction, in the developing egg resulting in the formation of ova with two No. 21 chromosomes instead of the usual one.

When such an egg is fertilized by a normal sperm, the result is an embryo carrying three normal No. 21 chromosomes. This "trisomy" of chromosome No. 21 causes Down's syndrome. An important feature of this kind of Down's syndrome is its increased incidence with advanced maternal age. A pregnant woman 40 years old is more than 10 times as likely to have an affected infant as one 25 years old. The disease is the single most common chromosomal aberration found in live-born infants.

In a rarer type of Down's syndrome the extra chromosome No. 21 is translocated onto another chromosome. A healthy carrier mother has only 45 chromosomes instead of the usual 46, but the total amount of genetic information is normal. During the formation of the ovum, however, segregation of chromosomes can give rise to an ovum carrying the translocated No. 21 plus the free No. 21. Fertilization of such an ovum leads to an embryo with an apparently normal chromosome number, but with an extra chromosome No. 21. The abnormalities in this kind of Down's syndrome are similar to those in the non-disjunction type.

Parallel with developments in cell bi-

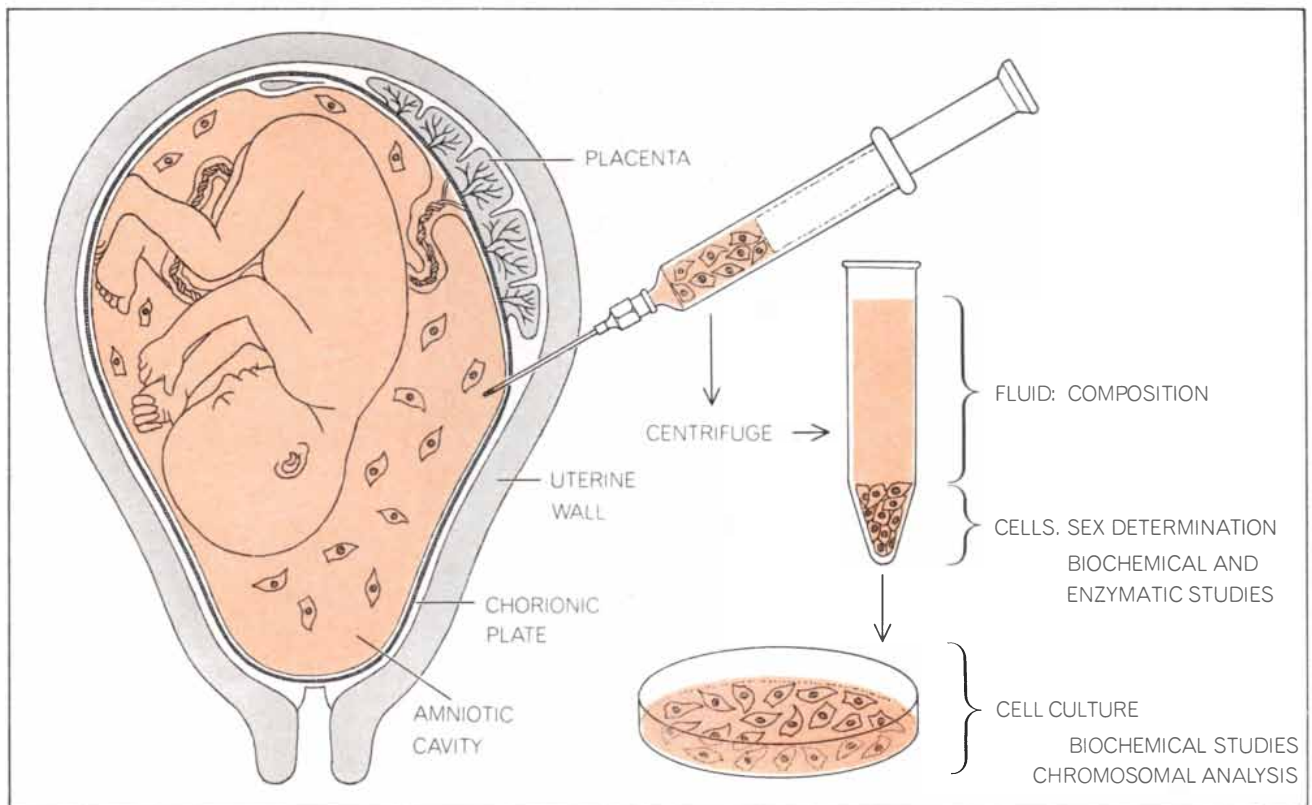
ology have been advances in our knowledge of the flow of genetic information from DNA through RNA to protein. The precise biochemical defects involved in several hundred human disorders have been discovered, and this is due largely to the realization that tissue-culture cells from patients often continue to show the biochemical defect characteristic of a given disease. Such culture methods have most often used skin cells, but recently geneticists have learned that amniotic-fluid cells can also be cultured and used diagnostically.

One disease that illustrates the usefulness of these methods is the Lesch-Nyhan syndrome, a severe neurological disease of males characterized by mental retardation, involuntary writhing motions called choreoathetosis and compulsive self-mutilation of the lips and fingertips by biting. In the healthy carrier mother one of the X chromosomes carries a defective gene for the enzyme hypoxanthine-guanine phosphoribosyl transferase (HGPRT), which is required for the conversion of the bases hypoxanthine and guanine into nucleotides for incorporation into new RNA and DNA by the "reutilization" pathway. Most

body cells can function normally without this enzyme, since there is another pathway for nucleotide synthesis. The function of cells in the basal ganglia of the brain, however, is severely impaired without the HGPRT pathway.

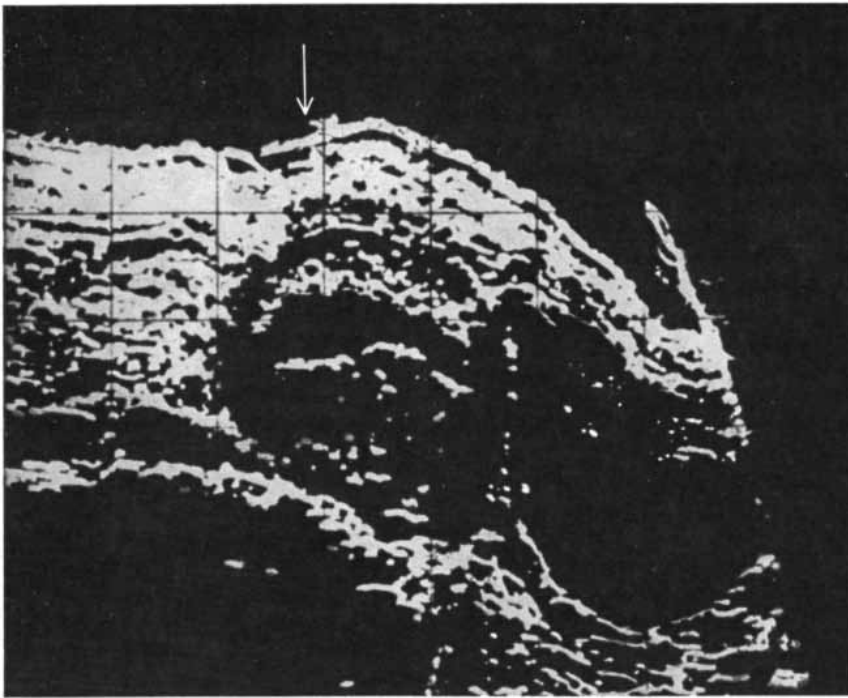
To determine whether or not a male fetus carries a defective HGPRT gene, amniotic-fluid cells in tissue culture can be labeled with radioactive hypoxanthine and then exposed to X-ray film. Normal cells, having incorporated the radioactive precursor, will appear densely labeled in this autoradiographic method, whereas Lesch-Nyhan cells will remain free of radioactivity. Alternatively cells can be homogenized and the enzyme assayed directly.

Many of the diseases that are associated with enzyme deficiencies show autosomal recessive inheritance: the defective gene lies on one of the 22 pairs of non-sex chromosomes (autosomes), and two mutant copies of the gene, one from each parent, are passed on to the offspring. The offspring are thus homozygous for the recessive gene and exhibit the disease; the parents are heterozygous carriers. In many instances where a single mutant copy of the gene is present about half of the normal amount of

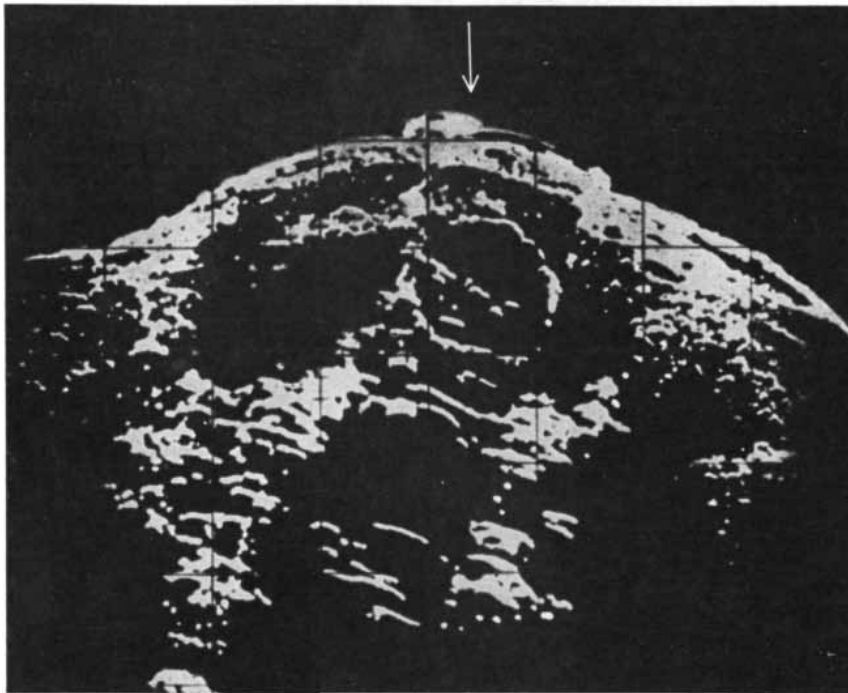


SAMPLE OF FLUID surrounding the fetus is taken by inserting a sterile needle into the amniotic cavity and withdrawing a small amount of fluid. The process is called amniocentesis. The fluid, derived mostly from fetal urine and secretions, contains fetal cells

(not drawn to scale). Care must be taken not to puncture the placenta or the fetus. The sample is centrifuged to separate cells and fluid. A variety of tests can be made. Optimum time for the amniotic tap for genetic diagnosis is about the 16th week of gestation.



LOCATION AND SIZE of the placenta can be determined by ultrasonic scanning. Bursts of high-frequency sound waves are emitted from a probe moved along the surface of the abdomen. Echoes returned from tissue interfaces within the body are displayed on a storage oscilloscope. The technique is simple, safe and rapid. These sonograms were made at the 18th week of gestation to locate the placenta before amniocentesis. The placenta appears as a crescent-shaped dotted area. The dark area directly below it is part of the amniotic cavity. Scattered echoes within the cavity are from the fetus. The dark shape on the right is the urinary bladder. The scan was made longitudinally from above the navel (*left*) to the pubic area (*right*). The arrow is at the site of the transverse scan shown below.



OVAL SHAPE to the right of center is formed by echoes from the fetal head. Above it and to the left is a section of the placenta. The dark area below the placenta is part of the amniotic cavity. The patient's left and right sides respectively are on the left and right of the photograph. The arrow is at the site of the scan in the top illustration. Both scans are necessary in order to locate the placenta precisely. The sonograms were prepared by Mitsunao Kobayashi of the Downstate Medical Center of the State University of New York.

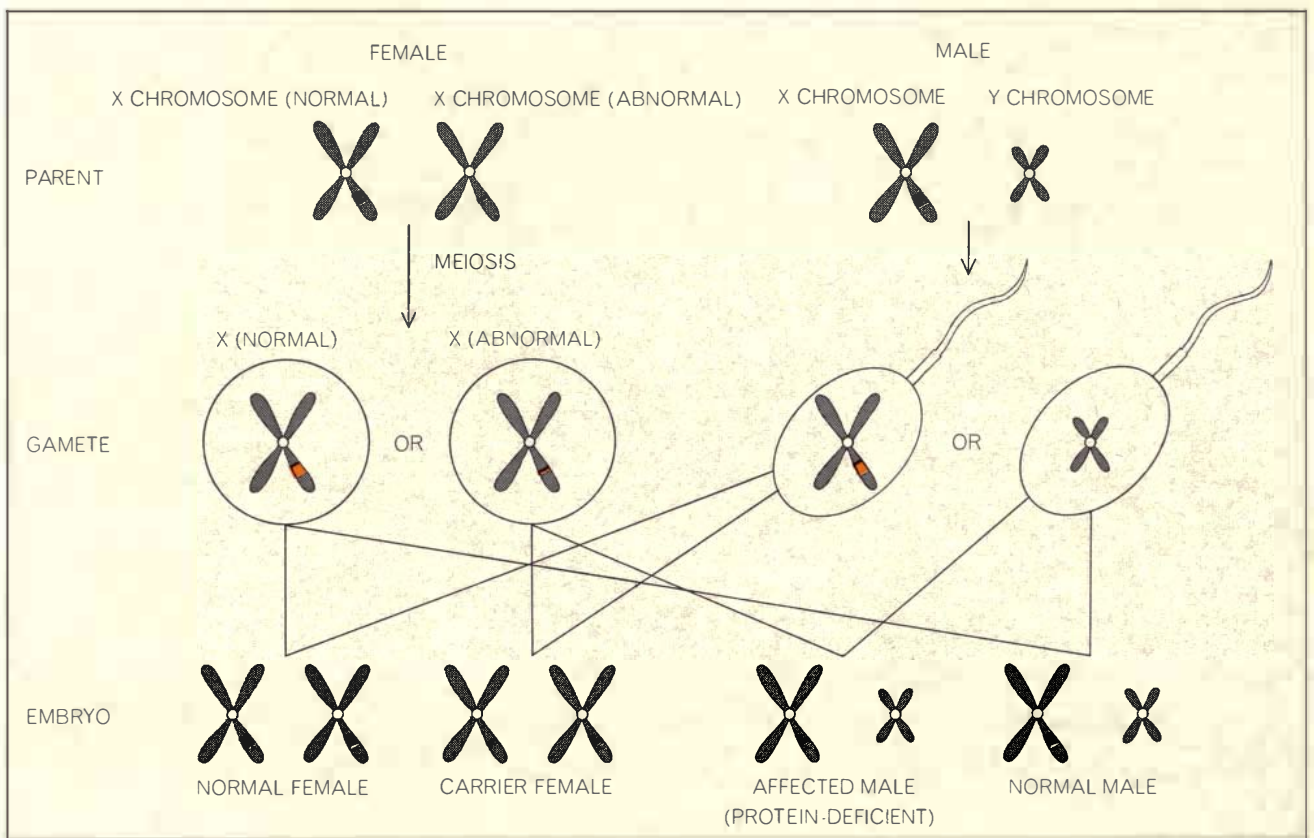
the gene product is made, which is often enough to protect against the disease. This is not the case, however, when the mutant gene is dominant.

One particularly devastating autosomal recessive disease is Tay-Sachs disease, which causes blindness, severe mental retardation and death, usually before three or four years of age. It is most common in Jews of northern European origin (Ashkenazy Jews). In 1969 John O'Brien and his colleagues at the School of Medicine of the University of California at San Diego discovered that in Tay-Sachs disease a mutation leads to a defective form of the enzyme hexosaminidase A, which normally splits the terminal sugar from a lipid-polysaccharide complex called GM₂ ganglioside. There results a massive accumulation of the undegraded ganglioside in nerve cells throughout the body. The enzyme deficiency is detectable in fetal amniotic cells, and O'Brien's group has followed 20 pregnancies in women known to be carriers. Seven affected fetuses were detected, and in all seven cases the women chose to terminate the pregnancy through abortion.

Some diseases in the fetus manifest themselves not by defects in amniotic-fluid cells but rather in abnormal concentrations of metabolites in the fluid itself. For example, fetuses with Hurler's disease (in which cells accumulate mucopolysaccharides, resulting in retardation and skeletal deformities) excrete large amounts of heparitin sulfate with their urine into the amniotic fluid.

Some 40 genetic diseases can now be diagnosed prenatally by tests on the amniotic fluid and its cells. Several referral centers, including the one at the University of California at San Diego, have facilities for performing all or almost all of these tests. It is likely that other methods of prenatal diagnosis will eventually become available, such as studying changes in the enzyme patterns in the mother's blood or even detecting fetal cells in the mother's circulation. Meanwhile the increased availability (and probable automation) of assay procedures, including chromosome analysis, will lead to widespread prenatal diagnosis through amniocentesis in the next few years. This fact compels us to reflect on several important questions.

The most obvious question concerns the safety of the procedure itself. For prenatal diagnostic purposes the optimum time to perform amniocentesis seems to be around the 16th week of gestation. By that time enough amniotic fluid has accumulated for a sample to be



HEMOPHILIA is transmitted by mothers who have a defective gene for a clotting protein in one of their X chromosomes. Female offspring do not develop the disease because they receive at least

one X chromosome that is not defective, but half of them like their mother will be carriers. A male offspring has a 50 percent chance of getting the defective gene and being afflicted with the disease.

easily obtained by needle puncture. The fetus is small and not likely to be traumatized, and sufficient time is still available to grow amniotic cells, perform the diagnostic procedures and proceed with a therapeutic abortion if that is desired. In the hands of the relatively small number of experienced individuals now performing amniocentesis the procedure does not seem to present much danger of traumatic injury to the mother or the fetus. The fetal parts can be manipulated away from the site of the needle puncture, and the placenta can be located by ultrasonic methods. One may expect traumatic complications to increase temporarily as less experienced physicians with insufficient specialized training begin to perform amniocentesis. Since any diagnostic procedure with a small but irreducible rate of complications is justifiably used only if the conditions being searched for lead to disease or damage much more frequently than the diagnostic procedure itself, it is important that these questions of safety be answered.

A more vexing problem concerns the possibility of developmental damage to the fetus through interference with the fetal environment, perhaps as a conse-

quence of removal of fluid and its metabolites or through changes in pressure within the uterus. To detect this kind of damage would require a long-term developmental and intellectual evaluation of infants who had experienced amniocentesis. The National Institute of Child Health and Human Development is now undertaking such studies through a newly organized Amniocentesis Registry, which will collect and evaluate long-term effects of the procedure on fetus and mother. Preliminary claims for the safety of amniocentesis have already been made, but since experience with the procedure is still limited, we must be prepared for the possibility that some untoward effects on the fetus will become evident as the number of amniotic taps increases.

If we assume that the procedure will prove to be relatively safe, we can ask how and for what purpose we want to use such methods of prenatal genetic diagnosis. Some have suggested that prenatal genetic screening through amniocentesis may become a routine part of prenatal care—similar to tests on the mother for syphilis, diabetes and high blood pressure—as an effort to detect most fetal diseases and malformations

before birth. This possibility seems remote. The problem of creating facilities to evaluate the three million births per year in the U.S. are of course immense, and many local and regional centers would have to be established. More important is the probability that there is almost certain to be a risk inherent in amniocentesis greater than the probability of detecting an abnormal fetus in an unselected population. This objection will obviously need to be modified if less hazardous methods of obtaining fetal genetic information are developed.

The most obvious purpose of such procedures is to reduce or eliminate the occurrence of genetic diseases that impose a devastating emotional burden on parents and often cause suffering and death in affected children. At present the only genetic diseases that might be detected *in utero* are those in which tissue-culture cells in the laboratory express the genetic abnormality of the disease, or those in which biochemical abnormalities are present in urine and other excretions and might therefore appear in the amniotic fluid. So far most developmental abnormalities, such as congenital heart disease, cannot be detected before birth.

Among the 1,600 genetic diseases that now are recognized, there will almost certainly be many that will not be expressed in the cells or the fluid obtained by amniocentesis. It is believed that all cells in the body, regardless of their function in differentiated tissues, carry the same genetic information. Any individual cell is therefore theoretically capable of performing functions of all other kinds of cells in that organism. We also know, however, that only some kinds of cells can conduct specialized functions such as the making of hemoglobin. If methods could not be found to activate or uncover the genes for hemoglobin in the skin or amniotic-fluid cells of patients with genetic forms of anemia, it might not be possible to detect these diseases in the uterus.

One factor that hinders the development of effective programs for the prevention of genetic diseases is the difficulty of identifying the pregnancies that are at risk. One of the clearest current indications for amniocentesis is advanced maternal age, since that is associated with the greatly increased risk of Down's syndrome. It has been estimated that if all pregnancies in women 35 years of age or older were evaluated by *in utero* detection methods, the rate of occurrence of this disease would be reduced to half the present level if selective abortion were practiced. Such age criteria, however, do not apply in many genetic disorders.

The other common indication for amniocentesis is a pregnancy in a woman who has previously borne a child with a genetic disease; this is called retrospective detection. If the disease is a dominant one such as Huntington's chorea, the risk of disease to the fetus is 50 percent. Monitoring subsequent pregnancies could readily detect all cases except those due to new mutations. Selective abortion on affected fetuses could virtually eliminate the disease. Unfortunately screening methods for Huntington's chorea and other dominant diseases are not available. If the disease is a recessive one, the potential effect of retrospective detection and selective abortion is much less impressive. We can expect to find only a small number of new cases, since the initial cases are all missed and subsequent pregnancies carry only a 25 percent probability of producing an affected child. If we assume a reproductive goal of two normal children per family, the number of new cases detected would at best be only 34 percent of the total. The effect of such programs on individual families known to have a history of genetic abnormality can nonetheless be great.

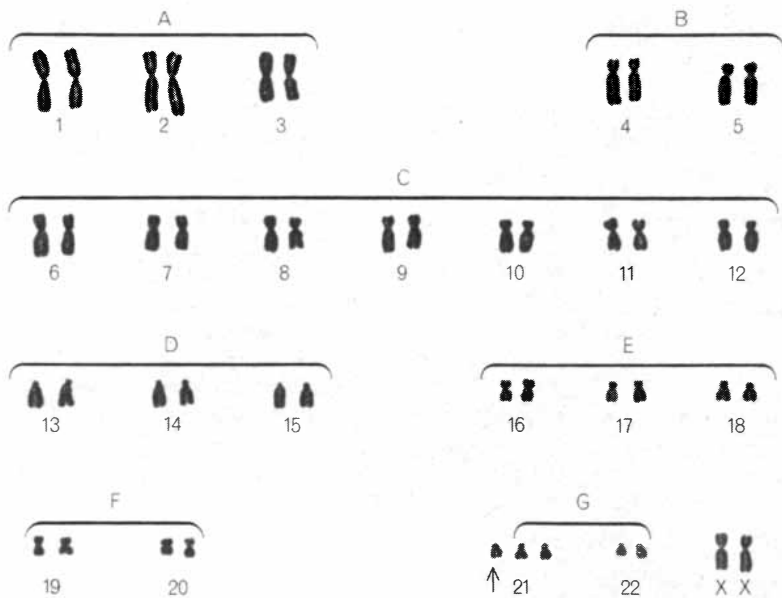
If prenatal diagnosis and selective abortion were coupled with extensive screening programs to find heterozygous carriers, profound reductions might be achieved in the incidence of some recessive diseases. If the screening program could detect each family in which both

parents were carriers, the monitoring of all pregnancies in only those families would result in the detection of virtually all new cases of a recessive disease, and selective abortion for affected fetuses could be practiced. It is possible that with such a regime only cases caused by mutations would occur. Programs of this kind would necessarily be elaborate and expensive, but geneticists have already undertaken programs to detect and prevent new cases of Tay-Sachs disease. Since the frequency of the gene for Tay-Sachs disease among Ashkenazy Jews is 10 times that of the general population, marriages among Jews are being screened by blood tests of both partners. In families where both husband and wife are found to be carriers it is planned to monitor all pregnancies and to offer abortions in cases where the fetus is found to be affected.

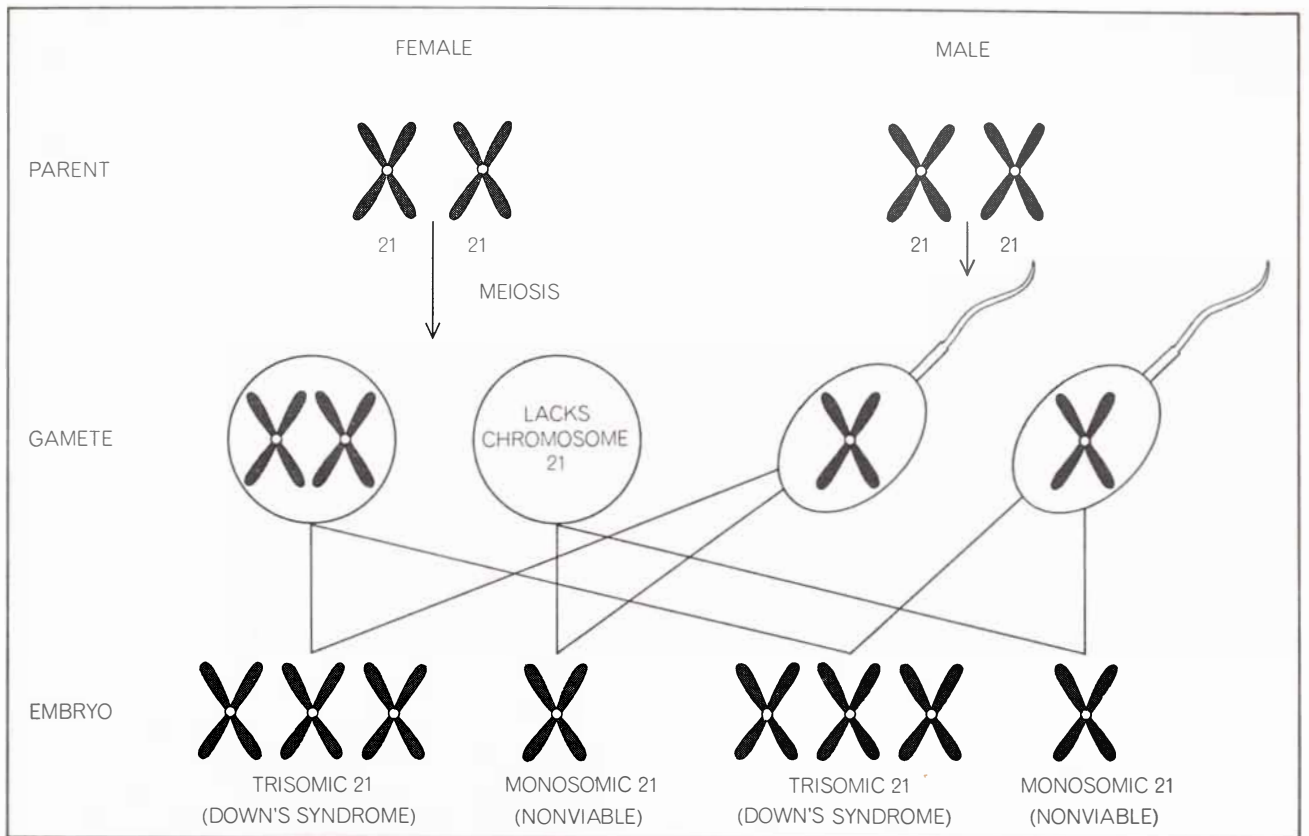
Cost-benefit analyses have shown that detection programs for Tay-Sachs disease and Down's syndrome alone would result in very large savings for individual families and for society as a whole if affected fetuses were aborted instead of being born and ultimately institutionalized at state expense. Four thousand infants with Down's syndrome are born each year in the U.S., and lifetime institutional care for each one costs approximately \$250,000. Such analyses, however, seldom define what they consider the benefit. Is it only black figures in the ledger instead of red? Economic considerations are undeniably important, but it seems a dangerous precedent to justify screening and selective abortion programs solely on the basis of comparing their cost with the economic burden to families and to society. One could argue cogently that we should be more willing to spend money for the elimination of disease even if it proves to be uneconomical.

Recently some geneticists, notably Arno G. Motulsky of the University of Washington School of Medicine and James V. Neel of the University of Michigan, have become concerned with the possibility that large-scale genetic manipulations such as prenatal detection and abortion might lead to detrimental changes in the quality and the diversity of the human gene pool. Such changes might be the inadvertent result of programs to eliminate disease or the deliberate consequence of eugenic programs to eliminate certain undesirable genes from the population.

Motulsky and Neel have recently shown that programs of prenatal detection and selective abortion might

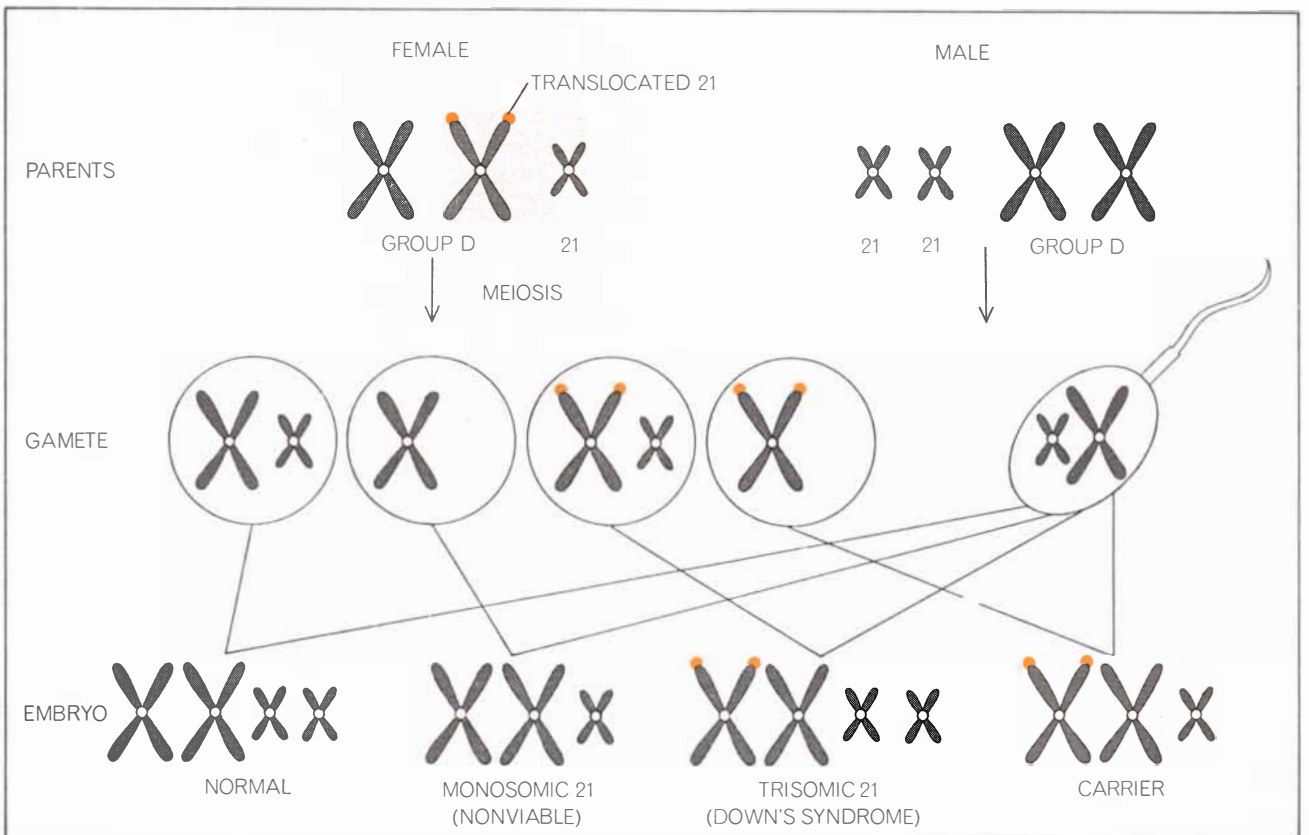


CHROMOSOMAL ANALYSIS of cells obtained by amniocentesis can determine if the developing embryo has Down's syndrome. This karyotype prepared by O. W. Jones shows that the girl has an extra No. 21 chromosome and will have the stigmata of mongolism.



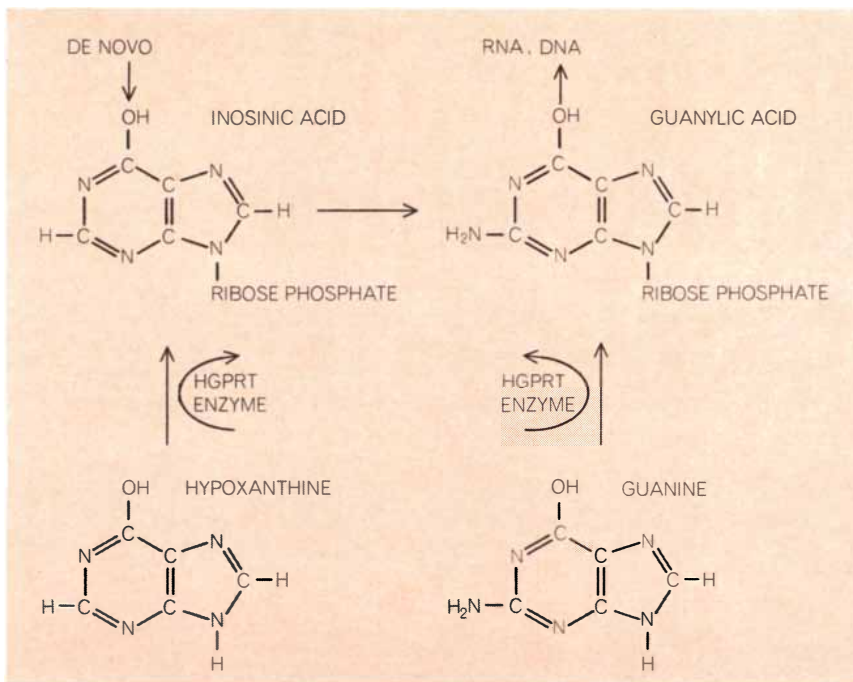
DOWN'S SYNDROME, or mongolism, results when chromosomes fail to separate (nondisjunction) during meiosis, giving rise to

some ova with two No. 21 chromosomes. When the ovum with the extra chromosome is fertilized, the embryo develops abnormally.

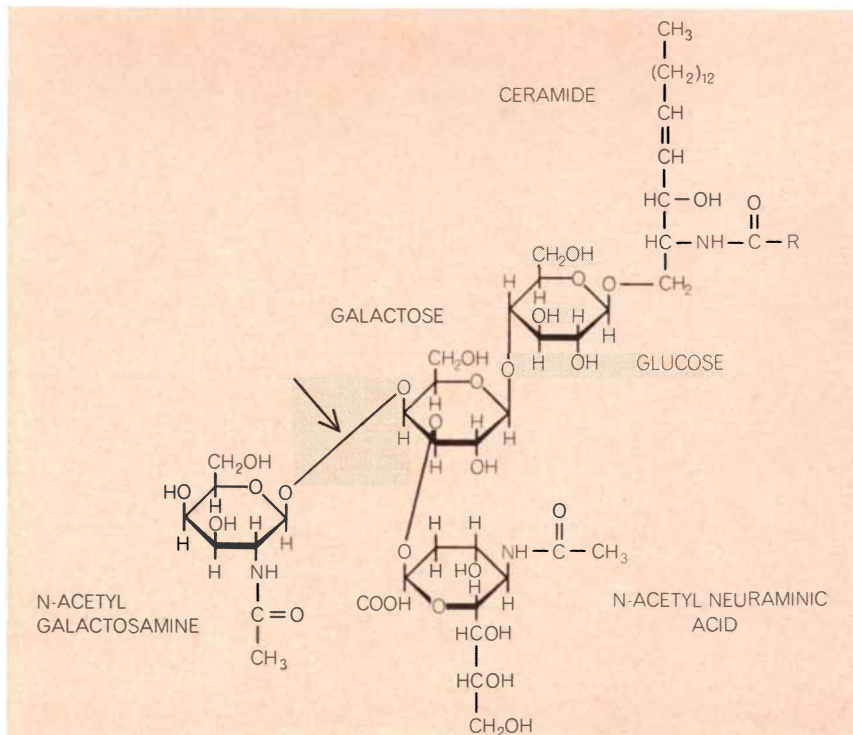


TRANSLOCATION of a No. 21 chromosome to another chromosome can also result in Down's syndrome if the ovum with the

extra chromosome is fertilized. Fewer than 5 percent of the cases of Down's syndrome are produced by the translocation mechanism.



NUCLEOTIDE SYNTHESIS by cells of the body can occur via two pathways: a *de novo* route and a reutilization route. In the latter the enzyme hypoxanthine-guanine phosphoribosyl transferase (HGPRT) catalyzes the attachment of ribose phosphate onto hypoxanthine and guanine. Most body cells can produce enough of the nucleotide, guanylic acid, by the *de novo* route, so that their function is not impaired. The basal ganglia of the brain, however, require the HGPRT-mediated pathway, and when the enzyme is missing, their function is severely impaired. This result is the Lesch-Nyhan syndrome, a fatal neurological disease.



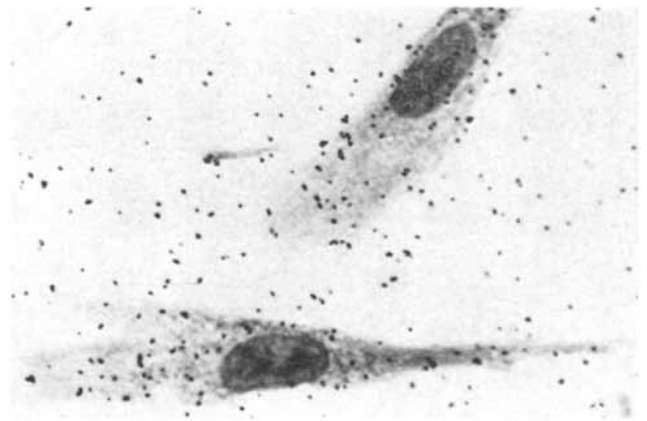
TAYSACHS DISEASE, which leads to blindness, severe retardation and early death in infants, is caused by the accumulation of the ganglioside GM₂ in nerve cells. The ganglioside is a complex molecule composed of a lipid fraction, ceramide, linked to a polysaccharide containing glucose, galactose, *N*-acetyl galactosamine and *N*-acetyl neuraminic acid (sialic acid). Lack of the enzyme hexosaminidase A, which participates in cleaving the terminal sugar *N*-acetyl galactosamine from the GM₂ ganglioside at the site indicated by the arrow, results in accumulation of the GM₂ ganglioside in nerve cells throughout the body.

bring about unexpected increases in the frequency of genes for some diseases. As an illustration let us assume that in the future each family will have two normal children and will compensate for fetuses lost through abortion. Under these conditions the prevention of natural gene loss through death or nonreproducibility of the affected homozygotes could lead to an increase over many generations of 50 percent in the gene frequency. For cystic fibrosis this means that over 50 generations the frequency of carriers in a population would increase from its present 5 percent to a new equilibrium level of 7.5 percent. Motulsky considers that, in view of the long time required, the change is minimal and probably of no real concern, particularly when it is compared with the effect on gene frequencies of a program of premarital counseling and the prevention of mating between heterozygous carriers. If any selective advantage exists for the heterozygote and persists in the future, as seems to be the case with sickle-cell anemia and cystic fibrosis, the frequency of carriers might rise over many generations to a startling level of 50 percent. Every second person would be a carrier.

Another startling effect could occur in X-linked diseases such as hemophilia, where no distinction can yet be made between affected and normal males *in utero*. If abortion of all male fetuses in carrier mothers were to become widespread, the result could be a 50 percent increase in the gene frequency *with each generation*.

The directed elimination of genes by selective abortion after prenatal detection is certainly feasible and, as Motulsky shows, is probably not deleterious in most instances. The gene responsible for a dominant disease such as Huntington's chorea could be virtually eliminated with a modest detection and abortion program, although that is not yet possible since biochemical tests for this disease and other dominant diseases are not available. It is unlikely that the loss of such a gene would in any way be injurious to the species. The elimination of genes for recessive diseases, however, would require not only much more elaborate screening programs for large segments of the population but also the abortion of all unaffected heterozygous fetuses. It is difficult to see how this could ever be justified.

Geneticists realize that genetic diversity is important for ensuring the adaptability, and therefore the survival, of a species in the face of continually changing evolutionary selective pres-



AUTORADIOGRAPHIC METHOD is used to determine if fetal cells contain the enzyme HGPRT. Lack of the enzyme results in the fatal Lesch-Nyhan disease. The fetal cells are grown in a tissue culture and then exposed to radioactive hypoxanthine. The cells are washed with acid and methanol to remove any free hypoxanthine.

The washed cells are placed in contact with a film that is sensitive to radioactivity. Normal cells (*left*) are able to incorporate hypoxanthine and become radioactive. They turn out black on the developed film. Mutant cells deficient in the HGPRT enzyme cannot take up the hypoxanthine and darken the film very little (*right*).

ures. Presumably the human species is no exception. This is not to say that our present gene pool is an optimum one, and it is certain that the evolution of our gene pool is continuing even now. Although one might argue that some changes can be made in our gene pool that are evolutionarily neutral or even advantageous, we must question our ability to use this capacity to even partially direct our genetic future with sufficient wisdom and foresight.

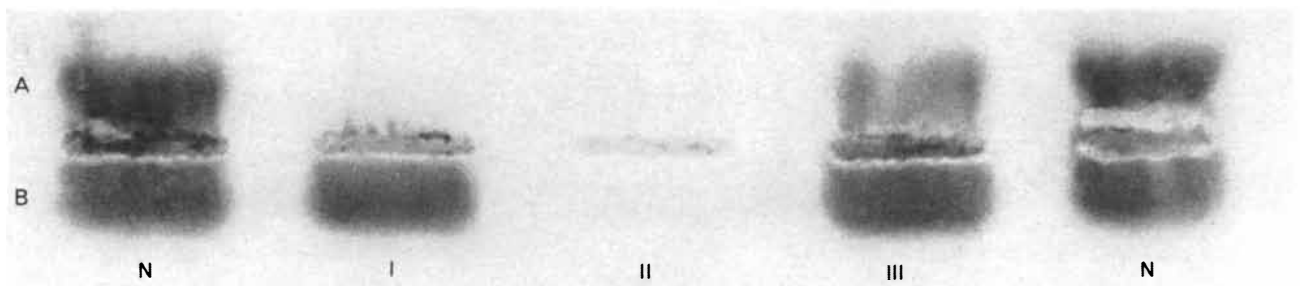
Until now prenatal diagnosis combined with selective abortion has been applied mostly in cases where there has been little or no doubt about the inevitability of disease with a demonstrated genetic abnormality. We are now, however, beginning to understand more about the role of normal genetic variation in man, and about the existence of aberrations that are not so closely associated with disease. Several recent clinical situations have emphasized the uncertainties in the relationship between the existence of a genetic abnormality and the development of clinical disease.

A chromosomal abnormality, the XYY syndrome, has recently been described in which some men have an extra Y chromosome. Clinical studies have suggested that such men are statistically more likely to develop aggressive anti-social behavior than normal XY males. Some of the affected men are criminals but most are not, and most important of all we have no firm evidence that it is the extra chromosome that is directly responsible for the suspected tendency toward criminal behavior.

In another instance a normal parent carrying a translocation of material from a No. 3 chromosome to another chromosome has given birth to a child with apparently the identical chromosomal abnormality but with severe mental retardation. The detection in fetal cells of this kind of translocation would therefore not have helped in determining if the fetus were destined to be severely retarded or of normal intelligence. These findings illustrate the fact that in some cases our knowledge of the mechanism by which a defective gene leads to the

development of human clinical disease is inadequate. We may also recall that some genes may confer a selective advantage on heterozygous carriers. Heterozygotes for sickle-cell anemia are less susceptible to infection with malaria. It is probable that other genes that are detrimental under some conditions are of value to the species. Knowledge of such challenges to our diagnostic and prognostic accuracy may make it increasingly difficult to provide information on which prospective parents can make informed and intelligent decisions.

Some fear that in a society where abortion is becoming acceptable, increasingly arbitrary standards may be applied in the making of decisions on the fitness or desirability of a given fetus. In present circumstances it is not difficult to imagine the emergence of pressures to set standards for desirability in genetically determined human characteristics. At the moment it is not at all clear how these standards might be arrived at, and whose standards they might be. Neel



STARCH-GEL ELECTROPHORESIS is used to separate two similar enzymes, hexosaminidase A and hexosaminidase B. This example, prepared by John O'Brien of the University of California at San Diego, shows that normal individuals (N) have both the A and

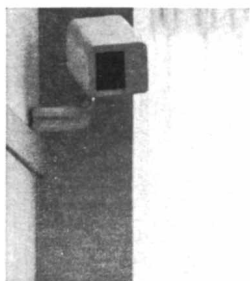
the B isozymes. Patients with Tay-Sachs disease (I) lack the A enzyme, and patients with Sandhoff's disease (II) lack both forms of the enzyme. A deficiency of the enzyme hexosaminidase A (shown in III) results in a disease known as juvenile GM₂ gangliosidosis.

DISORDER	DEFECTIVE ENZYME OR METABOLIC DERANGEMENT
ASSOCIATED WITH MENTAL RETARDATION	
CHROMOSOMAL ABNORMALITIES (DOWN'S SYNDROME, TURNER'S SYNDROME, XYY, ETC.)	EXCESS OR DEFICIENCY OF TOTAL GENETIC INFORMATION
ARGINOSUCCINIC ACIDURIA	ARGINOSUCCINASE
CITRULLINEMIA	ARGINOSUCCINATE SYNTHETASE
FUCOSIDOSIS	ALPHA-FUCOSIDASE
GALACTOSEMIA	GALACTOSE-1-PHOSPHATE URIDYL TRANSFERASE
GAUCHER'S DISEASE INFANTILE TYPE ADULT TYPE	ABSENT CEREBROSIDASE DEFICIENT CEREBROSIDASE
GENERALIZED GANGLIOSIDOSIS	ABSENT BETA-GALACTOSIDASE
JUVENILE GM ₁ GANGLIOSIDOSIS	DEFICIENT BETA-GALACTOSIDASE
JUVENILE GM ₂ GANGLIOSIDOSIS	DEFICIENCY OF HEXOSAMINIDASE A
GLYCOGEN STORAGE DISEASE TYPE 2	ALPHA-1-4 GLUCOSIDASE
HUNTER'S DISEASE	INCREASED AMNIOTIC FLUID HEPARITIN SULFATE
HURLER'S DISEASE	INCREASED AMNIOTIC FLUID HEPARITIN SULFATE
I-CELL DISEASE	MULTIPLE LYSOMAL HYDROLASES
ISOVALERIC ACIDEMIA	ISOVALERYL CoA DEHYDROGENASE
LESCH-NYHAN SYNDROME	HYPOXANTHINE-GUANINE- PHOSPHORIBOSE TRANSFERASE
MAPLE SYRUP URINE DISEASE	ALPHA-KETO ISOCAPROATE DECARBOXYLASE
METACHROMATIC LEUCODYSTROPHY LATE INFANTILE TYPE JUVENILE AND ADULT TYPES	ABSENT ARYLSULFATASE A DEFICIENT ARYLSULFATASE A
METHYLMALONIC ACIDEMIA	METHYLMALONYL CoA CARBONYL MUTASE
NIEMANN-PICK DISEASE	SPHINGOMYELINASE
REFSUM'S DISEASE	PHYTANIC ACID ALPHA-OXIDASE
SANDHOFF'S DISEASE	HEXOSAMINIDASE A AND B
SANFILIPPO DISEASE	INCREASED AMNIOTIC FLUID HEPARITIN SULFATE
TAY-SACHS DISEASE	HEXOSAMINIDASE A
WOLMAN'S DISEASE	ACID LIPASE
POSSIBLY ASSOCIATED WITH MENTAL RETARDATION	
CYSTATHIONINURIA	CYSTATHIONASE
HOMOCYSTINURIA	CYSTATHIONINE SYNTHASE
NOT ASSOCIATED WITH MENTAL RETARDATION	
ADRENOGENITAL SYNDROME	INCREASED AMNIOTIC FLUID CORTICO STEROIDS
CYSTINOSIS	INCREASED CELLULAR CYSTINE
FABRY'S DISEASE	ALPHA-GALACTOSIDASE
HYPERVALINEMIA	VALINE TRANSAMINASE
OROTIC ACIDURIA	OROTIDYLIC PYROPHOSPHORYLASE AND OROTIDYLIC DECARBOXYLASE

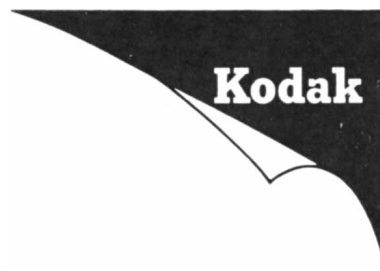
GENETIC DISEASES that at present can be detected prenatally by studies of fetal cells and amniotic fluid are listed. Most of the diseases result in severe mental retardation.

has pointed out that condemning many of today's infants to famine and inadequate development does not display greater respect for the quality of human life than is found in primitive societies that practice infanticide with undesired or defective newborn infants. Others have questioned the moral justification for making these life-death decisions. Through recent upheavals in our social, legal and religious institutions we are now faced with the dilemma of assigning to the fetus certain rights. In several instances damages have been awarded on behalf of fetuses in criminal and tort suits. At the same time abortion laws have been liberalized to the point of suggesting that early fetuses do not have the right to life if the mother wants to abort a pregnancy. Prenatal genetic diagnosis seemed at first no different from most other new diagnostic methods. Now we see that we are faced with problems of assigning values to individuals with given genetic characteristics and designing programs directed against them. Until now most of these characteristics have been associated with severe clinical disease. Now we are not always certain what the existence of genetic anomalies will mean to the health of an individual. These uncertainties could result in an accentuation of the conflict in our society between personal choice and governmental control, which could possibly come in the form of selected programs of compulsory screening and mandatory abortion for some conditions that are deemed socially intolerable. The obviously dangerous extensions of such a practice would impinge so drastically on our individual liberties as to make them unacceptable and morally unjustifiable.

Intriguing developments in our legal concepts of the unborn child seem imminent, since there are certain to be legal tests of the liability of parents and others for offspring born with genetically determined handicaps that are predictable. Such "wrongful life" suits have already been brought on behalf of illegitimate infants and some infants born with severe developmental defects due to prenatal infection with syphilis and German measles. Similar suits involving genetic diseases will soon test the concept that we—as parents, physicians and human beings—have obligations to the unborn to protect them from the likelihood of genetically determined defects. One may hope that advances in other social institutions will at the same time help us to resolve our individual and societal attitudes toward life, born and unborn.



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That camera up there can be set to expose silently one frame every 1¼ seconds, or one frame every 90 seconds, or anything in between. At normal projection speed the 7200 frames in the super 8 cartridge will run 6¾ minutes, into which is compressed a time span from 2½ hours to 7½ days. For glaciology that's probably not enough compression, but for many other scientific endeavors and for engineering studies it's just fine.

Now as it happens that camera up there is neither designed nor priced as a scientific instrument. It is intended to keep an eye on thieves and robbers. Considered in need of watching are a vast acreage of floor space devoted to banking, retailing, warehousing — and many gates. If there is no reason to process the film, so much the better. But there is demand for a great many more such cameras than if the market consisted of a scientist or engineer here and there who would like to try some time-lapse movies on some problem or phenomenon but hesitates to promise his business manager that time-lapse photography will usher in a new era of progress for the enterprise.

Sad as is the need for so many such cameras, let us hope that the ill wind will blow science and engineering a bit of good.

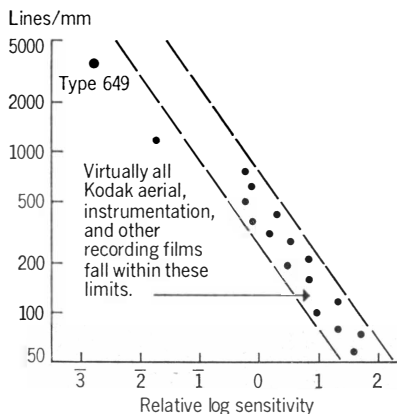
At less than \$240, the KODAK ANALYST Super 8 Camera may not be priced like a scientific instrument, but a request to Instrumentation Products, Eastman Kodak Company, Rochester, N.Y. 14650 can bring a visitor bearing the camera, counsel on its possible application to your problem, cartridges of KODAK MFX Film (less than \$4.50 each), and instructions for getting it processed as quickly as though there had been a bank robbery. That MFX film was specifically created for time-lapse photography at an effective exposure index of 160. For color (balanced for 3400 K) you use the fast new KODAK EKTACHROME 160 Movie Film (Type A).

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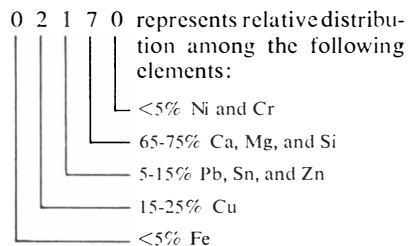
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Conversation and correspondence on this matter are welcomed by Department 916, Eastman Kodak Company, Rochester, N.Y. 14650.

Dust, the study of

"70003" seems to be airborne dust from stainless steel.

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If one day 70003 suddenly shows up in the air of a production area and persists thereafter, it bears looking into. Iron in the air may harm the product. Or 70003 in the air may be important as an early warning of trouble in a machine. We have learned how to interpret some of these 5-digit profile numbers that appear on the computer printout from a system whose input is an air sample. Other organizations may need more digits than 5 or fewer in their adaptations of our system.

At any rate, whoever wishes to adopt or adapt it for the logging of dust can look up *Applied Spectroscopy* 25:270-5 (1971). No Kodak products are used in the system, but the system is used in making Kodak products. If our methods of elaborate vigilance against inorganic contamination can help in ways apart from the reliability of the Kodak sensitized goods produced, so much the better.

The spectrograph used is a commercially available direct-reading instrument. The dirt is collected on filter paper in a fully described filter holder connected to a vacuum pump or inserted in a high-velocity air duct. The paper is burned in a hollow electrode with the gap maintained at 2mm for 30 sec by a cardioid cam. It's the method of reporting results that may be the most interesting.



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For picky people with particular problems: A design-your-own calculator

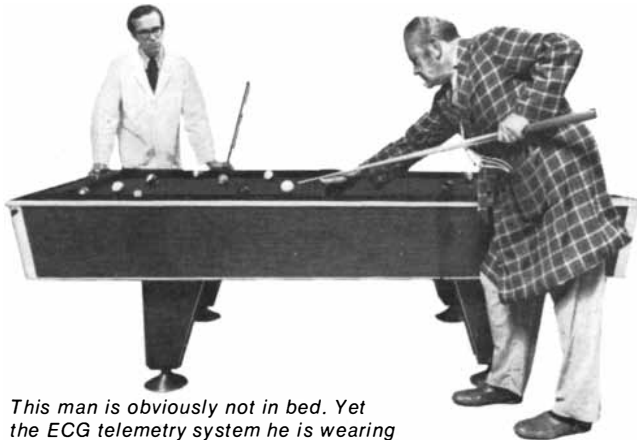
A user in virtually any discipline now can customize a powerful new programmable calculator to his specific computational needs.

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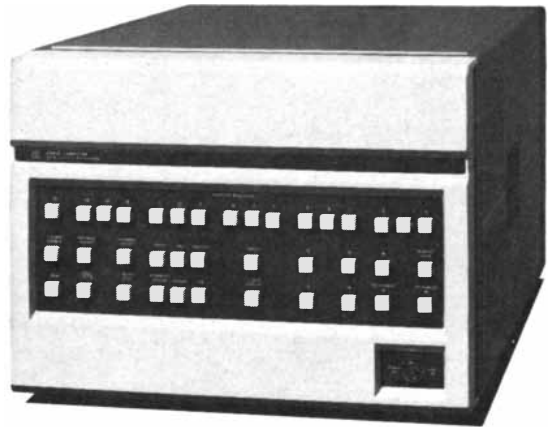
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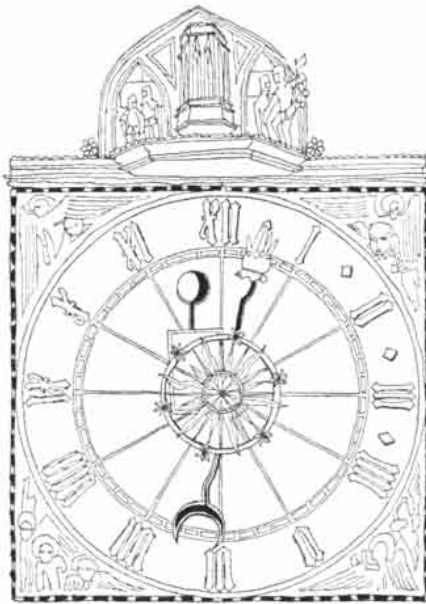
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Never in Any Circumstances

A treaty fully prohibiting the use of biological weapons appears likely to gain the approval of the United Nations General Assembly before the end of the year. A draft of the treaty was approved in September by the 25-nation Geneva disarmament conference after two years of negotiation. The drafting group depicted the agreement as another step "toward general and complete disarmament."

Under the treaty each signatory nation would agree "never in any circumstances to develop, produce, stockpile or otherwise acquire or retain... microbial or other biological agents, or toxins whatever their origin," and would likewise not make or stockpile "weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict." Nations that already have stockpiles of biological agents or weapons would be required to destroy them within nine months after the treaty becomes effective. The U.S., which is the only nation that has acknowledged having such stockpiles, is already destroying them. The U.S.S.R. has indicated that it has biological agents and weapons and has said it would undertake to destroy them.

For many months the negotiations on the treaty made little headway because of a difference between the U.S. and the U.S.S.R. over including chemical weapons in the ban. The U.S.S.R. wanted simultaneous prohibition of both chemical and biological weapons; the U.S. and

SCIENCE AND

Great Britain argued that certain chemicals have nonmilitary uses and that there was no dependable way to ascertain whether the possession of such agents was for military or for nonmilitary purposes. Early this year the U.S.S.R. agreed to separate the two issues and to join the U.S. in pressing for a ban now on biological weapons alone. The draft treaty calls the ban on biological weapons "a first possible step toward the achievement of agreement on effective measures also for prohibition of the development, production and stockpiling of chemical weapons" and states that the signatories are "determined to continue negotiations to that end."

If the treaty is approved, it will be the seventh in a series of treaties on aspects of disarmament that the UN has adopted over a period of some 12 years. The earlier treaties demilitarized Antarctica, controlled nuclear-weapons tests in the atmosphere, prohibited nuclear weapons in space, made Latin America a non-nuclear zone, barred the proliferation of nuclear weapons and prohibited emplacing nuclear weapons on the seabed. Once the treaty on biological weapons has been approved by the UN, ratification by 22 nations will put it into effect.

The Detection of Underground Tests

Since the Limited Test Ban Treaty of 1963 the U.S. has conducted 229 underground nuclear tests (compared with 310 before the treaty) and the U.S.S.R. at least 47 (compared with 126 before). These tests have provided seismologists with a large volume of data to manipulate in their effort to find ways of discriminating between underground explosions and earthquakes, the thorny issue on which efforts to frame a total test ban originally foundered in 1963. At that time U.S. negotiators took the position that 75 to 150 earthquakes per year in the U.S.S.R. could not be distinguished from low-yield underground explosions and therefore that on-site inspection was necessary. Since 1959 the U.S. has spent more than \$300 million trying to improve detection methods; Great Britain and Canada have spent lesser amounts. Nothing is known of the Russian effort.

The clearest evidence that seismic-detection methods are now highly de-

veloped was supplied this past summer by a Canadian report to the Conference of the Committee on Disarmament in Geneva, followed by a recent article in *Nature* by F. M. Anglin of the seismology division of the Canadian Department of Energy, Mines and Resources. Anglin describes a method "that completely separates a population of [27] underground explosions ... at the Urals, Caspian, East Kazak, Sinkiang and Novaya Zemlya test sites from a population of [51] shallow ... earthquakes ... within about 15° of these test sites."

The 27 explosions represent all the underground nuclear explosions set off in the U.S.S.R. and China in 1968, 1969 and 1970. (The underground tests in China have not been much publicized.) The 27 tests generated seismic signals whose "body wave" magnitude ranged from 4.2 to 6.2. Body waves, or *P* waves, are short-period compressional waves that travel through the earth's mantle and that can be recorded more clearly at distances between 3,000 and 10,000 kilometers from the event than they can be at shorter distances. They are thus well suited for the detection of clandestine events. A body-wave magnitude of 4.2 is produced when a nuclear device, exploded in solid granite, releases between five and 10 kilotons of energy, or roughly the energy of the Hiroshima bomb. A body-wave magnitude of 6.2 indicates an explosion in the megaton range.

In his analysis Anglin used the tape records produced by the Canadian array of 19 seismographs spaced 2.5 kilometers apart in the shape of a cross; the array is installed at Yellowknife on the northern shore of Great Slave Lake. It has been recognized for some time that earthquake records tend to be more "complex" than explosion records. Complexity can be quantified by comparing the amount of energy arriving between two and 35 seconds after the beginning of the record with the amount arriving in the first two seconds. As one would expect intuitively, a nuclear explosion releases all its energy at once, whereas a typical earthquake is produced by slippages that extend over several seconds. Nevertheless, Anglin found that discrimination based on complexity alone "results in about 20% of the explosions overlapping 40% of the earthquakes." The

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explosions in Novaya Zemlya, for example, tend to look like earthquakes in complexity.

In a search for a second discriminating parameter Anglin analyzed the frequency spectrum of the seismic waves. He found that explosions deliver somewhat more of their energy in the form of high-frequency waves than earthquakes do. This difference is maximized by a mathematical formula that sums the energy received in the first 6.4 seconds at frequencies between .32 and five hertz (cycles per second) and multiplies the sum by the frequency cubed. The equation is defined as the third moment of frequency. With this discriminating parameter alone Anglin found that 20 percent of the explosions overlapped about 15 percent of the earthquakes. When he plotted a scatter diagram with complexity along one axis and the third moment of frequency along the other, however, the 27 explosions were clearly separated from the 51 earthquakes.

Judgment

Should a scientific society constitute itself as an arbiter of facts and opinions advanced by individuals in the course of public controversy? This issue was joined in 1969 soon after the debate in the Senate on the Administration's proposal for a "Safeguard" anti-ballistic-missile program. At that time Albert Wohlstetter of the University of Chicago, who had testified in favor of the program, proposed to the Operations Research Society of America (ORSA) that it investigate the professional conduct of opponents of the program. ORSA adopted Wohlstetter's proposal, and in September it published the 135-page report of its six-member committee.

The report challenges the accuracy of statements made by both proponents and opponents of the Safeguard program, but most of its criticism is directed against five opponents who are not members of ORSA: Ralph Lapp, Wolfgang Panofsky of Stanford University, and George W. Rathjens, Steven Weinberg and Jerome B. Wiesner of the Massachusetts Institute of Technology. (Wiesner has just been inaugurated as president of M.I.T.) The ORSA committee was most critical of the opponents on the grounds that they underestimated the probable effectiveness of the Russian SS-9 missile as a vehicle for attacking the launching sites of U.S. Minuteman missiles. Wohlstetter had calculated that an attack by such missiles could destroy as much as 95 percent of the Minuteman

force. The committee also pointed to the fact that the opponents had based their arguments on the limited vulnerability of the Minutemen in the middle 1970's, whereas the Safeguard program was addressed to the late 1970's, when Russian weapons systems would be more advanced and the Minutemen would be more vulnerable. Among the witnesses mentioned by the committee was Wohlstetter; the committee found "no significant defects" in his testimony and praised a document he had prepared for the Senate as "a model for the professional and constructive conduct of a debate over important technical issues."

On the appearance of the ORSA committee's report Rathjens, Weinberg and Wiesner issued a detailed reply. They referred to the fact that, on learning that the study was to be undertaken, they had written the society to suggest that "any even-handed inquiry ought to look in considerable detail into the arguments and analyses offered by members of the Administration, particularly Messrs. Laird, Packard and Foster. It should examine not only the technical details of these statements but also such matters as the Administration's shifting rationale for its decision, its derivation of intelligence estimates and the possibility that it selectively released classified information to make its case." Rathjens, Weinberg and Wiesner assert that such questions are not taken up in the committee's report.

Concerning the charge that they had underestimated the probable effectiveness of the Russian SS-9, Rathjens, Weinberg and Wiesner state: "The threat hypothesized by the Administration has not developed. The SS-9 force has not grown as projected, and the present projections of SS-9 effectiveness as a counter-force weapon against the Minuteman are almost certainly more consistent with our estimates than with those used by the Administration and its supporters." With regard to the fact that their data referred to the middle 1970's instead of the late 1970's, they write that the data advanced by proponents of the Safeguard program also referred to the middle 1970's, and it was to these data that their arguments were responding.

The six members of the ORSA committee were Howard M. Berger of the Xerox Corporation, Thomas E. Caywood of A. T. Kearney & Co., Inc., Joseph H. Engel of the University of Illinois, John F. Magee of Arthur D. Little, Inc., Hugh J. Miser of the University of Massachusetts and Robert M. Thrall of Rice University. Caywood, Engel, Magee and

Miser are all past presidents of ORSA. The founding president of ORSA, Philip M. Morse of M.I.T., wrote the society: "This report... will be considered unfair, since it denounces by name persons who are not members of the Society, who thus have had no means of countervailing the charges except after the fact." The report of the ORSA committee states: "ORSA hopes it will not be necessary to conduct additional investigations of this nature."

The Loci of Memory

One of the oldest and most perplexing problems in brain research, namely where memory is stored, may have at last yielded to experimental analysis. James Olds, who 18 years ago discovered the "pleasure centers" in the hypothalamus and the midbrain regions, reports that he has direct evidence of specific memory sites in different parts of the brain.

Using a computer to monitor the activity of individual neurons in rat brains before, during and after learning, Olds and his group at the California Institute of Technology have mapped more than 400 points in the brain and found four areas that appear to be involved in memory storage. They are the ventral reticular formation, the posterior thalamus, the neocortex and part of the hippocampus. According to Olds, in all the locations except the posterior thalamus there was a clear separation of areas that showed evidence of primary memory storage and those that did not. He described the preliminary findings of his investigation at the recent annual meeting of the American Psychological Association.

A novel technique was developed by Olds to carry out the studies. He implants nine microelectrodes in several parts of a rat's brain. After the rat has recovered from the operation it can move about freely. A computer monitors the signals generated by the tapped neurons and also controls the signals and food rewards in the conditioning, or learning, phase of the experiment. First the computer establishes the typical pattern of response of neurons to either a visual or an auditory signal that is not rewarded. In the second phase a signal is paired with a food reward, and the neural responses are recorded during and after learning.

Learning centers were identified, Olds said, "by measuring the latency between the stimulus signal and the brain responses that arose anew or greatly increased during conditioning." Primary

new responses come within six to 20 thousandths of a second. Other new responses come within 30 to 200 thousandths of a second after the signal; they are called secondary responses. Primary responses were found at all levels of the brain but not in all areas; their distribution, however, followed the known boundaries of neuroanatomical structures. For example, there was a total lack of learning points on the midbrain side of the boundary between the midbrain and the thalamus. The adjacent posterior thalamic nucleus had a high density of learning points.

Although there was a sprinkling of learning points in all parts of the neocortex, the proportion of neurons that responded to a learning stimulus was quite small. Olds speculates that these neurons probably are related to the specific content of memory.

The gross features of the mammalian brain in rats and in man are similar, Olds said, and a great deal of the knowledge gained from studying memory mechanisms in the rat brain can be applied to the human brain. He believes different kinds of learning and memory go on simultaneously in the four parts of the brain he probed. "The four areas," he said, "will need to be confirmed in a further map involving a larger number of points and a finer mode of analysis."

Superficial Laser

A new type of solid-state laser in which the laser action takes place within a few ionic layers of the surface of the excited crystal may find important application as an active element in integrated optical computer-memory networks. The first successful operation of the new surface laser was reported recently in *Applied Physics Letters* by Frank L. Varsanyi, a physicist associated with Stanford University and the Isoray International Corporation.

Working with tiny single crystals of both praseodymium trichloride (PrCl_3) and praseodymium tribromide (PrBr_3), Varsanyi illuminated a freshly cleaved surface of each test crystal with an intense beam of monochromatic light from a wavelength-tunable dye laser (which was in turn excited by a repetitively pulsed nitrogen laser). The excitation light from the dye laser was able to "pump" ions within a micron or so of the surface of the target crystal into higher energy states, from which they could then drop to lower states, in the process emitting a beam of coherent laser light.

According to Varsanyi, "the combina-

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tion of the high ion density with the essentially 100% radiative quantum efficiency creates an extremely large gain per unit length and makes the device very compact." The amplification of the new laser is so large that a strong, highly directional laser beam can be made to emerge from an optically pumped length of just a few microns along the surface. The threshold for laser action in this case is less than one microjoule of pumping light.

As the energy density of the exciting beam is increased, a second threshold is reached whereby the incoming monochromatic light saturates layer after layer of active ions until the dimension of this "excitation pocket" becomes larger in the direction perpendicular to the surface than along the surface. At this point the surface laser action abruptly ceases, and a strong laser beam with the same wavelength as the surface one leaves the crystal in both the forward and the backward direction.

The potential usefulness of the surface laser in integrated optical networks would be facilitated by its extremely small size and ease of fabrication, the steerability of the beam direction and the fact that it is capable of operating efficiently at room temperature. Varsanyi estimates that packing densities of well over a million independent lasers per square inch of crystal surface seem "entirely reasonable."

The minuteness of the active area of the surface laser, he adds, "made possible some visually spectacular experiments, whereby the excitation light was focused on a tiny PrCl_3 or PrBr_3 crystal-lite that was hardly visible to the naked eye, and upon reaching the threshold energy density the little 'dust' particle lit up with the brilliant red glow of the laser output. It is not unlikely that this 'powder laser' dispersed in some appropriate carrier (liquid, gas or solid) opens up new possibilities in display technology."

The Export of Lunar Glass

Seven hundred thousand years ago some 100 million tons of glass, in the form of the small aerodynamically shaped objects known as tektites, were scattered over a large part of the earth from Australia to China. After a seven-year study involving the inspection of a million tektites, determination of the specific gravity of 47,000 and chemical analysis of 507 from 205 different sites, together with a computer program for defining trajectories, Dean R. Chapman of the Ames Research Center of the Na-

tional Aeronautics and Space Administration believes he has demonstrated that the huge mass represents debris blasted out of the crater Tycho on the moon. He describes his work in *Journal of Geophysical Research*.

The prevailing explanation of the Australasian tektites (although there have been dissenters) is that they are debris splashed out of the earth by the impact of a huge meteorite. It has been calculated, however, that for the tektites to have been strewn from Australia to China the impact of the meteorite would have had to remove most of the atmosphere from above the crater. This would have required 10^{32} ergs of energy (1,000 times more than the earth receives from the sun in a day), enough to excavate a crater several hundred kilometers in diameter. No such crater has been found, and it seems unlikely that it could have been obliterated without a trace. If the impact occurred on the moon, which has no atmosphere, a crater no more than 100 kilometers in diameter could reasonably send the necessary mass of glass flying earthward.

Chapman's study carefully defines the geographic area on the earth covered by the Australasian tektites. One possibility was that the area covered "would form a set of radial elements... projecting toward a common hub where the terrestrial crater of origin would be located." Such was not the case. The actual distribution indicates that the tektites fill an area with a peculiar hooklike shape consistent with the path that could have been followed by objects traveling from the moon to the earth.

With the computer Chapman attempted ("using the time-honored method of trial and error") to find plausible moon-earth trajectories that would deposit 100 million tons of tektite glass in the geographic pattern needed. These paths were computed for all the lunar craters both large enough and young enough to be a potential point of origin. The only one that met the requirements was Tycho. A major finding of Chapman's latest calculations is that the trajectory providing the required pattern on the earth has a takeoff angle that coincides exactly with one of Tycho's most prominent rays (the Rosse ray), which heads away from the crater at an angle 19 degrees north of east.

Of Cats and Men

Approximately 5 percent of the people who suffer from profound congenital deafness are afflicted with Waarden-

burg's syndrome, a hereditary condition characterized by six signs, including (besides deafness) wide skin folds between the nose and the eyes, a prominent nose root, overdeveloped medial eyebrows, eyes of two different colors and a white forelock. For obvious reasons detailed genetic, physiological, histological and developmental studies of this syndrome are difficult to conduct with humans. Fortunately an analogous condition has been observed in several other animals, including mice, dogs and cats. A recent study, undertaken in the hope that the cat could be used as a model for studies of hearing not feasible with man, has begun to yield important clues to the genetic origin of Waardenburg's syndrome.

The study, which has been under way for several years at the Eye Research Foundation of the National Institutes of Health, originally involved seven male and 14 female domestic cats, all with white fur and most with one or two blue eyes. The cats were housed in air-conditioned, windowless rooms with facilities for both individual and herd matings. No new cats were introduced to the colony during the last three years of the study.

A summary of the various physiological and genetic tests carried out on the original stock of cats and their offspring is given in a recent issue of *The Journal of Heredity* by Donald R. Bergsma and Kenneth S. Brown of the Eye Research Foundation. They report that "our results strongly support the conclusions reached by earlier workers that the white fur with blue eyes and hearing loss is usually due to an autosomal [non-sex-chromosomal] dominant gene. The distinction between genes at one or more than one locus cannot be made from our data, but the weight of evidence is in favor of only one locus." They add that this single gene appears to act on the development of structures derived from the early embryonic "neural crest," an observation that would appear to apply also to humans and other animals exhibiting the syndrome.

In an interesting sidelight to their study Bergsma and Brown report that although strong natural selection was observed against the gene responsible for the syndrome in white, blue-eyed, deaf domestic cats, "it appears to be maintained through human selection in the fact of reduced disease resistance and semisterility, as well as deafness and reduced vision in low light conditions." Cat-fanciers, they point out, have traditionally valued white cats with eyes that do not match in color.



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THE SAN ANDREAS FAULT

This well-known break in the earth's crust is actually not one fault but a system of faults. The break separates a northward-moving wedge of California, including Los Angeles, from the rest of North America

by Don L. Anderson

The San Fernando earthquake that occurred at sunrise on February 9, 1971, jolted many southern Californians into acute awareness that California is earthquake country. Although it was only a moderate earthquake (6.6 on the Richter scale), it was felt in Mexico, Arizona, Nevada and as far north as Yosemite National Park, more than 250 miles from San Fernando. It was recorded at seismic stations around the world. In spite of its relatively small size the San Fernando earthquake was extremely significant because it happened near a major metropolis and because its effects were recorded on a wide variety of seismic instruments. Within hours the affected region was aswarm with geologists mapping faults and seismologists installing portable instruments to monitor aftershocks and the deformation of the ground. It was immediately clear from data telemetered to the Seismological Laboratory of the California Institute of Technology in Pasadena from the Caltech Seismic Network that the earthquake was not centered on the much feared San Andreas fault or, for that matter, on any fault geologists had labeled as active. The faults in the area, however, are all part of the San Andreas fault system that covers much of California.

The San Andreas fault system (and its attendant earthquakes) is part of a global grid of faults, chains of volcanoes

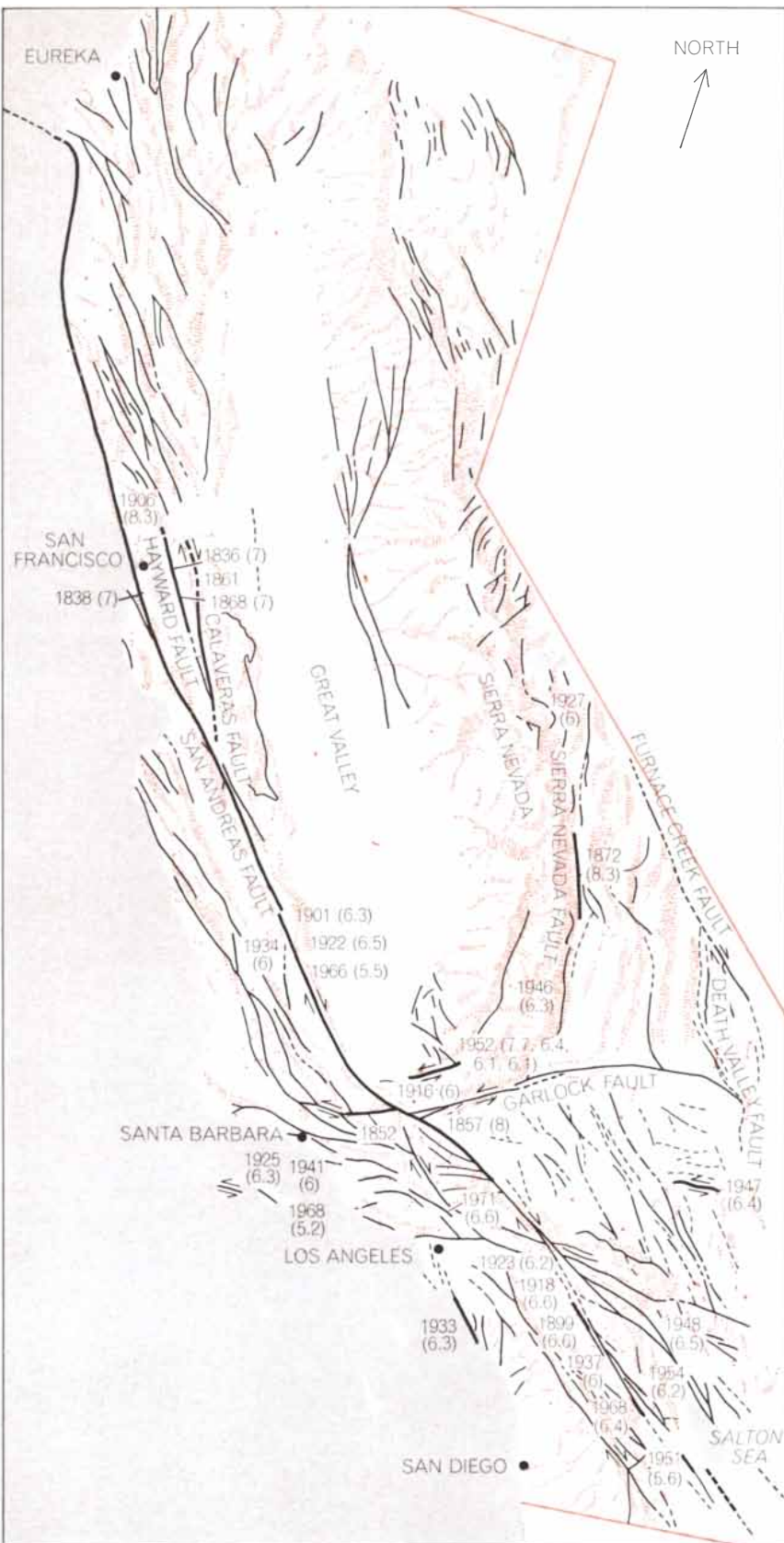
and mountains, rifts in the ocean floor and deep oceanic trenches that represent the boundaries between the huge shifting plates that make up the earth's lithosphere. The concept of moving plates is now fundamental to the theory of continental drift, which was long disputed but is now generally accepted in modified form on the basis of voluminous geological, geophysical and geochemical evidence. The theory had received strong support from the discovery that the floors of the oceans have a central rise or ridge, often with a rift along the axis, that can be traced around the globe. Within the rift new crustal material is continuously being injected from the plastic mantle below, forming a rise or ridge on each side of the rift. The newly formed crustal material slides away from the ridge axis. Since the magnetic field of the earth periodically reverses polarity, the newly injected material "freezes" in stripes parallel to the ridge axis, whose north-south polarity likewise alternates. By dating these stripes one can estimate the rate of seafloor spreading.

The San Andreas fault system forms the boundary between the North American plate and the North Pacific plate and separates the southwestern part of California from the rest of North America. In general the Pacific Ocean and that part of California to the west of the San Andreas fault are moving northwest

with respect to the rest of the continent, although the continent inland at least as far as Utah feels the effects of the interactions of these plates.

The relative motion between North America and the North Pacific has been estimated in a variety of ways. Seismic techniques yield values between 1½ and 2½ inches per year. The ages of the magnetic stripes on the ocean floor indicate a rate of about 2½ inches per year. Geodetic measurements in California give rates between two and three inches per year. The ages of the magnetic anomalies off the coast of California indicate that the oceanic rise came to intersect the continent at least 30 million years ago. Geologists and geophysicists at a number of institutions (notably the University of Cambridge, Princeton University and the Scripps Institution of Oceanography) have proposed that geologic processes on a continent are profoundly affected when a continental plate is intersected by an oceanic rise. At the rates given above the total displacement along the San Andreas fault amounts to at least 720 miles if motion started when the rise hit the continent and if all the relative motion was taken up on the fault. Displacements this large have not been proposed by geologists, but the critical tests would involve correlation of geology in northern California with geology on the west coast of Baja California, an area that has only recently been studied in detail. One can visualize how the west coast of North America may have looked 32 million years ago by closing up the Gulf of California and moving central and northern California back along the San Andreas fault to fit into the pocket formed by the coastline of the northern half of Baja California. This places all of California west of the San Andreas fault south of

DISPLACEMENT ALONG SAN ANDREAS FAULT is clearly visible in this aerial photograph of a region a few miles north of Frazier Park, Calif., itself 65 miles northwest of Pasadena, where the fault runs almost due east and west. This east-west section of the San Andreas fault is part of the "big bend," where the fault appears to be locked. The photograph is reproduced with north at the right. The hilly region to the left (south) of the fault line is moving upward (westward) with respect to the flat terrain at the right, causing clearly visible offsets in the two largest watercourses as they flow onto the alluvial plain.



SIMPLIFIED FAULT MAP of California identifies in heavy black lines the faults that have given rise to major earthquakes since 1836. The magnitude of all but two of the earthquakes is given in parentheses next to the year of occurrence. For events that predated the introduction of seismological instruments the magnitudes are estimated from historical accounts. For two major events, the earthquakes of 1852 and 1861, information is too sparse to allow a magnitude estimate. Arrows parallel to the faults show relative motion.

the present Mexican border [see illustration on page 60].

California is riddled with faults, most of which trend roughly northwest-southeast, like most of the other tectonic and geologic features of California (such as the Sierra Nevada and the Coast Ranges). The prominent exceptions are the east-west-trending transverse ranges and faults that make up a band some 100 miles wide extending inland from between Los Angeles and Santa Barbara. The San Gabriel Mountains, which form the rugged backdrop to Los Angeles, are part of this complex geologic region, and it was here that the San Fernando earthquake struck. The northeast-trending Garlock fault and the Tehachapi Mountains, which separate the Sierra Nevada and the Mojave Desert, also cut across the general grain of California. The area to the west of most of the northwest-trending faults is moving northwest with respect to the eastern side. This is called right-lateral motion. If one looks across the fault from either side, the other side is moving to the right.

Motion on the Garlock fault is left-lateral, which, combined with the right-lateral motion on the San Andreas fault, means that the Mojave Desert is moving eastward with respect to the rest of California. Parts of the faults that have been observed or inferred to move as a result of earthquakes in historic times are shown in the illustration at the left. Also shown are the dates of the earthquakes and the magnitude of some of the more important ones. In general both the length of rupture and the total displacement are greater for the larger earthquakes. Horizontal displacements as great as 21 feet were observed along the San Andreas fault after the San Francisco earthquake of 1906, which had a magnitude of 8.3 on the Richter scale. (The Richter scale, devised by Charles F. Richter of Cal Tech, is logarithmic. Although each unit denotes a factor of 10 in ground amplitude, or displacement, the actual energy radiated by an earthquake is subject to various modifications.) The San Fernando earthquake produced displacements of six feet, whose direction was almost equally divided between the horizontal and the vertical.

The trend of the San Andreas fault system is roughly northwest-southeast from San Francisco to the south end of the Great Central Valley (the San Joaquin Valley) and again from the north of the Salton Sea depression to the Mexican border. The motion along the faults

in these areas is parallel to the fault and is mainly strike-slip, or horizontal. Between these two regions, from the south end of the San Bernardino Mountains to the Garlock fault, the faults bend abruptly and run nearly east and west, producing a region of overthrusting and crustal shortening [see illustration below]. The attempt of the southern California plate to "get around the corner" as it moves to the northwest is responsible for the complex geology in the transverse ranges, for the abrupt change in the configuration of the coastline north of Los Angeles and ultimately for the recent San Fernando earthquake. The big bend of the San Andreas fault is commonly regarded by seismologists as being locked and possibly as being the location of the next major earthquake. Much of the motion in this region, however, is being taken up by strike-slip motion along faults parallel to the San Andreas fault and by overthrusting on both

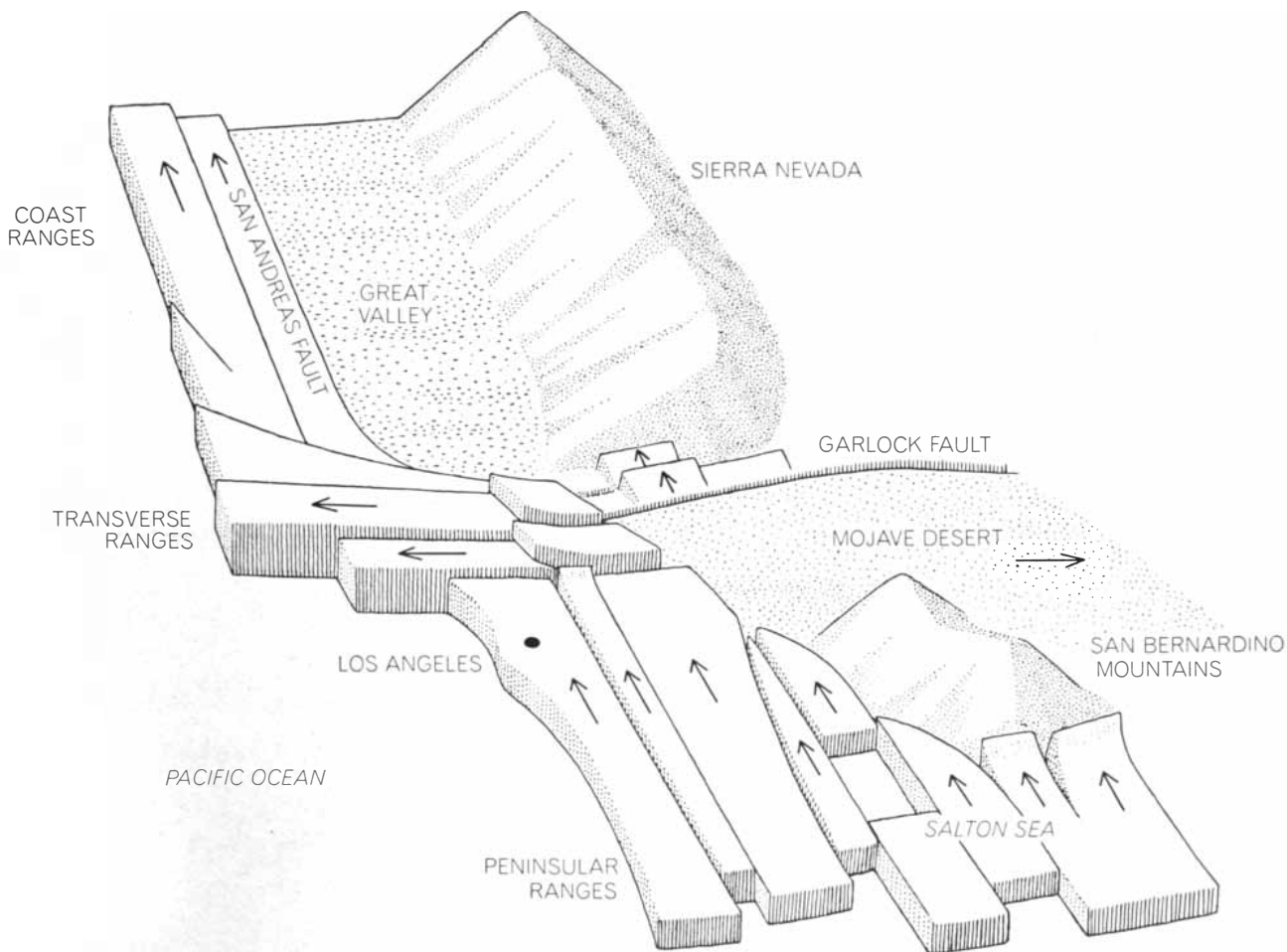
sides of the fault. The displacements associated with the larger earthquakes in southern California in the vicinity of the big bend have averaged out to about 2½ inches per year since 1800. The Kern County earthquake of 1952 (magnitude 7.7) apparently took care of most of the accumulated strain, at least at the north end of the big bend, that had built up since the Fort Tejon earthquake of 1857 (magnitude 8).

The San Andreas fault system cannot be completely understood independently of the tectonics and geology of most of the western part of North America and the northeastern part of the Pacific Ocean. This vast region is itself only a part of the global tectonic pattern, all parts of which seem to be interrelated. The earthquake, tectonic and mountain-building activities of western North America are intimately related to the relative motions of the Pacific and North American plates. Just as it is misleading

to think of the San Andreas fault as an isolated mechanical system, so it is misleading to think of the entire San Andreas fault as a single system. The part of the fault that lies in northern California was activated earlier and has moved farther than the southern California section. The northern portion is less active seismically than the southern section and seems to have been created in a different way. It is also moving in a slightly different direction.

Measuring Displacements

There are several ways to measure displacements on major faults. Fairly recent displacements are reflected in offset stream channels [see illustration on page 52]. Many such offsets measured in thousands of feet are apparent across the San Andreas fault in central California, some of which can be directly related to earthquakes of historic times.



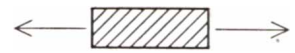
MOTION OF EARTH'S CRUST in southern California is generally northwest except where the lower group of blocks encounters the deep roots of the Sierra Nevada. At this point the blocks are diverted to the left (west), creating the transverse ranges and a

big bend in the San Andreas fault system. Above the bend the blocks continue their northwesterly march, carrying the Coast Ranges with them. The Salton Sea trough at the lower right evidently represents a rift that has developed between two blocks.

COMPRESSIONAL
FEATURES



TENSIONAL
FEATURES



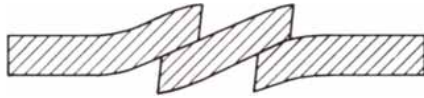
FOLDING



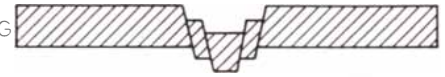
RIFTING



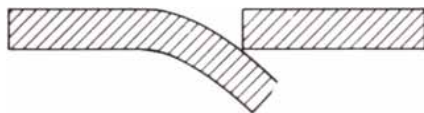
THRUSTING



DOWN-DROPPING



TRENCHING



THINNING

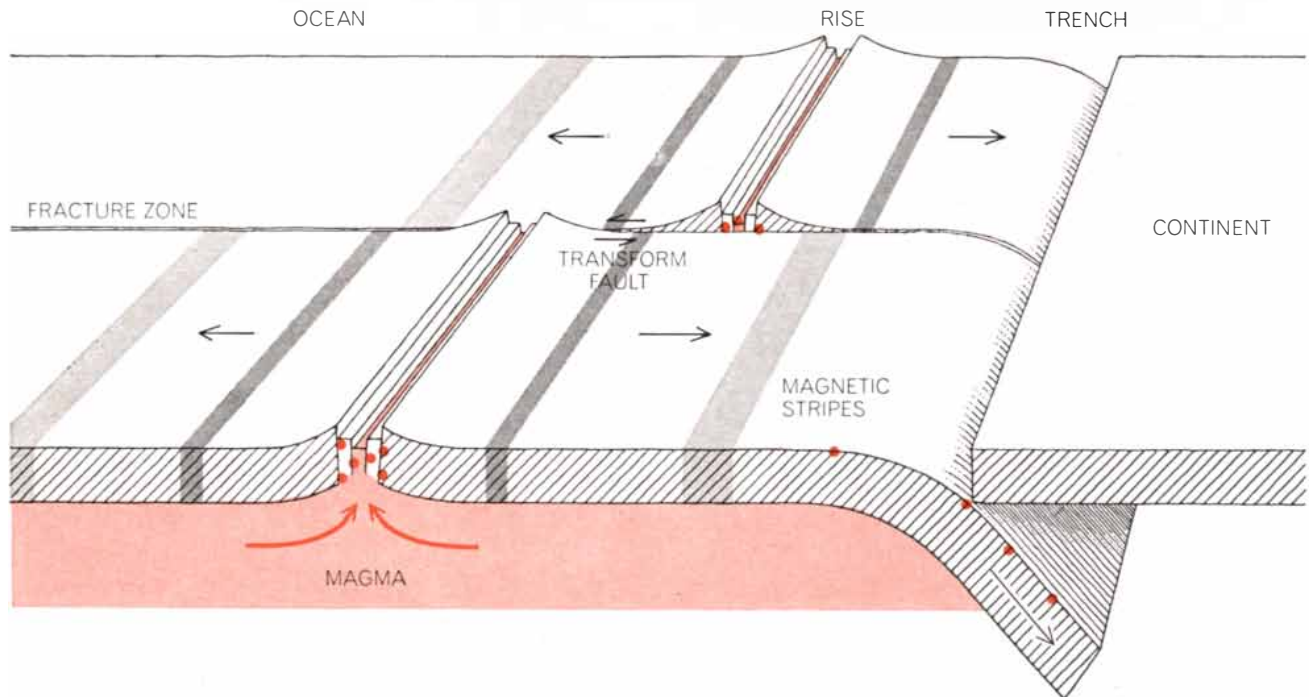


THICKENING



RESPONSE OF CRUSTAL PLATES to compression (*left*) and tension (*right*) accounts for most geologic features. According to the recently developed concept of plate tectonics, the earth's mantle is covered by huge, rigid plates that can be colliding, sliding

past one another or rifting apart. The rifting usually occurs in the ocean floor. The San Andreas fault marks the location where two plates are sliding past each other. Plate tectonics helps to explain how the continents have drifted into their present locations.



RIFT IN OCEAN FLOOR (*color*) initiates three major features of oceanic plate tectonics. The rift is bordered by a rise or ridge created by magma pushed up from the mantle below. The magma solidifies with a magnetic polarity corresponding to that of the earth. When, at long intervals, the earth's polarity reverses, the polarity of newly formed crust reverses too, resulting in a sequence

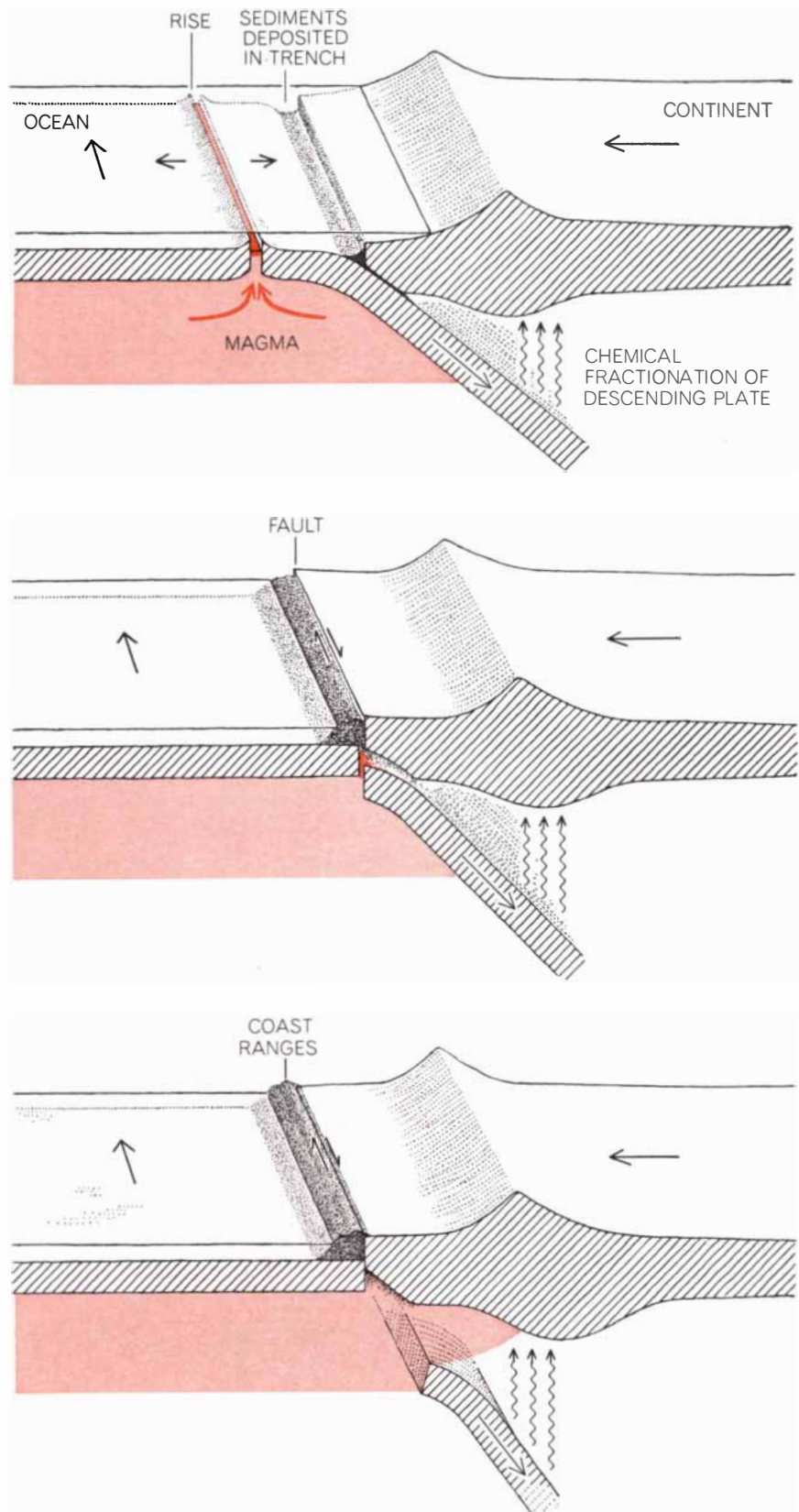
of magnetic "stripes." A trench results when an oceanic plate meets a continental plate. A fracture zone and transform fault result when two plates move past each other. Earthquakes (*dots*) accompany these tectonic processes. The earthquakes in the vicinity of a rise and along a transform fault are shallow. Deep-focus earthquakes occur where a diving oceanic plate forms a trench.

Erosion destroys this kind of evidence very quickly. By matching up distinctive rock units that have been broken up and moved with respect to each other it is possible to document offsets of tens to hundreds of miles. A sedimentary basin often holds debris that could not possibly have been derived from any of the local mountains; matching up these basins with the appropriate source region on the other side of the fault can provide evidence of still larger displacements. When these various kinds of information are combined, one obtains a rate of about half an inch per year for motion on the San Andreas fault in northern and central California over the past several tens of millions of years.

This is much less than the 2½ inches per year that is inferred for the rate of separation of Baja California and mainland Mexico and the rate that is inferred from seismological studies in southern California. There are several possible explanations for the discrepancy. Northern and southern California may be moving at different rates; this seems unlikely since they are both attached to the same Pacific plate. On the other hand, part of the compression in the transverse ranges may result from a differential motion between the two parts of the state. Another possibility is that all of the relative motion between the North American plate and the Pacific plate is not being taken up by the San Andreas fault or even by the San Andreas fault system but extends well inland. The fracture zones of the Pacific seem to affect the geology of the continent for a distance of at least several hundred miles.

The Great Central Valley and the Sierra Nevada lie between two major fracture zones that abut the California coast: the Mendocino fracture zone and the Murray fracture zone. The transverse ranges, the Mojave Desert and the Garlock fault are all in line with the Murray fracture zone. Recent volcanism lines up with the extensions of the Clarion fracture zone and the Mendocino fracture zone. The basins and range geological province of the western U.S., a region of crustal tension and much volcanism, may represent a broad zone of deformation between the Pacific plate and the North American plate proper. Seismic activity is certainly spread over a large, diffuse region of the western U.S.

Although the subject has been quite controversial, most geologists are now willing to accept large horizontal displacements on the faults in California, particularly the San Andreas. Displacements as large as 450 miles of right-lat-



INTERACTION BETWEEN RISE AND TRENCH leads to mutual annihilation. The trench, formed as the oceanic plate dives under the continental plate, slowly fills with sediments carried by rivers and streams (*top*). Meanwhile the melting of the descending slab adds new material to the continent from below. When the axis of the rise reaches the edge of the continent, the flow of magma into the rift is cut off and trench sediments are scraped onto the western (that is, left) part of the oceanic plate (*middle*). The descending plate disappears under the continent and the sediments travel with the oceanic plate (*bottom*). The northern part of the San Andreas fault may have been formed in this way.

eral slip have been proposed for the northern segment of the fault. Displacements on the southern San Andreas fault are put at no more than 300 miles. This discrepancy has been puzzling to geologists. My own conclusion is that the part of northern and central California west of the San Andreas fault has moved northwest more than 700 miles and that the southern San Andreas fault has slipped about 300 miles, which makes the apparent discrepancy even worse. The discrepancy disappears if one drops the concept of a single San Andreas fault and admits the possibility that the two segments of the fault were initiated at different times.

The two-fault hypothesis is supported by straightforward extrapolation of the record on the ocean floor. The two San Andreas faults formed at different times, in different ways and may be moving at different rates. The record indicates that the western part of North America caught up with a section of the East Pacific rise somewhere between 25 million and 30 million years ago. Before the collision a deep oceanic trench existed off the coast such as now exists farther to the south off Central America and South America. The trench had existed for many millions of years, receiving

sediments from the continent; subsequently the sediments were carried down into the mantle by the descending oceanic plate, which was diving under the continent. Based on what we know of trench areas that are active today one can assume that the plate sank to 700 kilometers and that the process was accompanied by earthquakes with shallow, intermediate and deep foci.

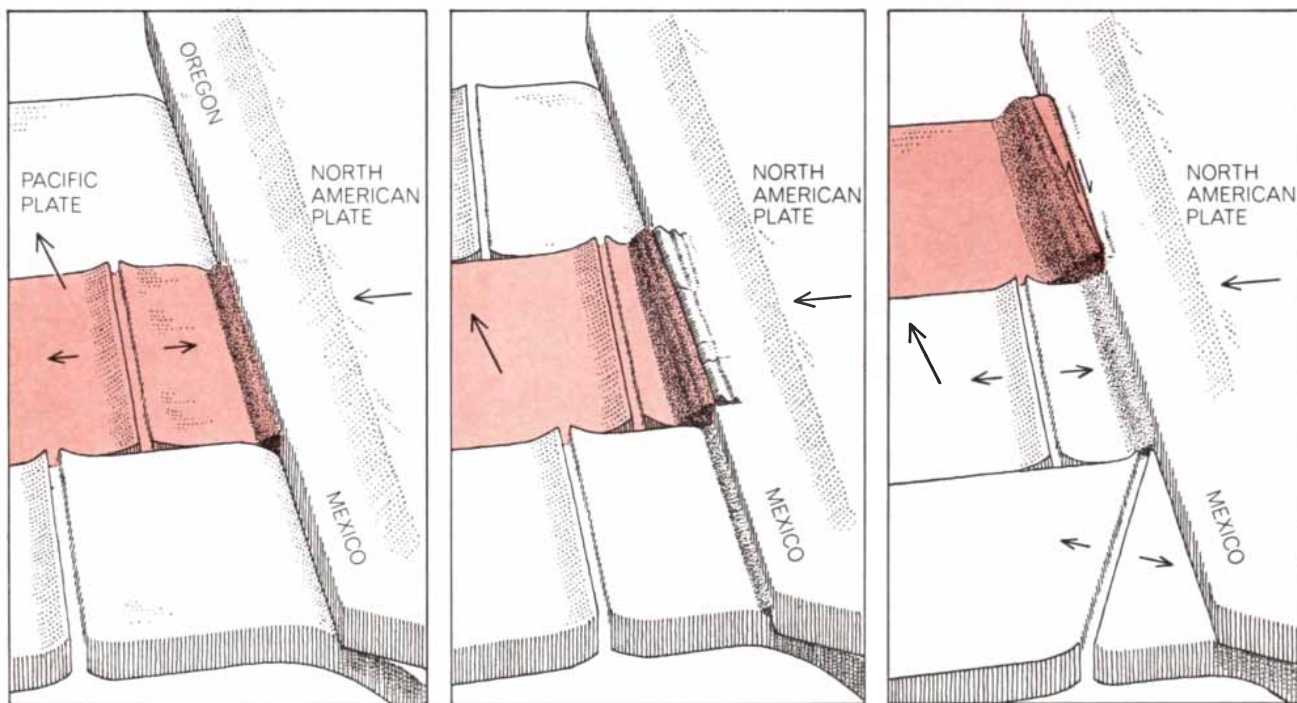
The Origin of Continents

Let us examine a little more closely what happens when an oceanic rise, the source of new oceanic crust, approaches a trench, which acts as a sink, or consumer of crust. Evidently the rise and the trench annihilate each other. The oceanic crust and its load of continental debris, which was formerly in the trench, rise because the crust is no longer connected to the plate that was plunging under the continent. The trench deposits are so thick they eventually rise above sea level and become part of the continent. The deposits are still attached to the oceanic plate, however, and travel with it [see illustration on preceding page].

In the case of the Pacific plate off California the deposits move northwest

with respect to the continent. This is the stuff of coastal California north of Santa Barbara, particularly the Coast Ranges. According to this view, the northern segment of the San Andreas fault was born at the same time as northern California. The rise and the trench initially interacted near San Francisco, which then was near Ensenada in Baja California. Ensenada in turn was near the northern end of the Gulf of California, which was then closed.

The tectonics and geologic history of California, and in fact much of the western U.S., are now beginning to be understood in terms of the new ideas developed in the theories of sea-floor spreading, continental drift and plate tectonics. Many of the basic concepts were laid down by the late Harry H. Hess of Princeton and Robert S. Dietz of the Environmental Science Services Administration. Tanya Atwater of the University of California at San Diego and Warren Hamilton of the U.S. Geological Survey and their colleagues have made particularly important contributions by applying the concepts of plate tectonics to continental geology. We now know that the outer layer of the earth is immensely mobile. This layer, the lithosphere, is relatively cold and



FORMATION OF SAN ANDREAS FAULT SYSTEM is depicted schematically in the six diagrams on these two pages. Some 30 million years ago (*left*) an oceanic rise system lay off the west coast of North America, which was carried by a plate moving toward the rise crests. The continental plate overrides the Pacific plate, producing a long trench. Meanwhile the entire Pacific plate is moving northwest. After a few million years (*right*) the rise nearest the continent is shut off. The trench by now has been filled with material eroded from the continent. These deposits will later become the California Coast Ranges.

NORTHERN SECTION of San Andreas fault is created when the former trench deposits become attached to the northward-moving Pacific plate (*left*). The San Andreas fault lies between the two opposed arrows indicating relative plate motions. Meanwhile to the south a tilted rise crest

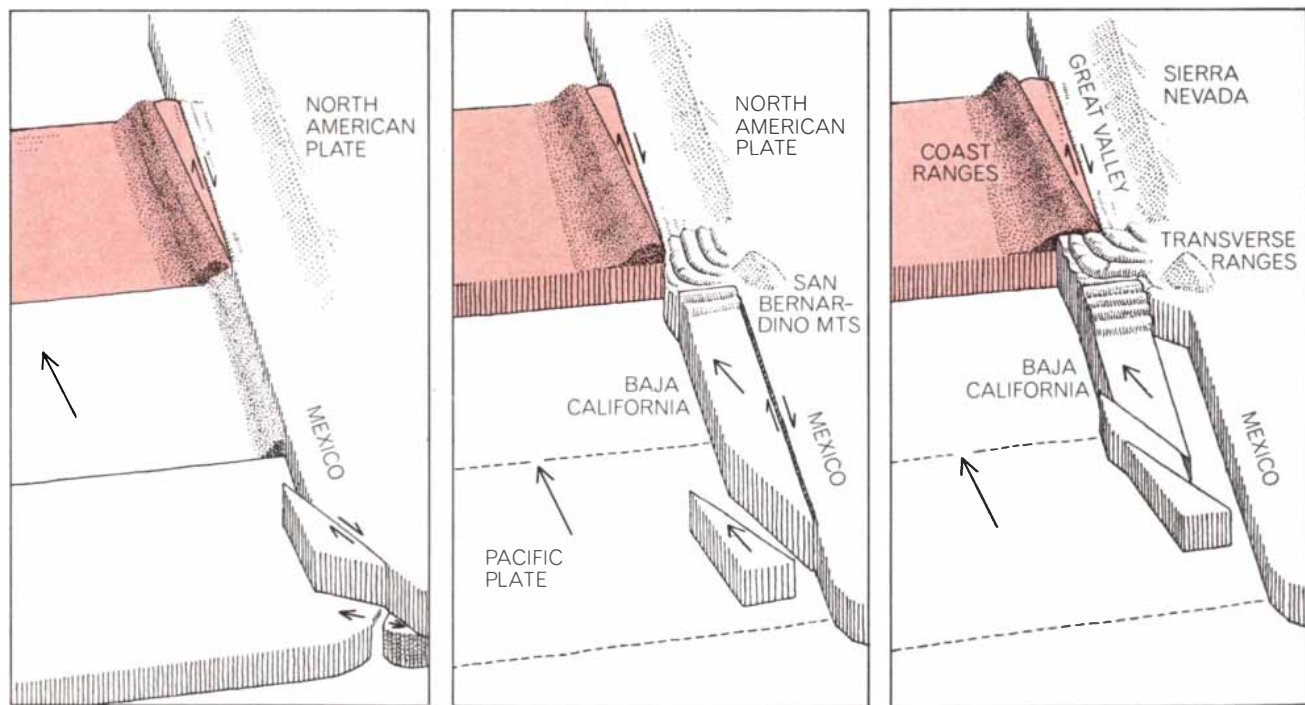
rigid and slides around with little resistance on the hot, partially molten asthenosphere.

Where the crust is thick, as it is in continental regions, the temperatures become high enough in the crust itself to cause certain types of crustal rocks to lose their strength and to offer little resistance to sliding. There is thus the possibility that the upper crust can slide over the lower crust and that the moving plate can be much thinner than is commonly assumed in plate-tectonic theory. The molten fraction of the asthenosphere, called magma, rises to the surface at zones of tension such as the mid-oceanic rifts to freeze and form new oceanic crust. The new crust is exposed to the same tensional forces (presumably gravitational) that caused the rift in the first place; therefore it rifts in turn and subsequently slides away from the axis of the rise. In addition to providing the magma for the formation of new crust, the melt in the asthenosphere serves to lubricate the boundary between the lithosphere and the asthenosphere and effectively decouples the two. The rise is one of the types of boundary that exist between lithospheric plates and is the site of small, shallow tensional earthquakes.

When two thin oceanic lithospheric plates collide, one tends to ride over the other, the bottom plate being pushed into the hot asthenosphere. The boundary becomes a trench. When the lower plate starts to melt, it yields a low-density magma that rises to become part of the upper plate; this magma becomes the rock andesite, which builds an island arc on what is to become the landward, or continental, side of the trench. (The rock takes its name from the Andes of South America. Mount Shasta in California is primarily andesite, as are the island arcs behind the trenches that surround the Pacific.) The thickness of the crust is essentially doubled as a result of the underthrusting. The material remaining in the lower plate is now denser than the surrounding material in the asthenosphere, both because it has lost a low-density fraction and because it is colder; thus it sinks farther into the mantle. In some parts of the world the downgoing slab can be tracked by seismic means to 700 kilometers, where it seems to bottom out. By this process new light material is added to the crust and new dense material is added to the lower mantle. A large part of what comes up stays up; a large part of what goes down stays down.

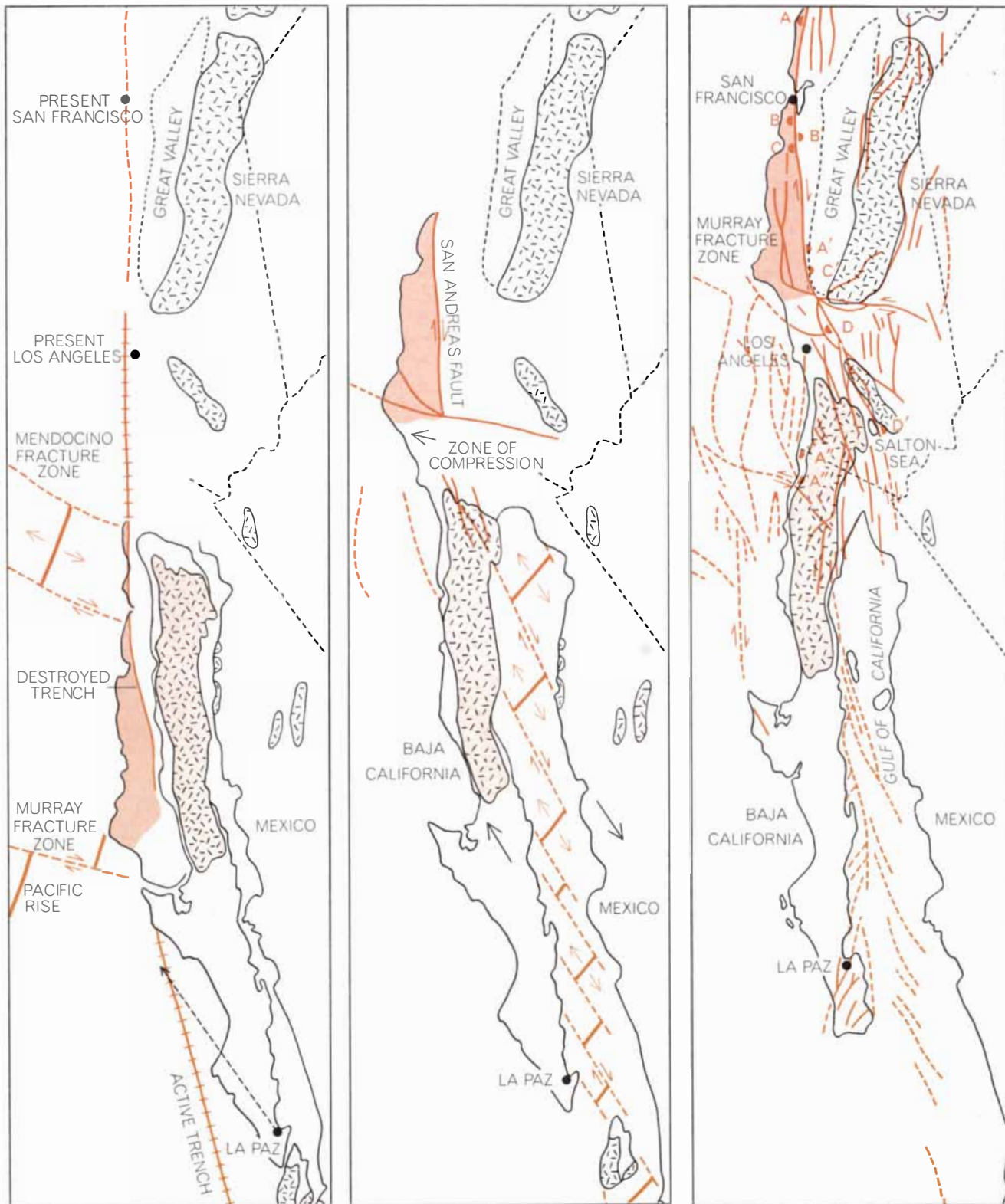
The introduction of chemical fractionation and a mechanism for "unmixing" makes the process different from the one customarily visualized, in which gigantic convection cells carry essentially the same material in a continuous cycle. The new process is able to explain in a convincing way how continents are formed and thickened. As the continent thickens and rises higher because of buoyancy, erosional forces become more effective and dump large volumes of continental sediments into the coastal trenches. A portion of the sediments is ultimately dragged under the continent to melt and form granite. The light granitic magma rises to form huge granitic batholiths such as the Sierra Nevada. A batholith is a large mass of granitic rock formed when magma cools slowly at great depth in the earth's crust. It is carried to the surface by uplifting forces and exposed by erosion.

The concept of rigid plates moving around on the earth's surface and interacting at their boundaries has been remarkably successful in explaining the evolution of oceanic geology and tectonics. The oceanic plates seem to behave rather simply. Tension results in a rise, compression results in a trench and lateral motion results in a transform fault



(not yet visible in the first pair of diagrams) is ready to encounter the continent end on at a break in the coastline south of Baja California. The collision (right) breaks off a part of the Baja California peninsula, which becomes attached to the Pacific plate and starts its journey to the northwest.

SOUTHERN SECTION of San Andreas fault is now fully activated (left) as the Baja California block begins sliding past the North American plate and collides with deeply rooted structures to the north, the Sierra Nevada and San Bernardino Mountains, which deflect the block to the west. More of Baja California breaks loose, opening up the Gulf of California. As Baja California continues to move northwestward (right) the Gulf of California steadily widens. The compression at the north end of the Baja California block creates the transverse ranges, which extend inland from the vicinity of present-day Santa Barbara.



EARLY AND LATE STAGES in the history of the San Andreas fault are depicted. Twenty-five million years ago (*left*) Baja California presumably nestled against mainland Mexico. The first section of oceanic rise between the Murray fracture zone and the Pioneer fracture zone has just collided with the continent. Trench deposits are uplifted and become part of the Coast Ranges of California. The block containing the present San Francisco area (*dark color*) is about to start its long northward journey. A block immediately to the east (*light color*) becomes attached to the Pacific plate and eventually is jammed against the San Bernardino Mountains. Three million years ago (*middle*) the Gulf of California has started to open. As the peninsula moves away from mainland

Mexico a series of rifts appear, fill with magma and are offset by numerous fractures. Baja California may have been torn off in one piece or in slivers. Southwest California and Baja California today (*right*) continue to slide northwest against the North American mainland. The illustration shows major fault systems and offshore fracture zones. On the basis of unique rock formations geologists infer that the Los Angeles area has moved northwest about 130 miles (*D' to D*) in the past 20 million years or less. Other studies indicate that the Palo Alto region has been carried about 200 miles (*C' to C*). Coastal rocks to the north of San Francisco have been displaced at least 300 miles (*A' to A*) and perhaps as much as 650 miles (*A'' to A*) in the past 30 million years.

and a fracture zone [see *bottom illustration on page 56*]. The interaction of oceanic and continental plates or of two continental plates is apparently much more complicated, and this is one reason the new concepts were developed by study of the ocean bottom rather than continental geology.

The boundary between two oceanic plates can be a deep oceanic trench, an oceanic rise or a strike-slip fault depending on whether the plates are approaching, receding from or moving past each other. The forces involved are respectively compressional, tensional and shearing. When a thick continental plate is involved, compression can also result in high upthrust and folded mountain ranges. The Himalayas resulted from the collision of the subcontinent of India with Asia. I shall show that the transverse ranges in California were formed in a similar way. Tension can result in a wide zone of crustal thinning, normal faulting and volcanism; it can also create a fairly narrow rift of the kind found in the Gulf of California and the Red Sea [see *top illustration on page 56*].

The interaction of western North America with the Pacific plate has led to large horizontal motions along the San Andreas fault, to concentrated rifting as in the Salton Sea trough and the Gulf of California, to diffuse rifting and normal faulting accompanied by volcanism in the basins and range province of California, Nevada, Utah and Arizona, to large vertical uplift by overthrusting as in the transverse ranges north and west of Los Angeles, to the generation of large batholiths such as the Sierra Nevada and to the incorporation of deep-sea trench material on the edge of the continent. Ultimately the geology, tectonics and seismicity of California can be related to the collision of North America with the Pacific plate.

Most of the Pacific Ocean is bounded by trenches and island arcs. Trenches border Japan, Alaska, Central America, South America and New Zealand. Island arcs are represented by the Aleutians, the Kuriles, the Marianas, New Guinea, the Tongas and Fiji. The arcs are themselves bordered by trenches. All these areas are characterized by andesitic volcanism and deep-focus earthquakes. Western North America is lacking a trench and has only shallow earthquakes, but the geology indicates that there was once a trench off the West Coast, and in fact there was once a rise. The present absence of a rise and a trench, the absence of deep-focus earthquakes and the existence of uplifted deep-sea sediments are all related.

Tracing back the history of the interaction of the Pacific plate with the North American plate, one is forced to conclude that the northern part and the southern part of the San Andreas fault originated at different times and in different ways. The northern part was evidently formed about 30 million years ago when a portion of rise between the Mendocino fracture zone and the Murray fracture zone approached an offshore trench bordering the southern part of North America. At that time the west coast of North America resembled the present Pacific coast of South America: there was a deep trench offshore, high mountains paralleled the coastline and large underthrusting earthquakes were associated with the downgoing lithosphere.

Origin of the Fault

As the rise approached the continent both the geometry and the dynamics of interaction changed [see *illustrations on pages 58 and 59*]. Depending on the spreading rate of the new crust generated at the rise and the rate at which the rise itself approaches the continent, the relative motion between the rise and the continental plate will decrease, stop or reverse when the rise hits the trench. The forces keeping the trench in existence will therefore decrease, stop or reverse, leading to uplift of the sedimentary material that has been deposited in the trench. In classical geologic terms these are known as eugeosynclinal deposits. Although they have been exposed to only moderate temperatures, they have been subjected to great pressures, both hydrostatic (owing to their depth of burial) and directional (owing to the horizontal compressive forces between the impinging plates). Eugeosynclinal sediments are therefore strongly deformed and become even more so as they are contorted and sheared during uplift. Much of the western edge of California and Baja California is underlain by this material, called the Franciscan formation. The formation is physically attached to the Pacific plate and is therefore moving northwest with respect to the rest of North America. The present boundary is the northern part of the San Andreas fault. Today this section of the San Andreas system extends from Cape Mendocino, north of San Francisco, to somewhere south and east of Santa Barbara, near the beginning of the great bend of the San Andreas fault, where the San Andreas and the Garlock faults intersect.

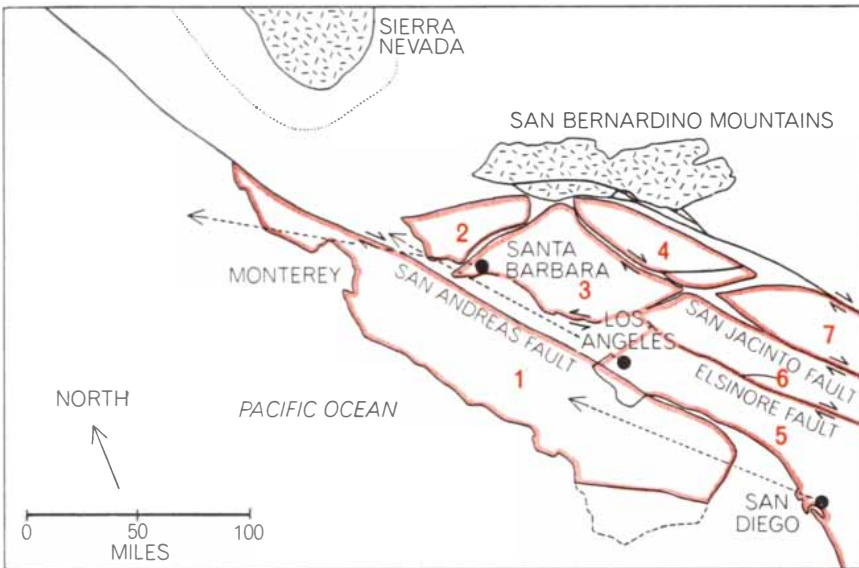
Meanwhile, 30 million years ago, an-

other section of the rise south of the Murray fracture zone was still offshore, together with an active trench. Baja California was still attached to the mainland of Mexico and the Gulf of California had not yet opened up. The southern part of the San Andreas fault had not yet been formed.

The abrupt change in the direction of the coastline south of the tip of Baja California suggests that here the rise approached the continent more end on than broadside. A sliver of existing continent was welded onto the Pacific plate and rifted away from Mexico, thus forming Baja California and the Gulf of California. Thereafter Baja California participated in the northwesterly motion of the Pacific plate, with the result that the Gulf of California widened progressively with time.

About five million years were required for northern California, which had broken off from Baja California, to be carried about 200 miles to the northwest. At the end of that time the Gulf of California and the Salton Sea trough had not yet opened. The faults that delineate the major geologic blocks in southern California had not yet been activated. The block bearing the San Gabriel fault, now north of San Fernando, occupied the future Salton Sea trough. The transverse ranges will eventually be formed from the Santa Barbara, San Gabriel and San Bernardino blocks by strong compression from the south when Baja California breaks loose from mainland Mexico. This also opens up the Gulf of California and the Salton Sea trough.

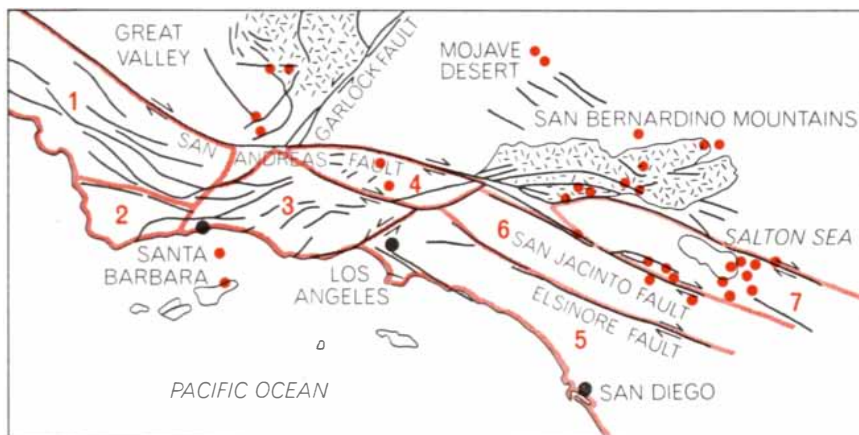
As northern California is being carried away from Baja California by the Pacific plate another segment of oceanic rise south of the Murray fracture zone approaches the southern half of Baja California, where the situation described above is repeated except that the rise crest encounters a sharp bend in the coastline and the trench hits just south of the tip of the peninsula. Now instead of approaching the continent more or less broadside the rise approaches the continent end on. Mainland Mexico is still decoupled from that part of the Pacific plate to the west of the rise by the rise and the trench. Baja California, however, is now coupled to the northward-moving Pacific plate and Baja California is torn away from the mainland. This happened between four and six million years ago. Magma from the upper mantle wells up into the rift, forming a new rise that works its way north into the widening gulf. Alternatively, the entire peninsula of Baja California could have broken off from the mainland at the



SEQUENCE OF SIMPLIFIED VIEWS shows the movement of major blocks in southern California over the past 12 million years. In the first view (*above*) the Gulf of California has not yet appreciably opened but the block carrying the Coast Ranges (1) has started to move rapidly northwest with activation of northern portion of San Andreas fault. Dots show origin and arrows show displacement of San Diego, Los Angeles and Santa Barbara.



TWO MILLION YEARS AFTER ACTIVATION of the southern portion of the San Andreas fault four blocks (2, 3, 4, 7) have been forced against the deep roots of the Sierra Nevada and San Bernardino Mountains. Compressive forces create the transverse ranges. Meanwhile the block carrying the Coast Ranges (1) has been carried far to the northwest.



GEOLOGY OF SOUTHERN CALIFORNIA TODAY is dominated by compressive forces operating in the big bend of the San Andreas fault, which connects the southern and northern parts of the system. Colored dots show the location of earthquakes in the recent past.

same time. As the peninsula, including parts of southern California, moves north it collides with parts of the continent that are still attached to the main North American plate. This results in compression, overthrusting and shearing and the eventual formation of the transverse ranges.

The southern part of the San Andreas fault system was therefore formed by the rifting off of a piece of continent. Today it represents the boundary between two parts of the continental plate that are moving with respect to each other. This part of the San Andreas fault was formed well east, or inland, of the southward projection of the northern San Andreas.

The northerly march of southern California and Baja California seems to have been blocked when the moving plate encountered the thick continental crust to the north, particularly the massive granitic San Bernardino mountain range, which includes the 11,485-foot San Geronio Mountain. Since large and high mountain ranges have deep roots, the crust in this region is probably much thicker than normal, perhaps as thick as 50 kilometers. Earthquakes in this region are all shallower than 20 kilometers, which may be the thickness of the sliding plates. The blocks veer westward and are strongly overthrust as they attempt to get around the obstacle; this movement generates the big bend in the San Andreas fault system. The deflected blocks eventually join up with the northern California block.

Earthquake Country

From a social and economic point of view earthquakes are one of the most important manifestations of plate interaction. From a scientific point of view they supply a third dimension to the study of faults and the nature of the interactions between crustal blocks, including the stresses involved and the nature of the motions.

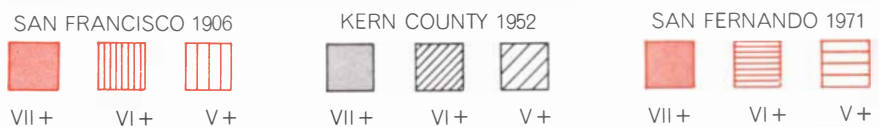
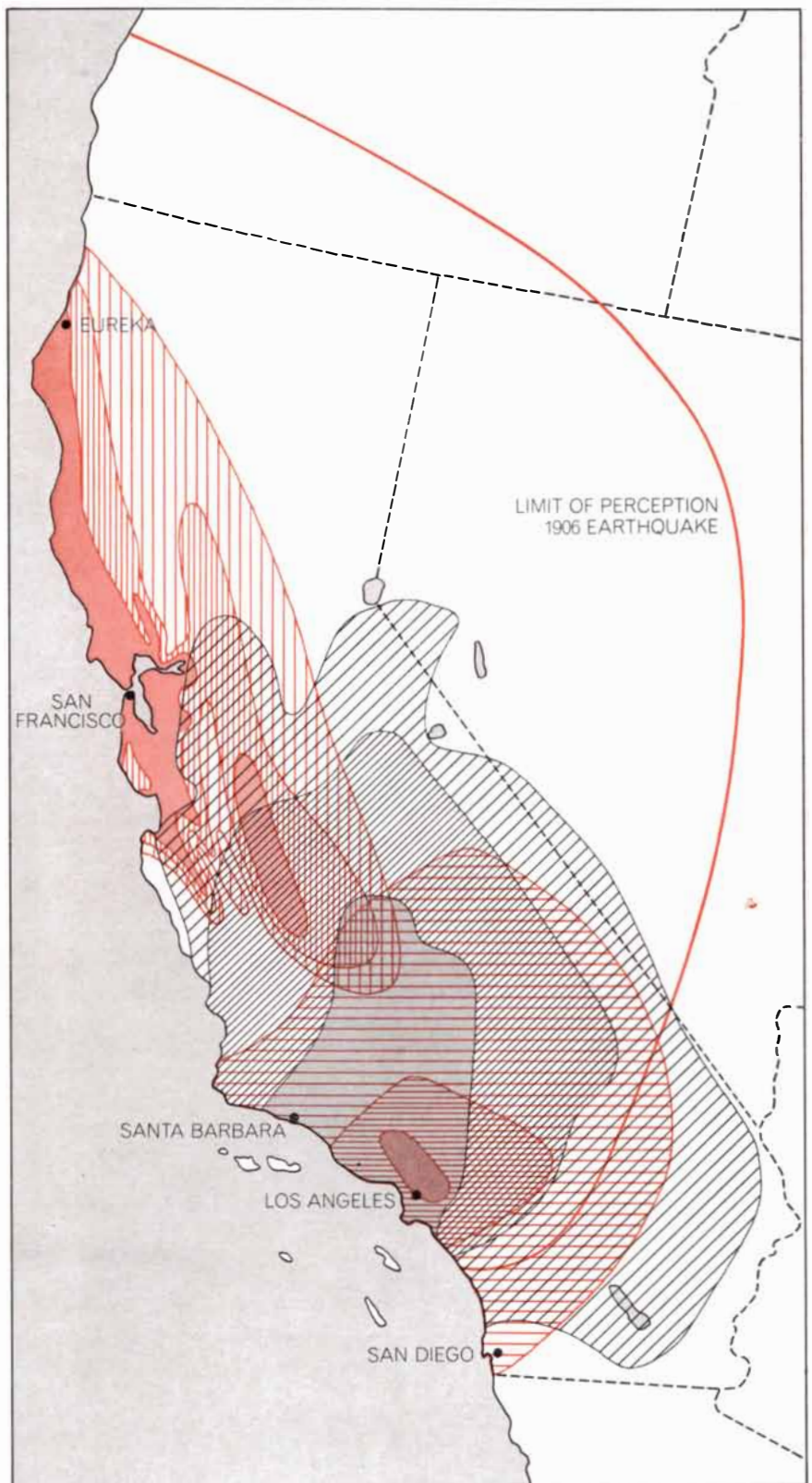
Seismologists at the University of California at Berkeley and at the Cal Tech Seismological Laboratory have been keeping track of earthquake activity in California for more than 40 years. Both groups have installed arrays of seismometers that telemeter seismic data to their laboratories for processing and dissemination to the appropriate public agencies. During the 36-year period 1934 through 1969 there were more than 7,300 earthquakes with a Richter magnitude of 4 or greater in southern California and adjacent regions [see illustration on page 64]. Many thousands more earthquakes of smaller magnitude are

routinely located and reported in the seismological bulletins. Although damage depends on local geological conditions and the nature of the earthquake, a rough rule of thumb is that a nearby earthquake of magnitude 3.5 or greater can cause structural damage. The average annual number of earthquakes of magnitude 3 or greater in southern California recorded since 1934 is 210; the number in any one year has varied from a low of 97 to a high of 391. The strongest earthquake in this period was the Kern County event of magnitude 7.7 in 1952. The aftershocks of that event increased the total number of events for several years thereafter.

In general the larger the earthquake, the greater the displacement across a fault and the greater the length of fault that breaks. The great earthquakes of 1906 and 1857 respectively caused large displacements across the northern and central parts of the San Andreas fault and relieved the accumulated strain in these areas. The accumulation of strain in southern California is relieved mainly by slip on a series of parallel faults and by overthrusting on faults at an angle to the main San Andreas system; that is what happened in the Kern County and San Fernando earthquakes. The unique east-west-trending transverse ranges were formed in this way. In the process deep-seated ancient rocks were uplifted and exposed by erosion.

Another seismically active area associated with major faults is south of the Mojave Desert near San Bernardino, where the faults show a sudden change in direction. The central part of the Mojave Desert is also moderately active. This is consistent with the idea that the sliding lithosphere is diverted by the San Bernardino Mountains. Faults and evidence of relatively recent volcanic events abound in the area. The northern part of Baja California is also quite active. An interesting feature of seismicity maps of southern California is the alignment of earthquakes in zones that trend roughly northeast-southwest, approximately at right angles to the major trend of the San Andreas system.

The map on the next page shows that the San Andreas fault itself has played only a small role in the seismicity of southern California over the past 30-odd years. One must not forget, however, that the great earthquake of 1857 probably broke the San Andreas fault for about 100 miles northwest and southeast from the epicenter. That epicenter is thought to have been near Fort Tejon, which is close to the projected intersection of the Garlock and San Andreas



ISOSEISMAL CONTOUR MAP shows the pattern and intensity of ground-shaking produced by the 1906 San Francisco earthquake of magnitude 8.3, the 1952 Kern County earthquake of magnitude 7.7 and the 1971 San Fernando earthquake of magnitude 6.6. The Roman numerals indicate levels of perceived intensities as defined by the modified Mercalli scale. A short description of each level in the scale appears in the text on page 65.

faults; the actual location of the epicenter is uncertain by hundreds of miles because there were no seismic instruments in those days. Since that time this part of southern California has been remarkably quiet and seems to be locked, generating neither earthquakes nor creep. Activity along the San Andreas fault picks up near Coalinga, which is about midway between Bakersfield and San Francisco. Alignments of earthquakes are apparent along the San Jacinto and Imperial faults in the Salton Sea trough near the Mexican border. Although these faults lie west of the main San Andreas fault, they are part of the San Andreas system. The White Wolf fault, which is northwest of and parallel to the Garlock fault, has also been quite active, particularly after

the Kern County earthquake, which occurred on this fault. The White Wolf fault lines up with the Santa Barbara Channel area, which has similarly been quite active.

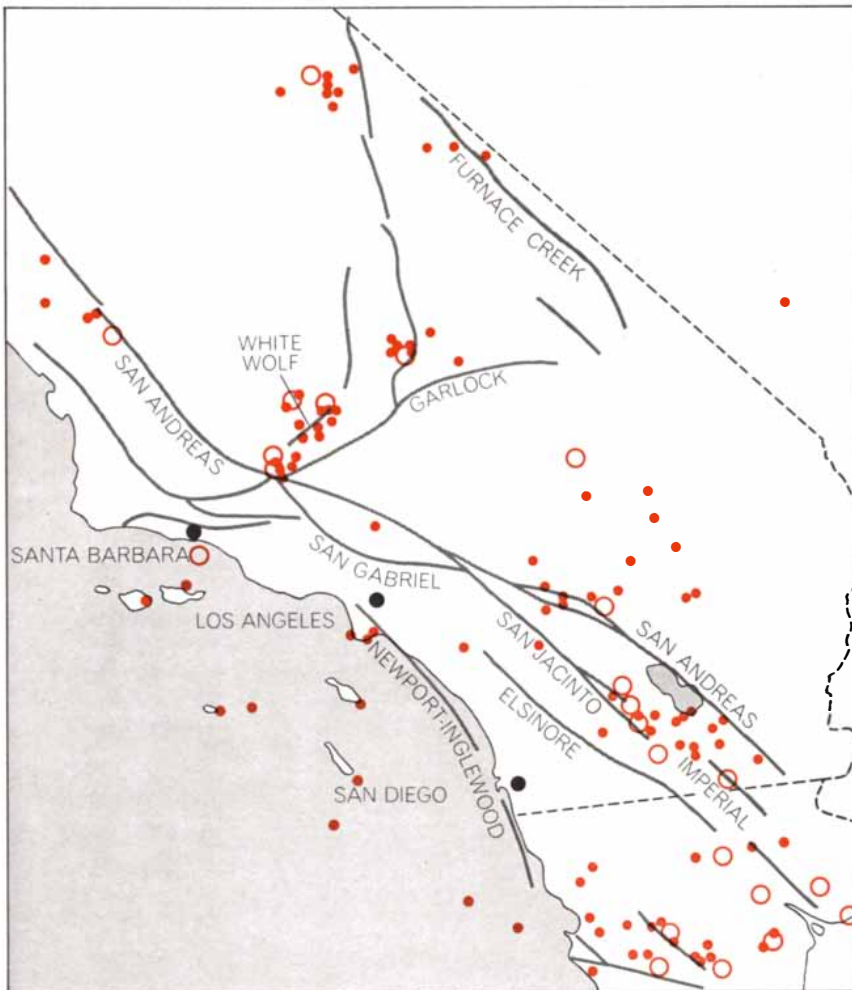
One way to quantify the seismicity of southern California is to count the number of earthquakes per year per 1,000 square kilometers and compare this figure for the world as a whole. For example, southern California averages one earthquake of magnitude 3 or greater per year per 1,000 square kilometers. Thus within the entire region there are about 200 such earthquakes per year. The rate for earthquakes of magnitude 6.6, the size of the San Fernando earthquake, is about one every five or six years. The actual rates, however, vary

considerably from year to year and depend somewhat on the time interval of the sample. The number of earthquakes decreases rapidly with size, and the average recurrence interval is not well established for the larger earthquakes. Southern California is about 10 times more active seismically than the world as a whole, which is simply to say that California is earthquake country.

Although certain areas in southern California are relatively free of earthquakes, none is immune from their effects. One of the largest quiet areas is the western part of the Mojave Desert wedge. This is surprising because the region is bounded on the northwest and southwest by areas that are obviously under large compression, as is shown by the upthrust mountains in the transverse and Tehachapi ranges and the large overthrust earthquakes that occurred in Kern County and San Fernando. It appears that the region is being protected from the northwesterly march of the southern California-Baja California block by the San Bernardino batholith and may represent a stagnation area in the lee of the mountains. Only a small number of earthquakes are centered near San Diego, although the larger earthquakes in northern Baja California and in the mountains between San Diego and the Salton Sea are felt in San Diego. The Great Central Valley north of Bakersfield and the eastern part of the Sierra Nevada are fairly inactive, as is a large area north of Santa Barbara in the Coast Ranges.

Magnitude and Intensity

It is somewhat deceptive to plot earthquakes as small points on a map. The points represent the epicenter: the point on the surface above the initial break. Once the break is started it can continue, if the earthquake is a major one, for hundreds of miles. Earthquakes of the thrust type, which result from a failure in compression, typically first break many miles below the surface; the surface break and maximum damage can be 10 miles or more from the epicenter. The distance over which strong shocks were felt during three large California earthquakes in this century (1906, 1952 and 1971) can be represented by plotting isoseismals: lines of equal intensity [see illustration on preceding page]. The shape of the pattern varies with the type of earthquake and with the nature of the local geology; structures on deep sedimentary basins or on uncompacted fill get a more intense shaking than structures on bedrock. The isoseismals of the



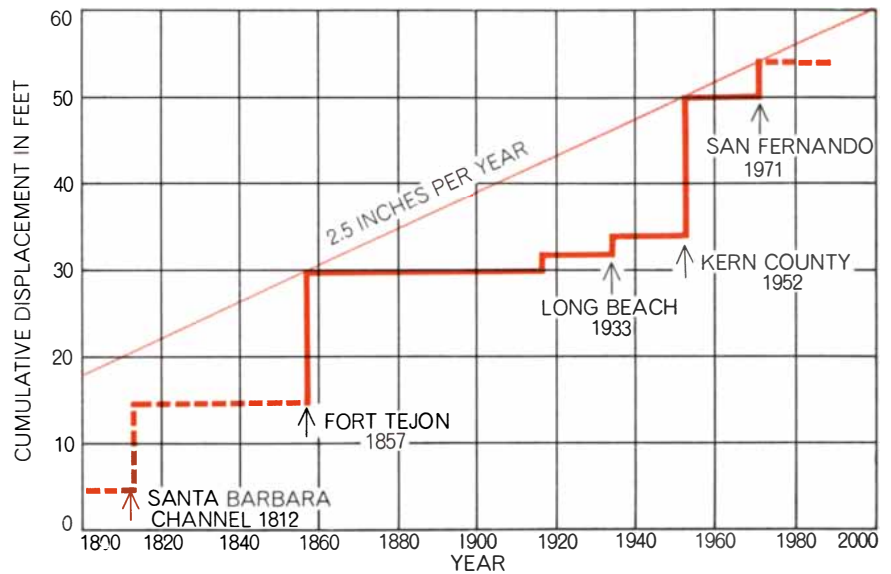
THIRTY-SIX-YEAR EARTHQUAKE RECORD shows the epicenters of all events of magnitude 5 or greater recorded in southern California and in the northern part of Baja California from 1934 through 1969. The epicenter is the point of the initial break in the earth's crust. Dots represent earthquakes between 5 and 5.9 in magnitude. Open circles indicate earthquakes of magnitude 6 or greater. The hypocenter, the point of the initial break in the earth's crust, is often many miles below the surface in thrust-type earthquakes, a type frequently observed in this region. In the 36-year period southern California and adjacent regions experienced more than 7,300 earthquakes with a magnitude of 4 or more. Earthquakes are about 10 times more frequent in this area than they are in the world as a whole.

San Francisco earthquake are long and narrow, both because of the orientation of the fault and the length of the faulting and because of the northwest-southeast trend of the valleys. The orientation of the valleys in turn is controlled by the orientation of the San Andreas fault.

The public and the news media are confused about the various measures of the size of an earthquake. There are many parameters associated with an earthquake; they are usually regarded as fault parameters. They include the length, depth and orientation of the fault, the direction of motion, the rupture velocity, the radiated energy, the causal stresses and their orientation, the stress drop (which is related to the strength or the friction along the fault), the energy spectrum, the amount of offset or displacement and the time history of the motion. Most of these parameters can be estimated from seismic records, even from signals recorded several thousand kilometers from the earthquake. To obtain high precision, however, one needs records from many well-distributed seismic stations together with field observations at the site of the earthquake.

The magnitude on the Richter scale is a number assigned to an earthquake from instrumental readings of the amplitude of the seismic waves on a standard seismometer, the Wood-Anderson torsion seismometer. The amplitude must be suitably corrected for spreading and attenuation in the earth, and for instrumental response if a non-standard instrument is used. The magnitude is closely related to the energy of the earthquake, the single most important quantity by which earthquakes can be ranked one against another. If all the corrections are adequately made, a seismologist anywhere in the world will assign the same magnitude. In practice, because of the complicated radiation pattern of earthquakes and because of the distortion of the waves traveling through the earth, the initial magnitude assigned by various observatories may differ slightly. The magnitude scale is logarithmic and is open-ended at both ends. It is not a scale with a maximum value of 10, as is often reported in the press, and negative magnitudes are routinely measured by seismologists working on microearthquakes.

The intensity scale was developed for engineering purposes and is a qualitative measure of the intensity of ground vibration and structural damage. These qualitative assessments are assigned Roman numerals from I to XII. Unlike the magnitude of an earthquake, the inten-



CUMULATIVE DISPLACEMENTS directly related to earthquakes indicate that southern California west of the San Andreas fault system is sliding northwestward at an average rate of 2½ inches per year. Major earthquakes relieve stresses that have built up over decades.

sity varies with distance and depends on the nature of the local ground. In general alluvial valleys, soft sediments and areas of uncompacted fill will magnify groundshaking and will register higher intensities than adjacent areas on solid rock.

The intensity scale in common usage today is the Modified Mercalli Intensity Scale. The following characterizations of intensity, abridged from longer descriptions, indicate the kind of observations on which the Mercalli scale is based:

I. Not felt except by a very few under special circumstances. Birds and animals are uneasy; trees sway; doors and chandeliers may swing slowly.

II. Felt only by a few persons at rest, particularly on the upper floors of buildings.

III. Felt indoors, but many people do not recognize as an earthquake. Vibrations like the passing of light trucks. Duration of the shaking can be estimated.

IV. Windows, dishes and doors rattle. Walls make creaking sounds. Sensation like the passing of heavy trucks. Felt indoors by many, outdoors by few.

V. Felt by nearly everyone; many awakened. Small unstable objects are displaced or upset; plaster may crack.

VI. Felt by all; many are frightened and run outdoors. Some heavy furniture is moved; books are knocked off shelves and pictures off walls. Small church and school bells ring. Occasional damage to chimneys, otherwise structural damage is slight.

VII. Most people run outdoors. Difficult to stand up. Noticed by drivers of automobiles. Damage is negligible in

buildings of good design and construction, slight to moderate in well-built ordinary structures, considerable in poorly built or badly designed structures. Waves on ponds and pools.

Intensity VII corresponds to the general experience within five or 10 miles of the surface faults associated with the San Fernando earthquake of last February. The following intensity levels were experienced in a small area of the northern San Fernando Valley and would be widely experienced in more severe earthquakes.

VIII. Steering of automobiles affected. Frame houses move on foundations if not bolted down; loose panel walls are thrown out. Some masonry walls fall. Chimneys twist or fall. Damage is slight in specially designed structures, great in poorly constructed buildings. Heavy furniture is overturned.

IX. General panic. Damage is considerable in specially designed structures; partial collapse of substantial buildings. Serious damage to reservoirs and underground pipes. Conspicuous cracks in the ground.

X. Most masonry and frame structures are destroyed with their foundations. Some well-built wooden structures are destroyed. Rails are bent slightly. Large landslides.

XI. Few, if any, masonry structures remain standing. Bridges are destroyed. Broad fissures in the ground. Rails are bent severely.

XII. Damage is nearly total. Objects are thrown into the air.

It is clear that the Mercalli intensity scale is people-oriented; anyone can es-

timate the intensity from his own experience during an earthquake. The National Oceanic and Atmospheric Administration compiles information on intensities by mailing out questionnaires to a sample of the population living in an area that has experienced a sizable earthquake.

In order to obtain more exact information about the ground motions involved in earthquakes engineers have developed strong-motion accelerometers that automatically trigger and start to record when shaken severely. Most of these instruments are installed in the seismic areas of the U.S., with a particularly heavy concentration in and around Los Angeles. The instruments are expensive and must be located very close to an earthquake to provide useful data. More than 250 of the instruments were triggered during the San Fernando earthquake, and a wealth of engineering data will be provided by these records.

A strong-motion instrument records ground acceleration as a function of time. Accelerations are commonly reported as fractions of a *g*, the acceleration due to gravity at the earth's surface.

One *g* is roughly .1 centimeter per second per second. In designing a building to withstand moderate earthquakes, engineers are concerned chiefly with the maximum accelerations, the period or frequency of shaking and the duration of shaking. Buildings in earthquake-hazard regions with stringent building codes are usually designed to withstand at least .1 *g* of acceleration; this corresponds to an intensity of about VII on the Mercalli scale.

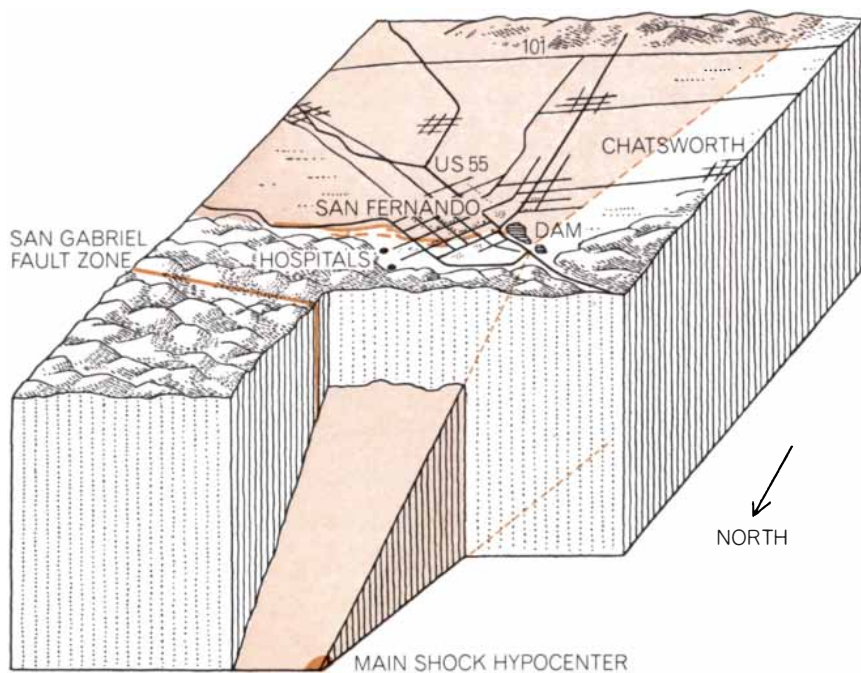
Although there is no direct correlation between intensity and magnitude, the zone of destruction increases as the magnitude increases for shallow-focus earthquakes. In general the larger the magnitude of an earthquake, the longer the fault length, the larger the displacement across the fault and the longer the duration of shaking. The longer fault length alone accounts for much of the increased area of destruction. For example, the San Francisco earthquake of 1906 had an intensity of VII or greater out to a distance of 500 miles from the epicenter, and this may not have been the largest California earthquake in historic times. The San Francisco earth-

quake had a magnitude of 8.3. The 1952 Kern County earthquake (magnitude 7.7) had an intensity of VII or greater out to 50 miles. The recent San Fernando earthquake (magnitude 6.6) damaged older structures out to 25 miles. An earthquake of magnitude 5.5, the Parkfield earthquake of 1966, produced comparable damage to a distance of 10 miles.

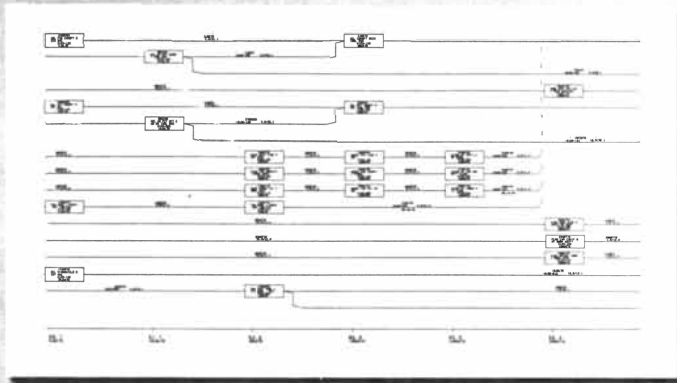
The February Earthquake

The San Fernando earthquake occurred in the San Gabriel Mountains just north of the San Fernando Valley, a densely populated northern suburb of Los Angeles. The San Gabriel Mountains are part of the structural province of the transverse ranges: the band of east-west-trending mountains, valleys and faults that is characterized by strong and geologically recent tectonic deformation. Geologists recognize that the region is one of recent crustal shortening caused by north-south compression. The mountains, produced by buckling and thrusting, are one result of this crustal shortening. They have been thrusting over the valleys to the south for at least five million years along fault planes that dip to the north or northeast.

Although many faults in this area in the past several thousand years, the San Fernando earthquake produced the first historic example of surface faulting. The San Gabriel Mountains rise abruptly some 5,000 feet above the San Fernando Valley and the Los Angeles basin to the south. During the earthquake of February 9 a wedge-shaped prism of the crystalline basement rock comprising the San Gabriel Mountains was thrust over the San Fernando Valley to the southwest, thereby raising the elevation of a section of the San Gabriel Mountains and sliding it slightly to the west. The displacement is consistent with the motions that have been occurring for millions of years, as one can infer from geologic offsets and uplifts. It also agrees with the general picture presented here, namely that the transverse ranges were formed by the collision of the southern and Baja California block with the central and northern California block, and with the concept that the southern California block is being diverted to the west by the massive San Bernardino batholith. One can infer that the thickening of the crust involved in the overthrusting and uplift of the San Gabriel Mountains made this region an additional obstacle to the northwesterly march of



HYPOCENTER OF SAN FERNANDO EARTHQUAKE (*dark color*) of last February was 13 kilometers deep and 12 kilometers south of the area where the principal ground-shaking occurred. The earthquake collapsed sections of two hospitals in the San Fernando Valley, taking 64 lives, and so seriously weakened the earthen wall of the Van Norman Dam at the northern end of the San Fernando Valley that 80,000 people living below the dam had to leave their homes until the water level in the reservoir could be lowered. Total damage caused by the earthquake is estimated at \$500 million to \$1 billion. This three-dimensional view is based on a drawing prepared by two of the author's colleagues, Bernard Minster and Thomas Jordan, who worked with information supplied by geologists and geophysicists of the California Institute of Technology. The view is looking toward Los Angeles.



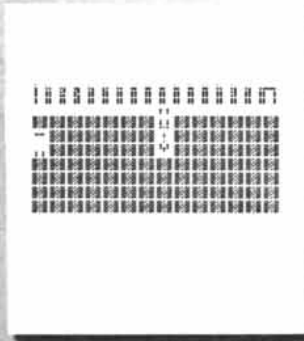
AUTONET PROGRAM



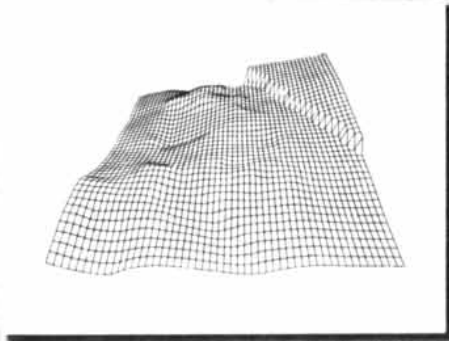
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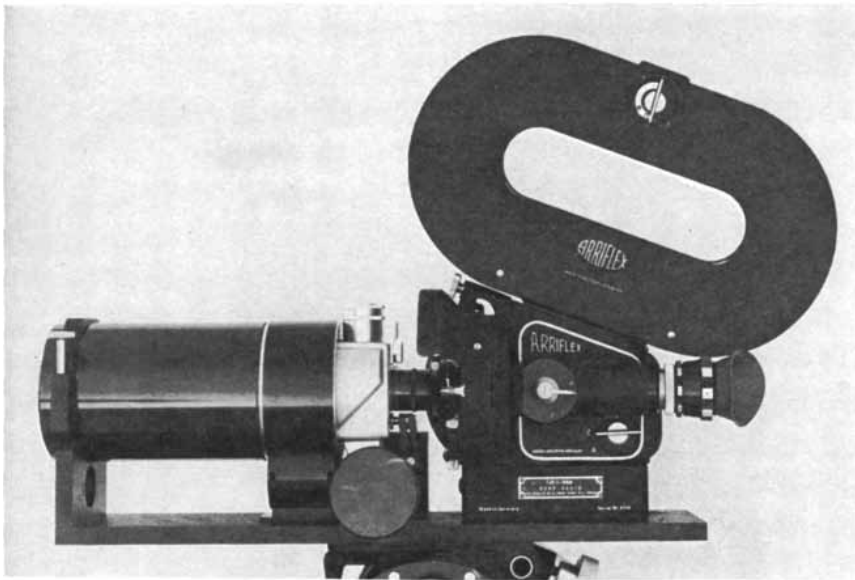
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**THE QUESTAR
CINEMA MODEL
can focus
from the craters
of the moon
to the eye of a fly
... instantly!**

Questar, with the assistance of famed cinema photographer David Quaid, has redesigned the focusing mechanism of its world-reknown telescope especially for the professional cameraman. Now this lens system, the only one in the world of 1400 mm. focal length that can focus from 8 feet to infinity, permits the cinematographer to adjust his focus from an extreme telephoto situation to a macro-closeup within the same film take. And all of this, the barrel containing the optical system, the control box, and the beautifully engineered system of controls, all mounted on a supporting platform, is light in weight. Moreover, it is possible to mount the Questar system on the Arriflex 35 mm. camera in approximately the same time required to mount a conventional lens.

The great thing about this system, David Quaid says, is that it will permit the cinematographer to do something that nothing else in the world will let him do. For example, from a distance of 8 or 10 feet, he can pick up an ant full screen, balanced on the tip of a blade of grass, and as the ant begins to move he pans, keeping it in exact focus as it crosses over to a tall tree and then climbs to its very topmost branch, the whole trip in perfect focus. He may then, if he wishes, switch to a woodland a mile away and focus sharply and instantly on leaves swaying in the breeze.

The precise engineering that has gone into this equipment makes it virtually vibration-free. It can be used not only with the Arri 35, but with 16 mm. reflex cameras. Special accessories are available, such as the Questar Calibrated Follow-Focus Gauge, a Barlow lens to increase the size of a distant object on the film, a positive lens which will diminish the size while increasing the light on a nearby object, and an aerial-image groundglass.

David Quaid says that the prototype of the Questar Cinema Model was used in producing several of the award-winning films made by David Quaid Productions.

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QUESTAR

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the southern California block. If it did, this would lend additional support to the notion that the plates in California are only 15 to 20 kilometers thick. An intriguing possibility is that the upper part of the crust is sliding with relatively little friction on a layer of rock rich in the mineral serpentine.

The hypocenter, or point of initial rupture, of the San Fernando earthquake was at a depth of 13 kilometers under the San Gabriel Mountains. The fault motion was propagated to the surface along a fault inclined northward at an angle of 45 degrees and broke the surface near the cities of San Fernando and Sylmar, at the boundary between the crystalline rocks of the mountains and the sediments of the valley [see illustration on page 66]. Two heavily damaged hospitals were between the epicenter and the surface break and were therefore on the upthrust, or elevated, block. The hundreds of aftershocks following the earthquake covered an area of approximately 300 square kilometers; the total volume of rock lifted up was about 2,500 cubic kilometers.

Even though the elevation difference between the peaks of the San Gabriel Mountains, such as Mount Wilson and Mount Baldy, and the floors of the adjacent valleys is impressive, it does not represent the total uplift. Erosion removes material from the mountains and deposits it in the valleys. The total amount of differential vertical motion probably exceeds two and a half miles, and horizontal displacements in the transverse ranges probably exceed 25 miles. Many thousands of earthquakes of the San Fernando type must have occurred in the area over the past several million years.

Seismic surveillance of the region with instruments dates back only four decades. In this period the northern San Fernando Valley was less active seismically than many other parts of the greater Los Angeles area, although it was comparable to the average for all southern California. On the basis of the seismic data there was no reason to believe the San Fernando area was any more or less likely than any other region of recent mountain-building in southern California to experience a large earthquake. On the other hand, the thrusting and bending associated with the geologic processes in the region, and the tilting that was associated with the earthquake and its aftershocks, suggest that a dense network of tiltmeters could provide a warning of the next large earthquake here.



Middle-of-the-road stereo people are missing the fun of Marantz.

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We sound better.

How Polaroid went to unusual lengths to give

A simple, inexpensive way to make studio-quality portraits of people.

As long as there have been cameras, there has been photographic portraiture. Because nothing interests people more than people.

But until now, there has never been a portrait camera that gives the amateur what he needs: portability, simplicity of operation, high picture quality, and low cost.

Polaroid Corporation has directed its efforts for some time toward filling this gap. And has succeeded.

Our approach was to resist the tendency toward complexity; we strove to maintain singleness of purpose. And to achieve that purpose, we were as willing to use

or modify existing principles as to design new features.

The result is that the new Polaroid Portrait Land Camera is the world's first and only portable, simple-to-use, low-cost camera that produces studio-quality portraits.

At the core of the problem was the dilemma of focal length vs. perspective distortion.

Pictures from conventional cameras, taken at close range, show pronounced distortion. Increasing the distance to the subject lessens distortion, but makes the image too small for a desirable portrait.

Techniques have been developed to try to overcome this problem. The telephoto lens is one; but it is expensive, and loses picture quality and corner illumination.

The most satisfactory solution has been the "studio" portrait camera. By using relatively simple lenses with a long focal length, and keeping them at full distance from the film, quality is maintained. But it is usually a heavy, expensive camera requiring careful adjustment.

With this background, Polaroid chose a 220mm, single-element lens, placed at full distance from the film plane. And to maintain lightness in the resulting elongated body, we molded it of a rigid though lightweight plastic. So the entire camera weighs under two pounds.

We added a shutter with a constant speed of 1/60 sec., and an aperture with a normal setting of f29.

We thus not only minimized perspective distortion,



people what they wanted but could never get.

but added enough depth of field so that precise subject distance is not required. And the shutter speed is optimal for conventional posed portraits.



Long focal length gives the same beauty as in the eye of the beholder.

Since the subject distance is fairly constant at 39 inches, we were able to design a unique combination viewfinder and split-image rangefinder with no moving parts. The user simply walks toward the subject until the two images coincide, and snaps the picture.

The entire mechanism was built into the camera handle, allowing a 5-inch base length. This compares with a maximum base of 2½ inches in most other cameras. And the greater the base length, the greater the accuracy.

Since one image must travel a greater distance than the other to reach the eyepiece, a compensating lens system, similar to a Galilean telescope, was built in.

And to maintain this high level of accuracy, adjusting set-screws allow each rangefinder to be individually calibrated at the factory for framing and ranging, and for avoiding other coincident image errors.

The rangefinder needs only 2 moving parts.



Duplicating the features of a studio camera was not enough. We needed studio lighting.

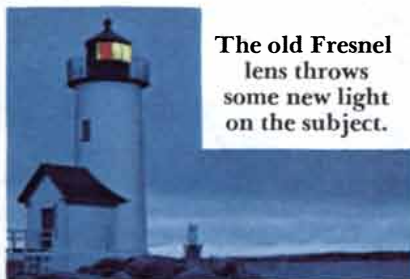
So we added a receptacle for a Magicube. It requires no battery. It yields four uniform flash shots without reloading. It will not advance when the fourth shot is finished, and the shutter locks to prevent taking another shot until the cube is replaced.

To utilize this burst of light to fullest advantage, we found a new way to apply an old principle.

In the 19th century, the Fresnel lens was developed to magnify the beam of a lighthouse without the great bulk of a conventionally-shaped lens. The theoretical surface of the lens was simply divided into small segments, all mounted in a single, flat plane.

Our modification of the Fresnel lens concentrates the light on the subject and transforms a small source of light (a tiny flashbulb) into a large area source.

And despite the concentration of the light, the effect is of controlled softness.



The old Fresnel lens throws some new light on the subject.

The camera has other interesting features. Such as a built-in timer to tell you when the picture is developed. A unique shutter mechanism, designed with a minimal number of moving parts, for higher reliability. And there are no exposure settings.

And, of course, it gives you a finished color portrait in a minute.

It uses only Polaroid Polacolor Land film (Type 108) in the big 3¾" x 4¼" format that gives a big close-up portrait. Which is why we're marketing the camera under the trade name of Big Shot.

But what we're most proud of is the concept. The totality. Being first to fill a common need, and to fulfill the goals we set for ourselves.

Which puts what we do in proper perspective.

**The Polaroid Portrait Land Camera.
Under \$20.**



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The New Covenanters of Qumran

About 180 B.C. a group of dissident Jews founded a religious commune in the Judean desert. Careful analysis of their legacy, the Dead Sea scrolls, reveals much about their life and beliefs

by Shemaryahu Talmon

It is now almost 25 years since the discovery of the ancient writings that have become widely known as the Dead Sea scrolls. In that time hundreds of scholars have intensively examined this unique evidence of the mind and social structure of a group that lived in the Judean desert in a silent period between the Old Testament and the New: the three centuries starting about 200 B.C. Initially scholars took a comparative approach and sought to identify the group with one or another of the nonconformist Jewish sects that were known to exist at that time; others found parallels between a "Teacher of Righteousness" mentioned in the scrolls and Jesus Christ. It now appears that the story the scrolls have to tell is different and much richer.

Like many other great archaeological discoveries of the Near East, the first scrolls were brought to light not by a planned excavation by trained scholars but by accident. In the summer of 1947 two young Bedouin shepherds were grazing their goats in the Judean desert near the northwestern shore of the Dead Sea. The locality, which has the modern Arabic name of Qumran, is about seven miles south of Jericho. While searching for a strayed goat, one of the shepherds came on an opening in the rocks. He investigated and found that the hole seemed to lead to a large cave. Returning the next day, he and his companion crawled through the opening. On the floor of the cave they found eight large, oblong earthenware jars, some of them still covered with bowl-shaped lids. Seven of the jars were empty, but the eighth

contained one large leather scroll and two smaller ones.

For some time the shepherds kept the scrolls in their tent. Eventually they took them to Bethlehem, the nearest trading center, and showed them to a shopkeeper who thought they might be ancient Syriac manuscripts. He took the scrolls to the monastery of St. Mark in Jerusalem, the seat of the Syrian archbishop, where the writing was identified as Hebrew. In the ensuing months members of the monastery did some illegal freelance digging in the cave and discovered four more leather scrolls and several large leather fragments.

The somewhat clandestine character of the discoveries naturally raised questions in the scholarly community about the authenticity of the scrolls. These suspicions soon proved to be unfounded. The antiquity of the scrolls was independently established by E. L. Sukenik, an epigrapher and archaeologist who acquired three of the scrolls for Hebrew University at the end of 1947, and by J. C. Trever and W. H. Brownlee of the American School of Oriental Research in Jerusalem, who examined some of the scrolls early in 1948. Close paleographic analysis left no doubt in their minds that the scrolls dated back to the last two centuries B.C. or the first century of our era. Carbon-14 tests later confirmed the paleographic dating.

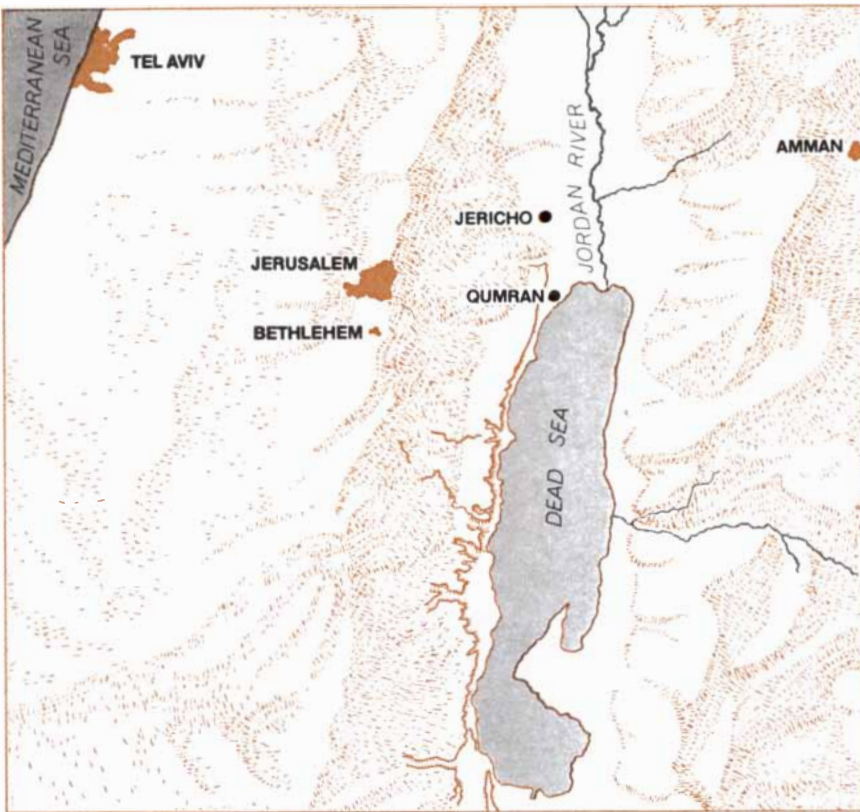
Archaeological excavations in the Qumran area between 1951 and 1956 further defined the age of the scrolls. The ruins of fairly large communal buildings were discovered. Evidence

was found that the buildings had been occupied in several phases between about 180 B.C. and A.D. 67 or 68, when the Roman general Vespasian's legions destroyed the settlement while on the march from Jericho to Jerusalem. The inhabitants presumably hid scrolls from their library in nearby caves before the communal center was destroyed.

Soon after the discovery of the scrolls in 1947, when it became apparent that they could be sold for substantial amounts, the Bedouin tribesmen in the area scoured the countryside for other caves that might contain ancient treasures. Some 200 caves were searched. In addition to Cave I at Qumran, another 10 caves in the area were found to contain written material; the richest find was in Cave IV. Pottery similar to the jars in the first cave was found in 25 other caves.

Most of the manuscripts are long leather sheets that were made by stitching hides together. The needle marks are clearly recognizable even where the sinew thread has rotted away. The letters were inked on the porous side of the leather (the side from which the hair had been shaved). There are horizontal lines ruled into the leather, probably with a bone stylus, for guiding the penman. In some cases vertical lines set the written column apart from the margins. The writing is in Hebrew square letters, forerunners of the modern Hebrew alphabet. The scrolls differ in length; the longest is estimated to have been about 50 feet long when it was fully unrolled. They seem to have two standard widths: the scrolls in one group measure about eight inches and those in the other about 12 inches. There were two corresponding types of jar that served as scroll receptacles, each with a capacity of three or four scrolls. One can visualize rows of

RULE OF THE COVENANT set out the regulations of the dissident group at Qumran, who constituted themselves as the "New Covenant" at the beginning of the second century B.C. A passage from the Rule scroll is shown on the opposite page. The square Hebrew letters are forerunners of the modern Hebrew alphabet. The writing is read from right to left.



DEAD SEA SCROLLS were discovered near Qumran in a mountainous desert area of Judea about seven miles south of Jericho and 15 miles east of Jerusalem and Bethlehem.



SOURCE OF THE SCROLLS was a settlement of dissident Jews near the Qumran wadi (a rainy-season riverbed) on the northwestern shore of the Dead Sea, which is 1,286 feet below sea level. The richest finds of scrolls and scroll fragments were in Cave I and in Cave IV.

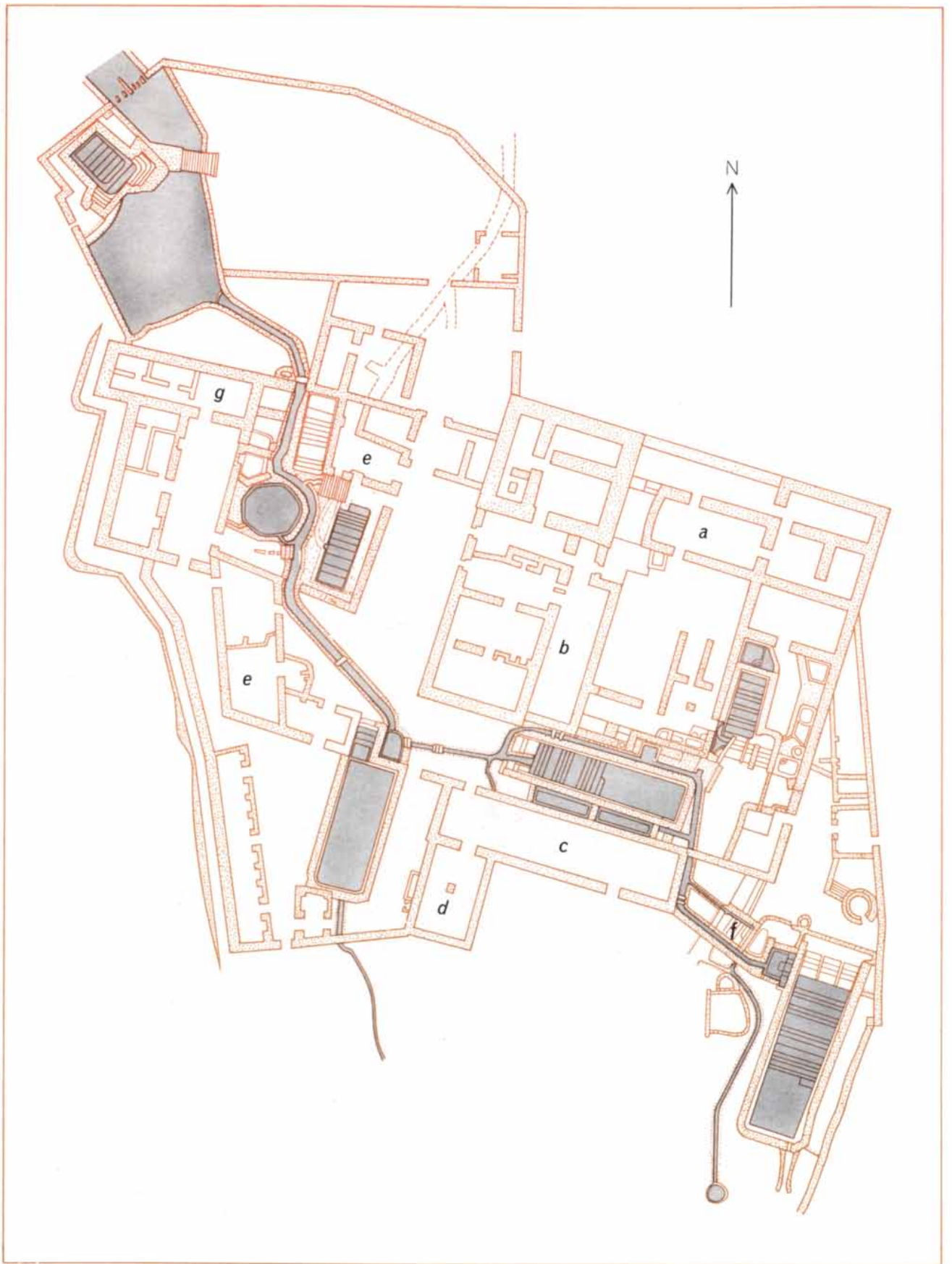
these jars standing next to one another in an ancient library, somewhat resembling the Mesopotamian archive of clay tablets stored in baskets.

The first lot of scrolls turned out to be fairly representative of three categories of literature in the settlement's library: (1) biblical manuscripts, (2) Apocrypha and pseudepigrapha (nonscriptural religious writings) and (3) literature specific to the communal group. Subsequent scroll discoveries have added to the collection of biblical manuscripts, which made up about a quarter of the library. With the exception of the Book of Esther, all the Old Testament writings are represented in the Qumran library, some by only a few fragments and some by almost complete scrolls.

On the whole the writings in the biblical, Apocryphal and pseudepigraphic scrolls are not specifically related to the Qumran settlement; rather they are representative of a type of literature that had a fairly wide circulation among Jews at the time. Four of the scrolls from Cave I, however, are prime examples of the writings of the people who lived at Qumran.

The first of these scrolls, the Peshar Habakkuk (or, as it is sometimes called, the Habakkuk commentary), paraphrases the sayings of the Old Testament prophet Habakkuk. It offers valuable, although somewhat veiled, information about certain phases in the history of the Qumran settlers. The second scroll, the Hodayoth, is a collection of individual thanksgiving psalms by an unidentified author and reflects much of the group's specific beliefs. The theology of the Qumran settlement was strongly eschatological: it was preoccupied not merely with daily morality but preponderantly with ultimate matters such as death and immortality. This is brought out in the War Scroll, which portrays in detail the final battle where the Sons of Light vanquish the Sons of Darkness. In the fourth scroll, the Rule of the Covenant, the organization and the penal code of the group is set forth.

The scrolls tell the story of a group of dissident Jews who had constituted themselves as the "New Covenant" at the beginning of the second century B.C. They established their communal center at a seemingly uninhabitable site near the Dead Sea. Their ideology was basically egalitarian and their social structure rigidly hierarchical; the social fabric had a martial coloring similar to that of the medieval military and paramilitary ecclesiastic orders. The Qumran settlers



GROUND PLAN of the Qumran communal buildings is based on the findings of archaeologists who excavated the ruins between 1951 and 1956. The complex included a kitchen (a), a scriptorium (b), an assembly and banquet hall (c) with an adjacent pantry (d),

workshops (e), an elaborate system of cisterns and water conduits (shown in gray) and what appears to be a ritual bath (f). Coins found in the ruins (g) and other artifacts show that the settlement had several phases of occupation between 180 B.C. and A.D. 68.

saw themselves as God's army preparing for a preordained battle against all evildoers that was to precede the establishment of their own messianic kingdom on earth. Their designations of themselves often include the Hebrew word *yahad*, which means "unity," "community," "in common." Rendered into English, some of the designations are: Commune of the Sons of Light, Commune of the Enlightened, Commune of the Sons of God, and Commune of the Saints (or Pious).

These appellations have almost no parallel in rabbinic, Hellenistic and early Christian writings. The epithet "Commune of the Sons of Zadok," however, was immediately recognized by scholars. It was connected with the Zadokite Fragments found in the *genizah* (a storage room for discarded books and documents) of a synagogue in Fustat, near Cairo, in the 1880's. These copies of the Zadokite documents proved to be of medieval origin, but their similarity in nomenclature and contents to the writings in the Rule of the Covenant scroll from Qumran suggested a fundamental link between the two sets of documents. This supposition became a certainty when several more fragments of the Zadokite work were found later at Qumran.

From the very beginning it was ob-

vious that the contents of the Qumran scrolls did not conform to orthodox rabbinic Judaism. Even so, scholars resisted the idea that the scrolls could have come from an unknown group of Jewish dissenters whose existence had not been recorded by the historiographers of that era. The scrolls did not offer unequivocal clues to the identity of their authors, and so scholars attempted to find an answer by taking the comparative approach.

The Covenanters' theology and literature were compared with what was known about the beliefs and writings of other nonconformist Jewish groups at that time: the Essenes, the Sadducees, the Zealots, the Samaritans and the early Christians. Parallels between the Covenanters and other dissenting Jewish groups certainly exist; indeed, it would be surprising if they did not, since the groups were both dissenting and Jewish. It is nonetheless precarious to make causal connections between groups on such a basis.

It must be considered methodologically unsound to try to identify the Qumran Covenanters by comparing them with other Jewish sects about which much less information is available. If an identification by comparison is to be attempted at all, the firsthand Qumran

material should be used to check, verify and complement the secondhand reports on similar sects in rabbinic, Hellenistic and Christian sources.

Indeed, methodological considerations require that a self-contained analysis of the Qumran material should take precedence over the comparative approach. Rather than obscuring the identity of the Covenanters by emphasizing singular features they share with sects such as the Essenes or with the nascent Christians, we should concentrate on establishing the social characteristics of the Covenanters themselves.

Taking this approach, the founding members of the Qumran community can best be defined as a group of dissident Jews who fiercely believed in the early coming of a Messiah. They were convinced that a literal interpretation of a biblical prophecy told them exactly when their millennium would arrive. They took at full value the utterances of the prophet Ezekiel, who on the eve of a Babylonian siege of Jerusalem predicted that Israel would suffer 390 years of iniquity and punishment. It seems that the Covenanters read a message of hope into the prophet's oracle of wrath; they interpreted it to mean that 390 years after Jerusalem's fall to the Babylonians



VIEW OF THE RUINS AT QUMRAN, looking south to the Dead Sea, shows the massive stone walls that were used to construct the buildings. The settlement was founded by a Jewish group that

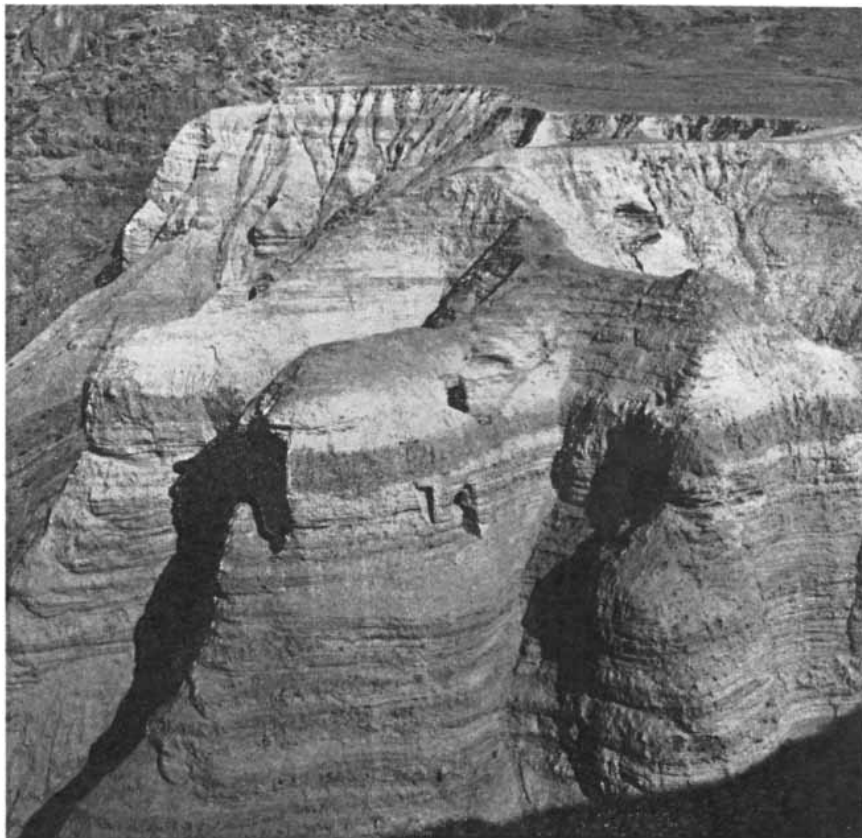
moved into the désert to prepare for an imminent millennium that never came. The isolated group evolved into an institutionalized order that designated itself as the Commune of the Sons of Light.

in 587/586 B.C. the fortunes of Israel would be restored. In anticipation of this great event they moved from Jerusalem into the Judean wilderness to prepare in soul and body for their imminent salvation. The emergence of the Qumran community in about 180 B.C. fits closely with their predicted date for the coming of the millennium.

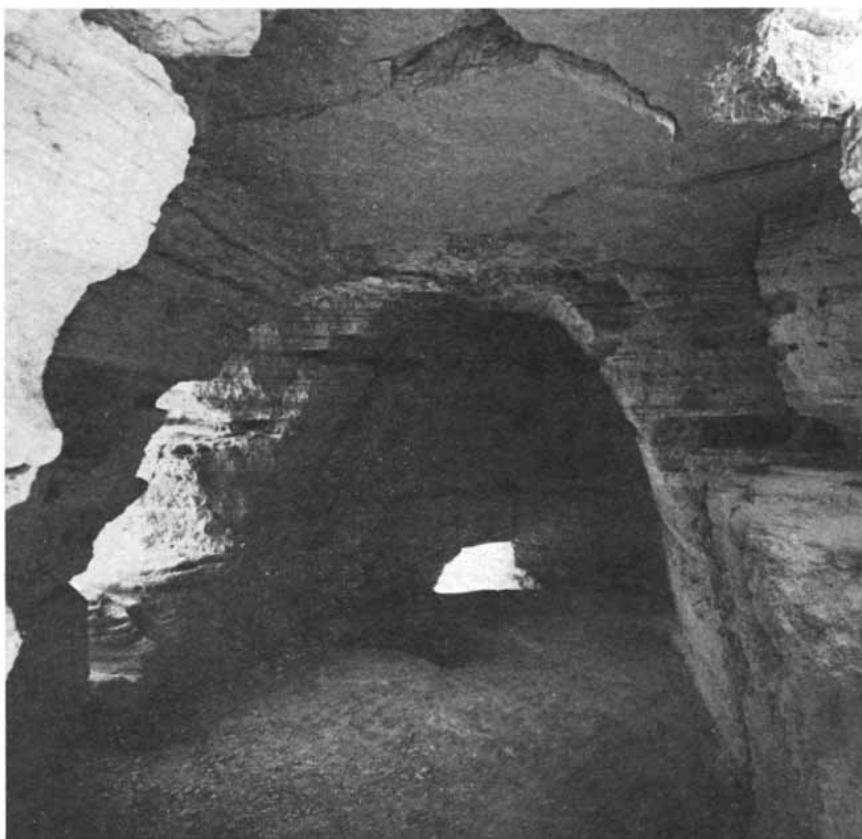
The Covenanters' conviction that the exact details of the forthcoming eschatological drama had been imparted to them alone gave them an intense consciousness of being an elite (which their contemporaries undoubtedly saw as unwarranted arrogance). They viewed themselves as a divinely appointed elect. The "New Covenant" they had established in the desert had been envisioned by the prophet Jeremiah: "Behold, the days come, saith the Lord, that I will make a new covenant with the house of Israel and with the house of Judah." The New Covenanters had seen the light. They were the Sons of Light in whom the divine promise would be finally realized, as it is specified in the Old Testament prophecies. Their communal life was a reactivation of the life of biblical Israel before the destruction of Jerusalem by the Babylonians.

The theology and the social structure of the Qumran community was stressed between an idealized concept of biblical Israel and a utopian vision of a future world that was to be a glorified restoration of the biblical past. In the Covenanters' writings facts and fancy, historical realism and wishful thinking coalesced indiscriminately. Once the fantastic nature of the Qumran writings is fully appreciated, one can see that it is difficult to establish an exact timetable of the Covenanters' internal history. Only some phases of the community's development can be inferred.

According to the Zadokite documents, when the millennium failed to arrive at the appointed time the founding members of the group were like blind men groping in the dark. They waited 20 years for the Messiah who, like Godot in Samuel Beckett's play, never came. Then from their midst arose a Moses-like figure, the Teacher of Righteousness who was divinely appointed to lead the group out of its confusion. There are few details in the Qumran writings about the Teacher's origins and life. It is stated that before he died he suffered afflictions and bodily harm. The reference gave rise to the assumption by some scholars that the Teacher died as a martyr, which in turn suggested a parallel with Jesus Christ. This speculation is untenable. There is little in the scrolls



ENTRANCE TO CAVE IV can be seen on the face of the cliff in the center of the photograph. The cave is less than one mile west of the ruins of the settlement at Qumran.



INTERIOR OF CAVE IV contained many scroll fragments. It is thought scrolls from the Qumran library were hidden in the cave to prevent their destruction by Roman legions.

that can be construed to indicate that the Teacher did not die a natural death, and absolutely nothing to suggest that his death ever attained a spiritual meaning for the Covenanters.

The Teacher was born out of the emotional stress that came from the Covenanters' unrealized hopes for the millennium. His very appellation implies that he should be viewed not as an innovator of new religious precepts but rather as an inspired interpreter who transformed the group's anarchistic utopian messianism into a viable religious and social system. Under his guidance the amorphous millennialist group crystallized into an institutionalized order: the New Covenant. The antiestablishment anarchists formed an establishment of their own, and it soon surpassed the old one in its social rigidity and legalistic exactitude.

The elite consciousness of the founding members was reinforced by a tightly knit hierarchical social structure that evolved in the isolated community. In order to maintain a high level of group cohesion the Covenanters had an intricate system of internal supervision. Each member was supervised by his peers and also by those of higher rank. In assembly discussions and even in the seating arrangements of the community hall seniority prerogatives were rigidly observed. An ideological collectivism facilitated the workings of this system of mutual control. Little was left to the discretion of the individual.

The slightest deviation from the prescribed standards, for example disobedience to higher-ranking members, speaking out of turn or spitting on the floor during assembly, brought severe penalties. The penalties consisted in the

wrongdoer's daily rations' being cut by a third or a half for a specified period. Since members turned all their property over to the commune when they joined, there was not much in the way of other sources of food. A severer punishment was temporary expulsion from the commune and a ban on contact with other members. Josephus, the Jewish-Hellenistic historian, gives a similar picture of the Essenes' communal organization and way of life at En-gedi. He relates that a member who had been expelled into the wilderness would suffer severe hardships and that some would starve to death. In this detail as in many other matters relating to the Essenes, however, Josephus' account appears to be based on second-hand evidence and should be taken with a grain of salt.

The Essenes' central establishment, like that of the Covenanters, consisted exclusively of men who had vowed celibacy. Outside the central group both sects allowed marriage and admitted married people to membership. There are scattered references to married Essenes in some ancient sources, and marriage in the Covenanters' community is corroborated by the detailed series of family laws in the Zadokite documents. These laws seemed to apply to members who lived in camps outside the monastic center at Qumran. The exact nature of the Covenanters' celibacy, or for that matter the Essenes', cannot be unequivocally determined. Essene monasticism reputedly entailed lifelong celibacy; the sect relied on the adoption of orphans to provide for the continuity of the community. There is evidence that at Qumran temporary celibacy was prescribed for all male members, with possibly a lifelong commitment by a select few who had been singled out for leadership positions.

In the Qumran system the life roles of a man were prescribed by his age. A male born of Covenanter parents entered the "youth echelon" at age 10. He applied to become a member of the commune at age 20, and at that time he was allowed to establish a family. He remained under probation for three years. If he passed this stage successfully, then at 25 he became an active participant in the commune's civic and cultic affairs. At 30 he became a full-fledged soldier-member, ready to discharge military and communal tasks according to his age and abilities. Retirement from active service came at 60. The setting of the age of marriage at 20 and the age of military duty at 30 thus provided a period of 10 years for creating a family. If this was



TWO TYPES OF CERAMIC JARS served as protective containers for the leather scrolls in the Qumran library. Each jar was designed to hold three or four tightly rolled scrolls.

the way the system worked, it would have guaranteed the continuity of the Covenanters' commune by natural propagation rather than by adoption. Celibacy for only part of a member's life must have acted as a kind of social safety valve. The arrangement provided the commune with a corps of dedicated members who had voluntarily renounced procreation after having established a family. The separation of family roles and communal roles probably diminished the tensions and conflicts between familial and communal obligations that are latent in most collective social systems.

The deliberate assignment of roles by age also ensured a measure of social mobility and advancement in the commune's hierarchy and helped to absorb some of the grievances that would normally arise in such a rigid social structure. The enforced retirement from active service at age 60 and the periodic induction of novices kept the social system open-ended. From the time the novice joined he knew that although he was starting out as a "backbencher," he would automatically end up in the front row if he passed the annual muster during his first three years of probation. If he happened to excel in the performance of his duties, he had a good chance of becoming a member of the governing council or of attaining the rank of supervisor. One cannot but marvel at this sophisticated combination of a basic egalitarianism, a rigid hierarchical social structure and a built-in provision for change in the individual's role.

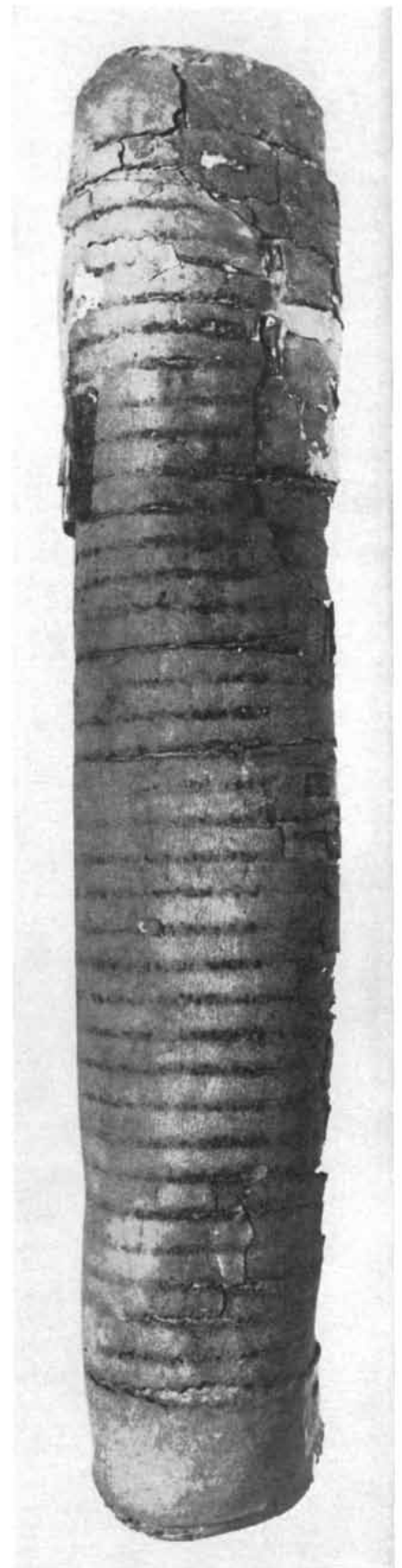
As the Covenanters' ideology consolidated into institutionalized heterodoxy, the orthodox Jewish authorities began to take steps to repress the movement. It seems that the rabbinic leaders took action only at this stage of the Covenanters' development; earlier they had apparently viewed the community without alarm. At that time Judaism was surprisingly liberal toward controversies about theology and ritual. Freedom of opinion was seldom curbed; disputation was the lifeblood of the rabbinic academies. In order to understand the Jewish leaders' change of attitude, one must bear in mind that those who held dissident views on the legal foundations of certain practices were expected to abide by the majority decision or by the authoritative decree in their observance of the practice. If a dissenting sage whose point of view had been overruled continued to act in an unorthodox way, he was declared a rebellious elder and became liable to be sentenced to death by a Jewish court. When the schismatic beliefs of

the Covenanters were made the actual basis of their institutions, they passed from the status of admissible disputants to being punishable proponents of heterodox beliefs and pursuers of a sectarian way.

A decisive factor in the Covenanters' final separation from Jewish society was their adherence to a solar calendar that exceeded the Jewish lunar calendar by an average of 10 days a year. The calendar of the Covenanters had some features worthy of mention. It had a total of 364 days divided into four three-month quarters, the months numbering 30, 30 and 31 days and each quarter having exactly 13 weeks. In this arrangement any date in a given quarter always fell on the same day of the week. The first day of the first month—and therefore the first day of the fourth, seventh and tenth month—invariably fell on a Wednesday, the day of the week on which God had created the luminaries that are the foundation of any time reckoning. Moreover, since by biblical injunction the two major pilgrimage festivals, Passover and Tabernacles, are to be observed on the 15th of the first and seventh month, in the Covenanters' calendar they would always fall on Wednesday. This is also the case with the third pilgrimage festival, Pentecost, which is fixed on the 15th of the third month.

The importance of a common calendar as a prime socializing agent is illustrated by the controversy generated by the Qumran calendar. The distinctive time-reckoning of the Covenanters probably had an even more disruptive effect on their relations with outsiders than their deviant theological doctrines. The Covenanters' specific calendar completely isolated them from their fellow Jews, whose pace of life was harnessed to the lunar cycle. It was impossible for the Covenanters to participate concurrently in the festivals with other Jews. The calendar is possibly the most conspicuous indicator of the Covenanters' defiance of the Jewish authorities.

From the Qumran manuscripts we know that the leaders of Judaism actively opposed the secession of the Covenanters. For their part the Covenanters expressed their resentment of the top-ranking high priest in the Temple at Jerusalem, whom they called the "Wicked Priest." He became the special antagonist of their community and of the Teacher of Righteousness. According to the story in the Peshar Habakkuk, the Wicked Priest pursued the Teacher to his place of "exile," that is, Qumran, and



GENESIS APOCRYPHON scroll, which is shown here before it was opened for study, is one of the documents that was found in Cave I. The scroll is written in Aramaic and is a paraphrase of the book of Genesis.

forced the Covenanters to desecrate the holiest season by making them eat and drink on their solemn Day of Fast.

Even though the Qumran calendar is imperfect, it was admirably practical. It was not, however, invented by the Qumran community. Reformists and revisionists such as the Covenanters seldom proclaim their ideas to be innovative; rather they propagate their ideas as the embodiment of traditional concepts that have been adulterated by those in power. There is good evidence for assuming that the Covenanters' calendar had its roots in the Old Testament. When the calendar is taken as a grid for charting biblical dates, for instance the account of the Israelites' journey in the desert after the Exodus, it is found that the people usually set out from the encampment on a Sunday and never traveled on a Saturday (the Jewish holy day) or on a festival. No other calendar system gives such an accurate indication of the faithful observance of the days of rest by the ancient Hebrews. This striking correspondence cannot be accidental, and it is

likely that the Covenanters preserved (or possibly elected) a calendrical system they could hold out as proof that they possessed the living heritage of the biblical past, and that it was they who were the true biblical Israel.

The Covenanters' self-image of being representatives of biblical Israel is the key to understanding their history, ideology and eschatology. Their concepts, literary language and motifs are closely related to those expressed in the Old Testament books of Deutero-Isaiah, Haggai, Zechariah, Malachi, Ezra and Nehemiah. The Covenanters conceived of themselves as the genuine successors of the postexilic Israelites. Viewed in this light, some of the central life experiences of the Covenanters gain a symbolic dimension. The retreat into the desert was a vicarious realization of the desert visions expressed in Deutero-Isaiah. Both retreats were conceived as an indispensable prelude to a future salvation. For the Covenanters the desert phase was the hiatus between their de-

parture from Jerusalem and their eschatological capture of the city. They saw their history as a reenactment of the various phases of Israel's history: exodus from Egypt, sojourn in the desert, conquest of Canaan.

The hostile intervention of the high priest and the unanticipated deferral of the millennium brought about a reformulation of the Covenanters' historical concept: they would have to vanquish the forces that opposed the realization of their eschatological destiny before the New Jerusalem could be achieved. The eschatological battle that would shake the foundations of the universe is portrayed in the Qumran War Scroll along the lines of Ezekiel's vision of Gog and Magog and the apocalyptic engagements foreseen in the Book of Daniel.

The last war is to be fought for 49 years with a cease-fire every seventh (that is, sabbatical) year. The outcome is never in doubt. The Sons of Darkness conveniently take the onslaughts of the Sons of Light lying down. In the year of jubilee (the 50th year) the Covenanters consummate their victory with the conquest of the Holy City (Jerusalem). There they reestablish the Temple and appoint the priests of the House of Zadok, the only priests they consider legitimate.

The description in the War Scroll of the apocalyptic battle provides clues to the messianic ideas of the Covenanters. Again their adherence to biblical patterns is clearly recognizable. In the hands of the Covenanters the concept of the Messiah turns up as a distinctive dichotomy: a Messiah of Israel, associated with King David, and a Messiah of the House of Aaron. This duality of a lay Messiah (Davidic) and a priestly Messiah (Aaronic) reflects the biblical Judaic conception of a dualistic structure of government. This conception is found in the sayings of the prophet Zechariah, who demanded a clear-cut demarcation of jurisdiction between the monarchy and the priesthood.

A considerable number of Qumran manuscripts have not yet been completely edited, and therefore many pertinent issues in Qumran history and theology remain open. After a quarter of a century of scholarly analysis, however, the importance of the Qumran scrolls can be assayed. Before their discovery all our knowledge of ideological trends, literary achievements and forms of social and religious organization in the two and a half centuries before the destruction of the Second Temple in Jerusalem by the Romans in A.D. 70 came from Jewish and Christian chroniclers who



OPENING FRAGILE SCROLLS was an arduous task. After they were opened the scrolls were flattened between sheets of glass. The tattered first column of the second sheet of the Hodayoth scroll, a collection of thanksgiving psalms, is shown here. This scroll and others from Cave I are housed in the Shrine of the Book at the Israel Museum in Jerusalem.

DAYS OF THE WEEK

	S	M	T	W	T	F	S
				1	2	3	4
I	5	6	7	8	9	10	11
IV	12	13	14	15	16	17	18
VII	19	20	21	22	23	24	25
X	26	27	28	29	30	1	2
II	3	4	5	6	7	8	9
V	10	11	12	13	14	15	16
VIII	17	18	19	20	21	22	23
XI	24	25	26	27	28	29	30
III	1	2	3	4	5	6	7
VI	8	9	10	11	12	13	14
IX	15	16	17	18	19	20	21
XII	22	23	24	25	26	27	28
	29	30	31				

SOLAR CALENDAR followed by the New Covenanters may have had its roots in the Old Testament. A year consisted of 364 days divided into four identical three-month quarters of 91 days each. Any date in a given quarter always fell on the same day of the week. The New Covenanters held out their calendar as proof that they were the living heritage of the true biblical Israelites.

wrote about this period retrospectively. Most of these writings are found in two monolithic sources. One is the literature of normative Judaism: the Mishnah, the Talmud and the Midrash. The other source is the writings of nascent Christianity: the New Testament and the works of early church fathers. It is natural that the synagogue and the church perpetuated only the ideas that were well within the mainstream of accepted and orthodox concepts. Dissenting trends were either intentionally suppressed or simply not handed down in writing. Although we have the Apocrypha, pseudepigrapha and Jewish-Hellenistic writings that to a certain degree express theological notions that differ from normative Jewish and Christian ideas, they cannot compare with the rich literature of the synagogue and the church in breadth and depth of information. With the discovery of the Qumran library modern scholars for the first time could read material that originated in the dark age before the beginning of the Christian Era. The Qumran documents help to fill, at least in part, the blank pages between the two Testaments.

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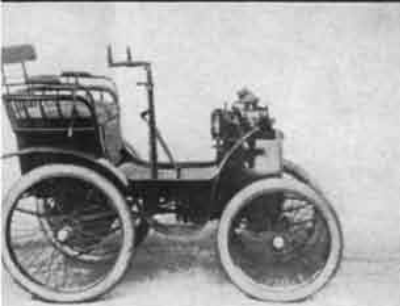
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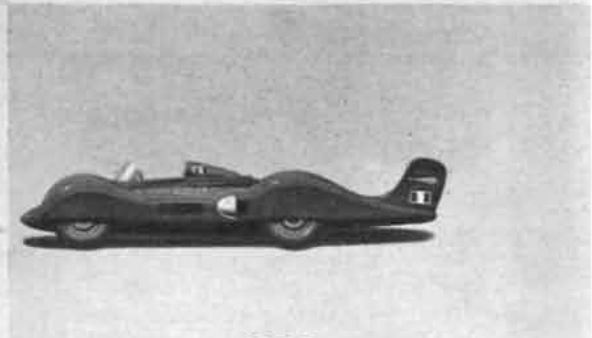
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PROSTAGLANDINS

These recently isolated hormone-like substances show much clinical promise. They affect a wide range of physiological processes, from the contraction of the uterus to secretion from the stomach wall

by John E. Pike

In the early 1930's several investigators studying human semen and animal seminal tissues discovered that these materials contained substances showing high physiological potency. Two gynecologists in New York, Raphael Kurzrok and Charles C. Lieb, examining the effects of fresh semen on strips of uterus from hysterectomized women patients, found that the seminal fluid caused the uterine tissue to relax or contract, depending on whether the woman was fertile (having borne children) or was sterile. At about the same time Maurice W. Goldblatt in England and Ulf S. von Euler in Sweden obtained other striking effects in experiments with human semen and with extracts from the seminal vesicular gland of sheep. They reported that the active substance could stimulate muscle tissue to contract or, on injection into an animal, could produce sharp lowering of the blood pressure. To this previously unknown, remarkably potent material von Euler gave the name prostaglandin.

Actually the term was a misnomer. The active substances had come not from the prostate gland but from the seminal vesicles, glands that also contribute to the semen. It was eventually learned that "prostaglandins" could be found in other body fluids and tissues, including the menstrual fluid of women. The prostaglandins are now known to be a family of substances showing a wide diversity of biological effects. They give promise of pharmacological uses in many medical areas. Although they resemble other known hormones in their dramatic effects, chemically they are a quite different class of compounds. Von Euler deduced from his investigations, and studies have since confirmed, that the prostaglandins are fatty acids. This was a considerable surprise, as fatty acids had not previously been suspected

of playing the kind of role the prostaglandins are now observed to perform.

For some 20 years after the original discovery of the prostaglandins little was learned about their chemistry or their specific properties. One of the reasons is that the body produces these highly potent substances in very small quantities; for example, a man normally synthesizes only about a tenth of a milligram per day of two of the most important prostaglandins. Furthermore, prostaglandins are rapidly broken down in the body by catabolic enzymes. Consequently the amount in the tissues is so small that the prostaglandins could not be obtained in quantity or studied chemically until refined techniques were developed for isolating and analyzing them.

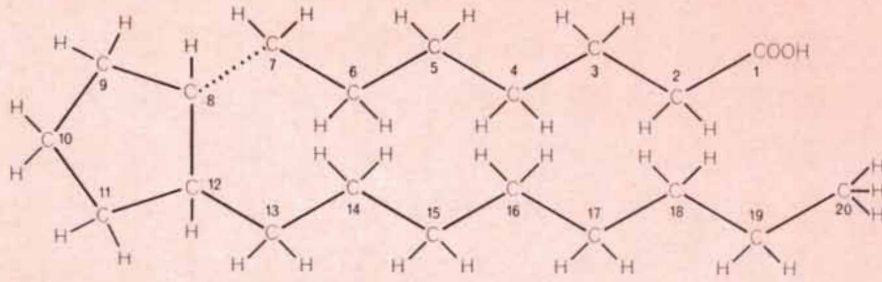
Interest in the prostaglandins grew, however, as extracts of crude acidic lipids (fatty substances) obtained from a variety of other sources proved to owe their biological activity to their prostaglandin content. By the late 1950's biochemists began to achieve success in purifying prostaglandins and examining their molecular structure. Sune Bergström and his associate Jan Sjövall in Sweden crystallized two of these substances, called PGE₁ and PGF₁-alpha. Working with minute amounts, they were able to decipher the structure of the two compounds, including some details of their three-dimensional configuration, with the help of gas chromatography, mass spectroscopy and X-ray analysis. With Bengt I. Samuelsson and other investigators they proceeded to work out the structure of several additional prostaglandins. They were all seen to be closely akin, and the distinctive biological effects of the various compounds in the family could be related systematically to their structural

variations [see illustration on opposite page].

It is now well established that the prostaglandins are 20-carbon carboxylic acids (that is, incorporating the COOH group) and that they are synthesized in the body from certain polyunsaturated fatty acids by the formation of a five-member ring and the incorporation of three oxygen atoms at certain positions [see top illustration on pages 86 and 87]. The enzymes involved in their synthesis have been found to be widely distributed in a variety of tissues, and the synthesis of prostaglandins has been demonstrated in many tissues, from the vesicular gland of sheep to the lung tissue of guinea pigs. It has also been established that after "primary" prostaglandins have been formed from fatty-acid precursors they can be converted into other members of the family by changing the primary structure.

The linking of the prostaglandins to polyunsaturated fatty acids provided clues to some of the prostaglandins' important functions. For example, one of the common fatty-acid precursors for prostaglandin is arachidonic acid. The main source of this substance is the phospholipids, which constitute a principal component of the cell membrane. Consequently it appears that the conversion of arachidonic acid to prostaglandin may play an important role in the regulation of the membrane's functions. It seems that the cell membrane is a prime site for the formation of the prostaglandins. Since there is no indication that any cells carry a store of prostaglandin, the likelihood is that the substance is produced by the membrane as needed. The tiny amount of prostaglandin we find in most tissues may therefore represent just the amount produced in the interval between the removal of the tissue and its preparation for extrac-

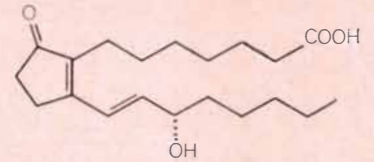
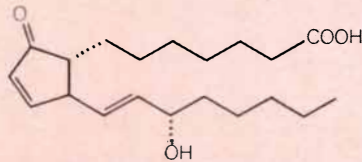
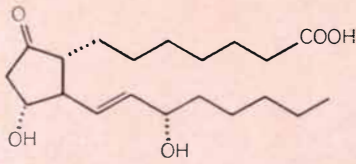
PROSTANOIC ACID



PGE₁

PGA₁

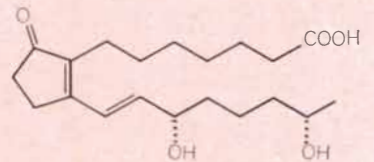
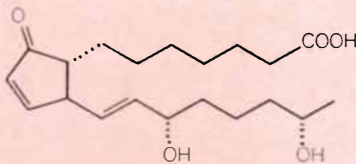
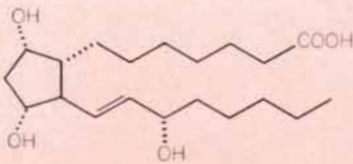
PGB₁



PGF₁-ALPHA

19-HYDROXY-PGA₁

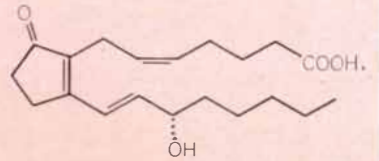
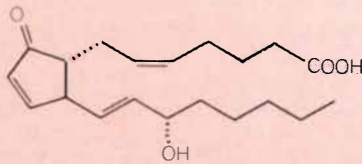
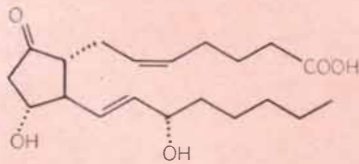
19-HYDROXY-PGB₁



PGE₂

PGA₂

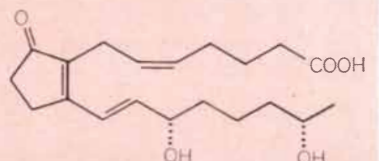
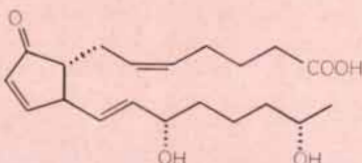
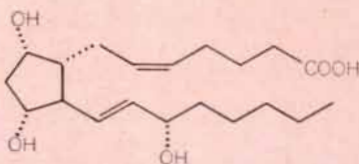
PGB₂



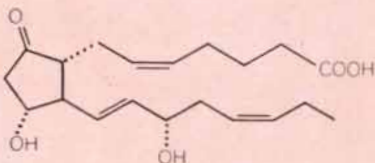
PGF₂-ALPHA

19-HYDROXY-PGA₂

19-HYDROXY-PGB₂

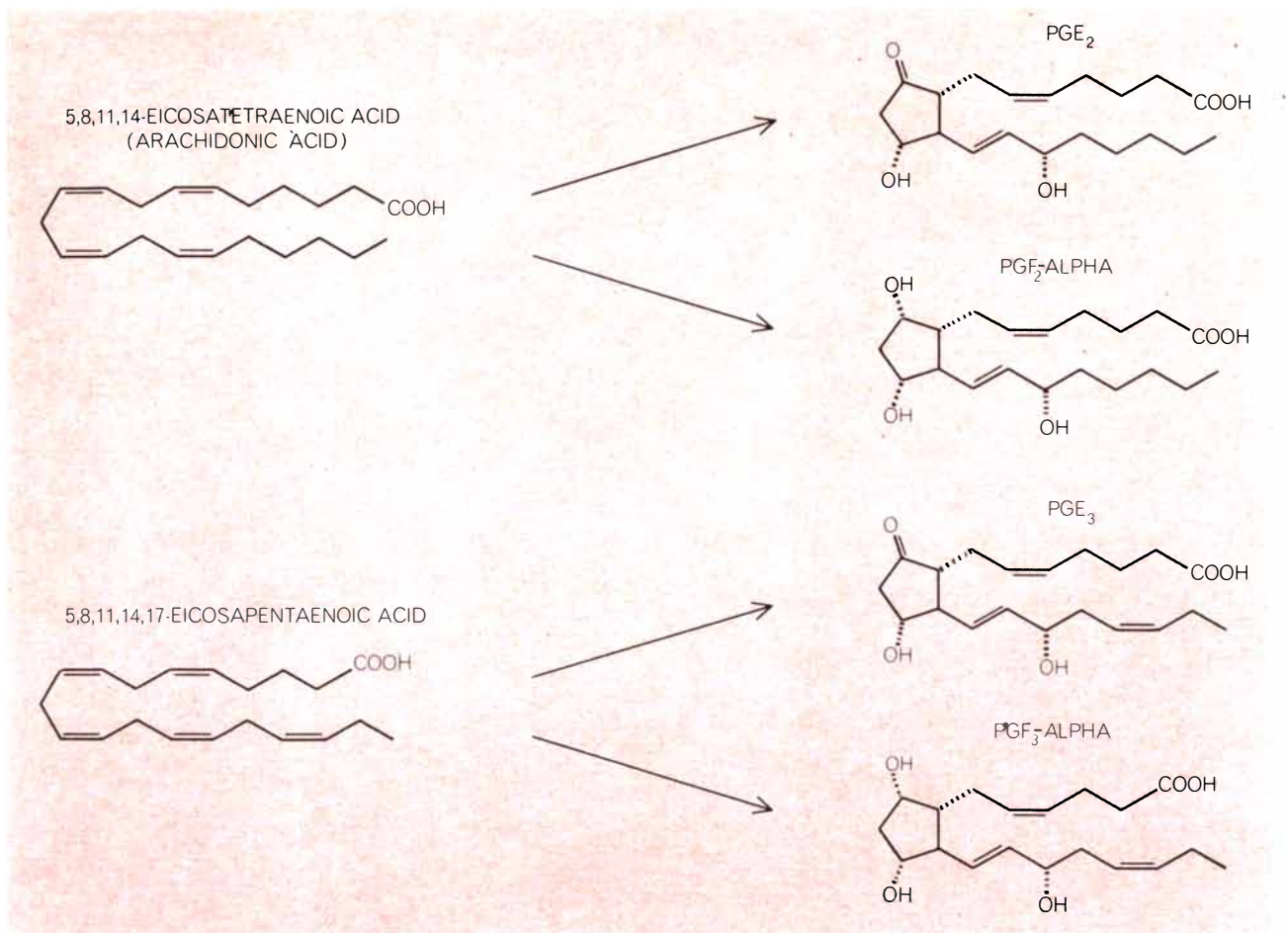


PGE₃



SOME IMPORTANT PROSTAGLANDINS are represented on this page by diagrams of their molecular structure. In general all the prostaglandins are variants of a basic 20-carbon carboxylic (COOH-bearing) fatty acid incorporating a five-member cyclopentane ring (*top*). Slight structural changes are responsible for quite distinct biological effects. Prostaglandins of the 1, 2 and 3 series respectively incorporate one, two and three double bonds.

The molecules designated PGE and PGF are called primary prostaglandins; the PGE structures have an oxygen atom (O) attached to the cyclopentane ring at carbon site 9, whereas the PGF structures have a hydroxyl (OH) group at the same site. Dehydration of a PGE molecule leads to either a PGA or a PGB compound. Broken bonds are those that extend below the plane of the cyclopentane ring. Hydrogen atoms are shown only in top diagram.



PROSTAGLANDINS ARE SYNTHESIZED in the body from certain polyunsaturated fatty acids by the formation of the five-member ring and the incorporation of three oxygen atoms at certain posi-

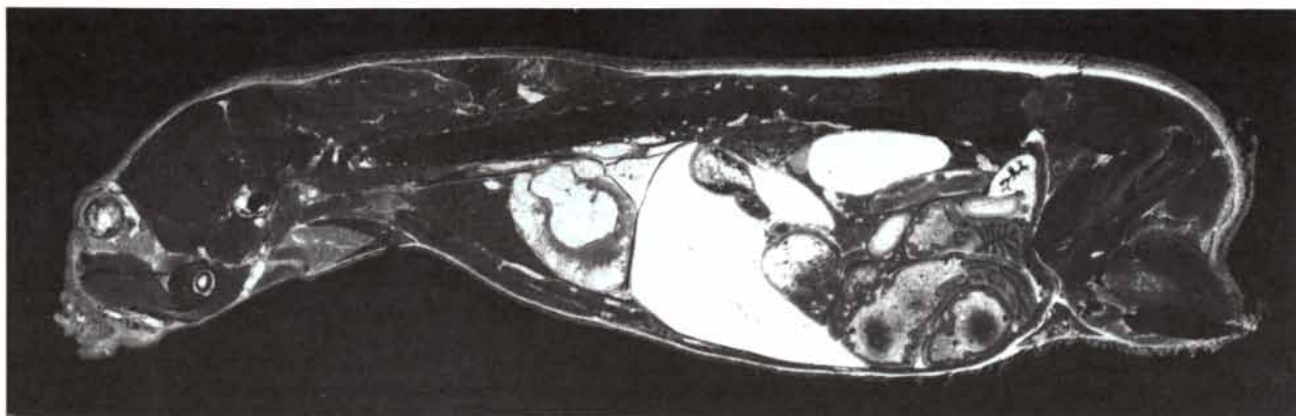
tions. For example, either PGE₂ or PGF₂-alpha can be formed directly from arachidonic acid (*top diagram at left*), whereas PGE₃ or PGF₃-alpha can be formed from a closely related fatty-acid pre-

tion of the substance. This amount typically is only about one microgram per gram of wet tissue. The seminal fluid of man or the extract from a seminal gland, on the other hand, usually contains 100 times this concentration of prostaglandins. Were it not for this rela-

tively rich source, the prostaglandins might still be awaiting discovery.

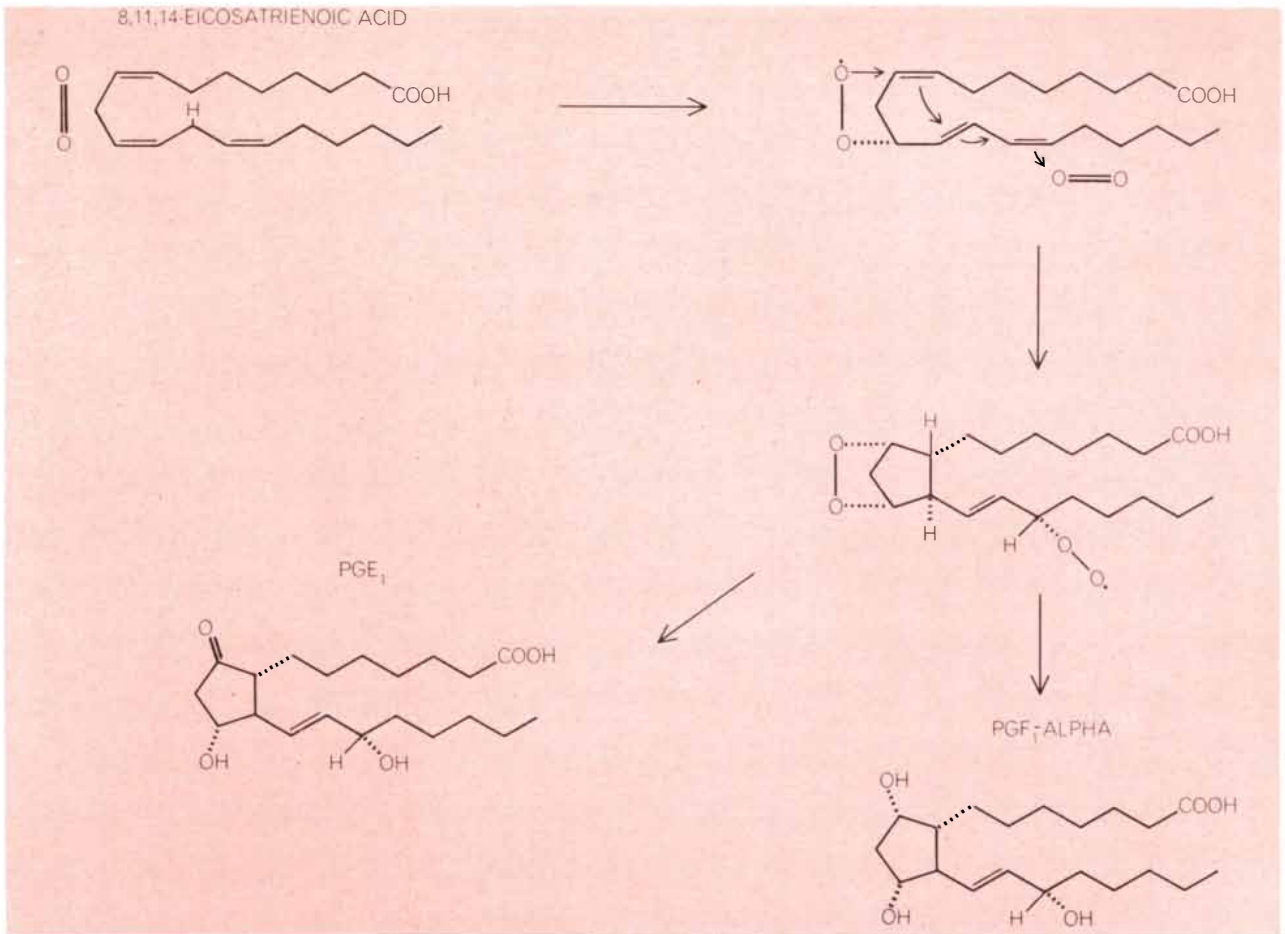
In addition to the involvement of the cell membrane, another fascinating question raised by the interrelation of fatty acids and prostaglandins has to do with diseases arising from dietary de-

ficiencies. It has long been known that certain polyunsaturated fatty acids are essential in a mammal's diet. Rats fed a fat-free diet suffer a stunting of growth, inability to reproduce and a characteristic skin lesion. The question arises: Could the administration of prostaglan-



RAPID DISTRIBUTION of prostaglandin in the body is demonstrated by these two autoradiograms made by Bengt I. Samuelsson of the Royal Veterinary College and Eskil Hanson of the Astra

Pharmaceutical Company, both in Stockholm. The autoradiograms show the distribution of radioactivity (*light areas*) in a female mouse (*left*) and a male mouse (*right*) 15 minutes after each had



cursor (bottom diagram at left). The probable mechanism of this type of biosynthesis is illustrated at the right. Two molecules of atmospheric oxygen provide three new oxygen atoms to a hypo-

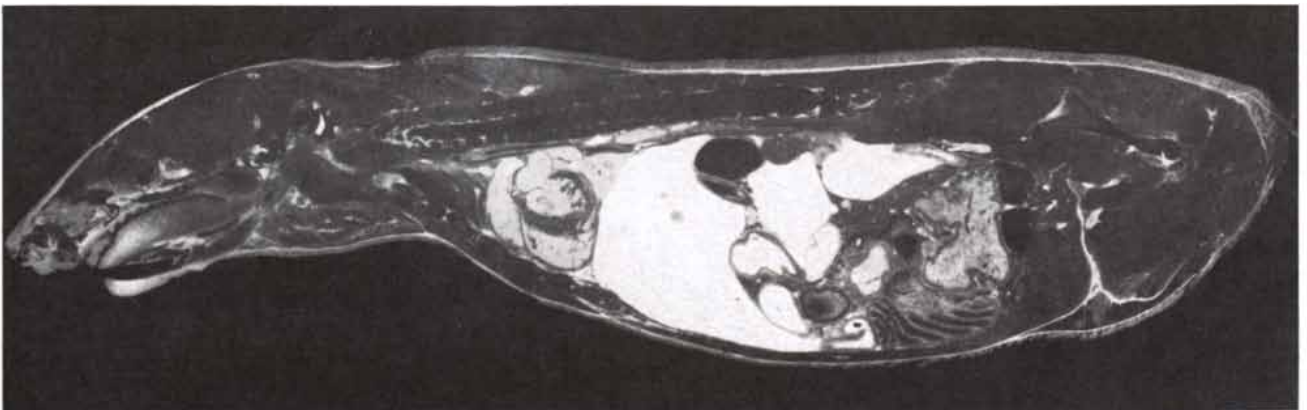
thetical intermediate structure, which then leads to either the PGE or the PGF structure. These primary structures can thereafter be converted into other members of the prostaglandin family.

dins remedy the fatty-acid deficiency? James R. Weeks of the Upjohn Company found that treatment of deficient rats with prostaglandins had no effect on the external signs of deficiency. David A. van Dorp and his co-workers in the Netherlands have found a clear connec-

tion, however, between prostaglandins and the fatty acids that are essential in the diet. Only those fatty acids that serve as precursors for the synthesis of prostaglandins are effective in curing rats that have been subjected to a fatty-acid deficiency. This suggests that some

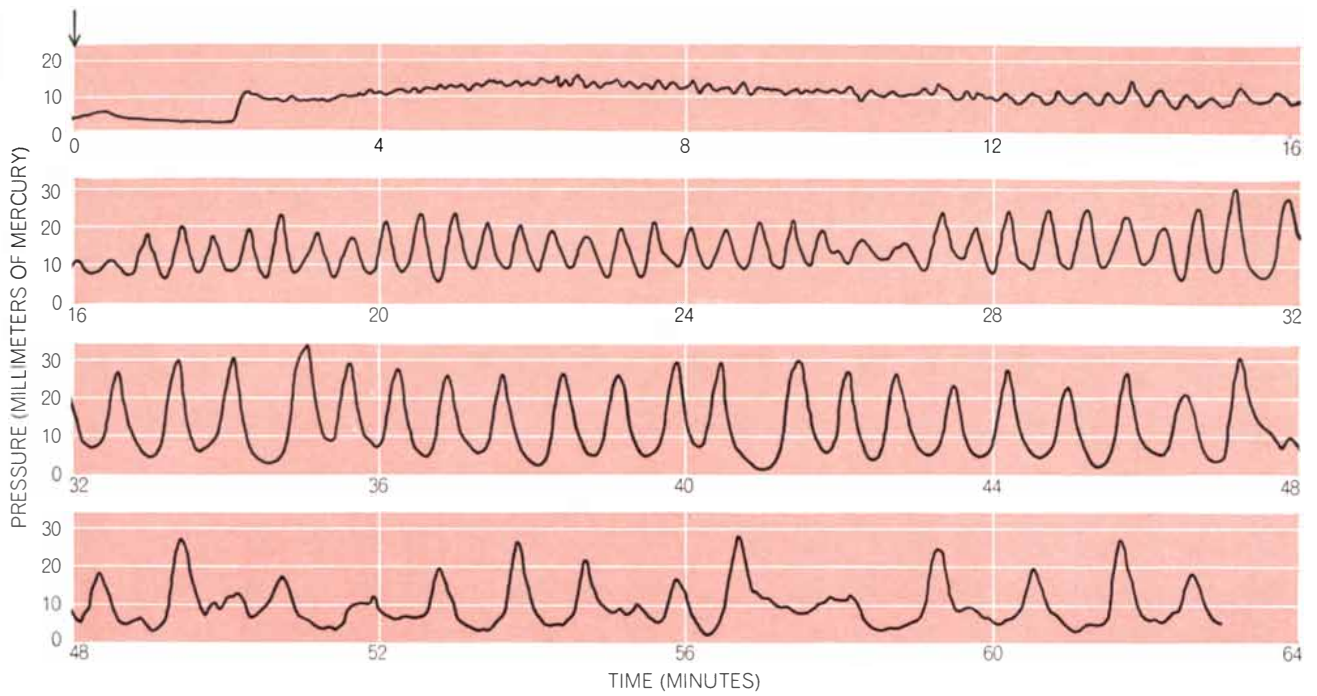
less obvious, perhaps metabolic, aspect of the deficiency disease in rats deprived of the essential fatty acids may be due in part to failure to synthesize necessary prostaglandins.

Once it was recognized that the prostaglandins are formed from fatty acids



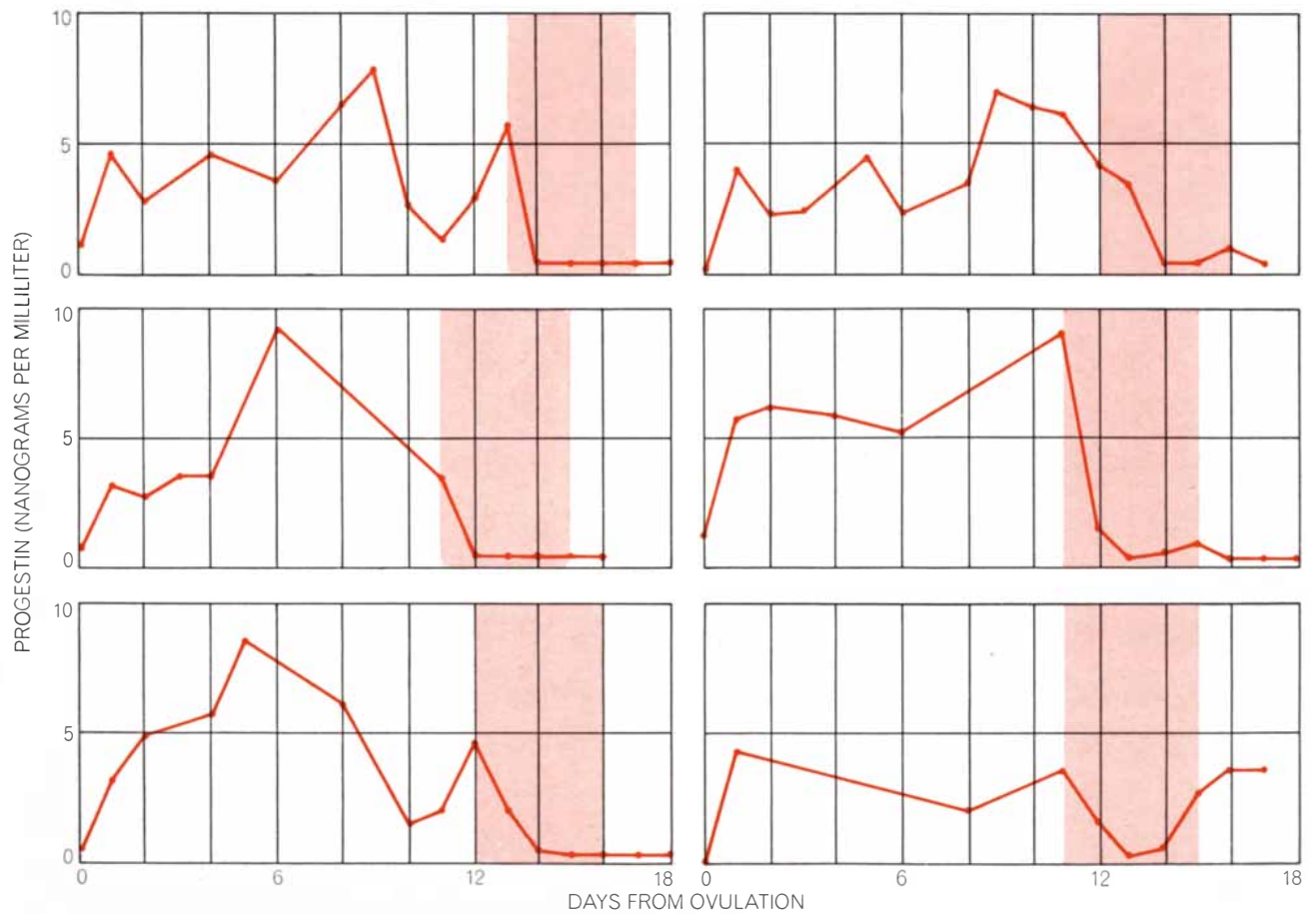
been injected intravenously with a small amount of radioactively labeled PGE₁. High concentrations of the prostaglandin are evident in the liver, the kidney and the subcutaneous connective tis-

sue of both animals and also in the uterus of the female and the thoracic duct of the male. The autoradiograms were made by placing a cross section of each animal on a radiation-sensitive plate.



STRIKING EFFECT of prostaglandins on the female reproductive system is evidenced by the fact that uterine contractions can be stimulated by a very low dose of either PGE_2 or $PGF_2\text{-alpha}$. This particular trace, divided into four parts, records pressure changes

in a monkey uterus following an injection of PGE_2 at the time indicated by the arrow. Prostaglandins have already been used to facilitate childbearing labor in several thousand women, and there are indications that they may be widely adopted for this purpose.



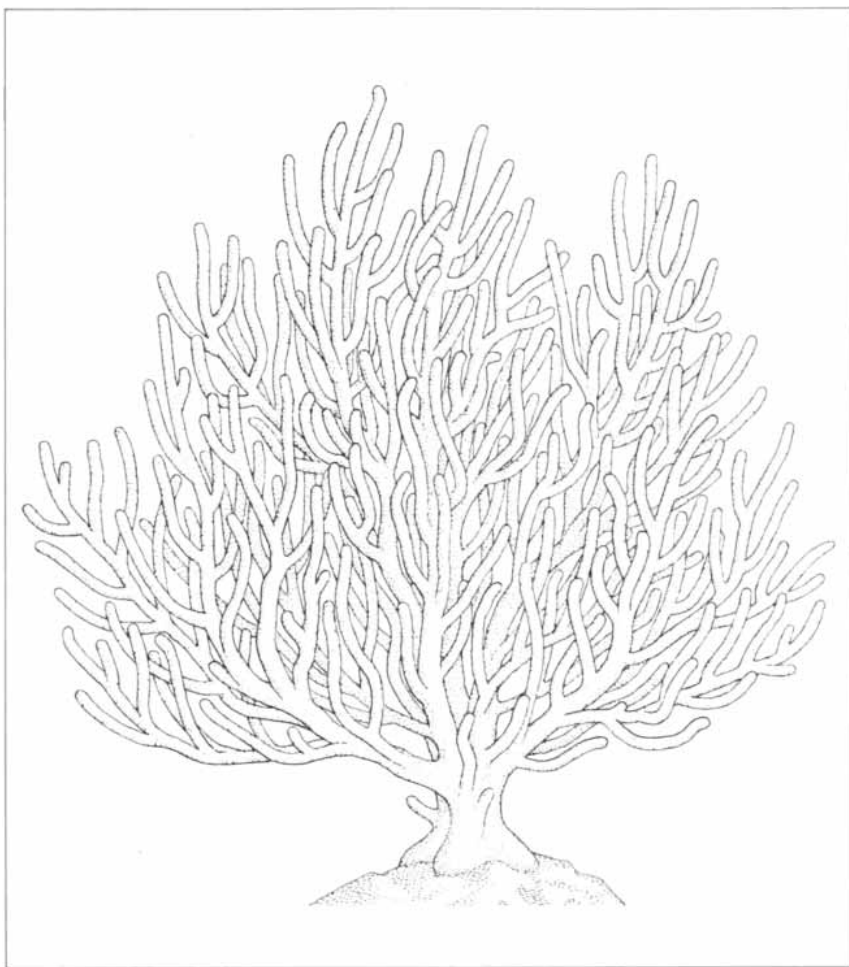
DRAMATIC REDUCTION in the secretion of progesterone by the ovaries of mated female monkeys followed the administration of $PGF_2\text{-alpha}$. In these graphs of the progesterin levels in six such monkeys the prostaglandin was administered during the periods

indicated by the colored bands. Since progesterone is needed to ensure implantation of a fertilized ovum in the wall of the uterus, there seems to be a strong possibility that prostaglandins may become important agents in helping to control population growth.

it became possible to turn to laboratory production of these scarce and expensive substances for experimental work. It was found that a fatty acid (gamma-linolenic acid) extracted from seeds of the borage plant (a European herb) could be converted into a polyunsaturated fatty acid that was a precursor for a prostaglandin biosynthesis. Enzymes for the biosynthesis were obtained from the seminal vesicular glands of sheep. This resort to artificial biosynthesis produced gram quantities of the prostaglandin and supported studies for several years. Recently chemists at the Upjohn Company and Elias J. Corey and his co-workers at Harvard University developed methods of total synthesis of prostaglandins from more common materials, so that the problem of supply of the substances for research is no longer so acute.

Incidentally, remarkably high concentrations of a prostaglandin isomer were found by Alfred J. Weinheimer and R. L. Spraggins of the University of Oklahoma in a type of coral, the sea whip or sea fan *Plexaura homomalla*, a primitive sessile animal found in coral reefs off the Florida coast. This isomer has been successfully converted to biologically important prostaglandins by Gordon Bundy, William P. Schneider and their co-workers at the Upjohn Company. Apparently prostaglandins once played more elementary roles than they do in mammals, and it is interesting to speculate on their origin and evolutionary development. Polyunsaturated fatty acids are absent in bacteria, but they do turn up in blue-green algae and some higher plants as well as in animals. The prostaglandins may represent an evolutionary step in which, thanks to the availability of molecular oxygen, these complex molecules were formed as agents for the regulatory functions of specialized cells.

The increase in the supply of prostaglandins for experiments has made possible a wide exploration of their effects and powers. These tests have demonstrated that the prostaglandins are among the most potent of all known biological materials, producing marked effects in extremely small doses, and that their existence in the body is remarkably ephemeral. For example, it is found that after a radioactively labeled prostaglandin is injected intravenously into a subject's arm, the injected material is metabolized very rapidly; in as short a time as a minute and a half 90 percent of the radioactivity is dispersed in



NONMAMMALIAN SOURCE of prostaglandins is represented by the sea whip or sea fan *Plexaura homomalla*, a type of coral found in reefs off the Florida coast. The coral contains high concentrations of a prostaglandin precursor, which has been converted to biologically important prostaglandins by workers at the Upjohn Company. There has been considerable interest in this primitive organism as a starting material for synthesizing prostaglandins.

metabolic products, as is shown in samples of venous blood taken from the other arm. Evidently the body's cells possess a copious supply of catabolic enzymes designed to confine the action of the prostaglandins to particular areas.

The principal interest in the prostaglandins has focused on their remarkable versatility and the wide range of their effects. The effects themselves may be quite specific; for example, one prostaglandin (PGE_2) lowers blood pressure, whereas a closely related member of the family (PGF_2 -alpha) raises blood pressure. In general the effects of the prostaglandins are based on certain broad powers: regulation of the activity of smooth muscles, of secretion, including some endocrine-gland secretions, or of blood flow. Through these actions they are capable of affecting many aspects of human physiology, and this accounts

for the great current interest in their pharmacological possibilities.

Particularly striking are the effects on the female reproductive system. An intravenous injection of a very low dose of either PGE_2 or PGF_2 -alpha was shown by Marc Bygdeman to stimulate contraction of the uterus. This finding, together with the finding by S. M. M. Karim, now at the Makerere University School of Medicine in Uganda, that prostaglandins are present in the amniotic fluid and in the venous blood of women during the contractions of labor, suggested that the prostaglandins may play an important role in parturition. The substances have been used to facilitate childbearing labor in several thousand women. Infusion of PGE_2 at the rate of .05 microgram per kilogram per minute has been found to induce delivery within a few hours. Oral administration of PGE_2 or PGF_2 -alpha has also been re-

ported to be effective. Further studies of the most effective dosage and route of administration of the drug, as well as evaluation in comparison with other methods of inducing labor, may lay a basis for wide adoption of the use of a prostaglandin for this purpose.

The possible use of prostaglandins as agents for abortion and for inducing menstruation (in cases of menstrual failure) is also being investigated. There is evidence that prostaglandins produce these effects by some process more complex than the mere stimulation of uterine contraction. Infusion of $\text{PGF}_2\text{-}\alpha$ in female monkeys after mating has been found by Kenneth T. Kirton to produce a dramatic reduction of the secretion of progesterone by the corpus luteum of the ovary, which is needed to ensure implantation of a fertilized ovum in the wall of the uterus. One suggested explanation is that the prostaglandin may induce regression of the corpus luteum, an event that generally does not occur after an ovum is fertilized. There seems to be a strong possibility that prostaglandins or perhaps synthetic analogues may become important agents in controlling population growth.

In an entirely different area of physiology, the prostaglandins, illustrating

their versatility, seem to hold promise for the prevention of peptic ulcers. Andre Robert of the Upjohn Company has shown that the prostaglandin E_1 or E_2 can inhibit gastric secretions in dogs. The dogs were first given a stimulant for secretion (histamine, pentagastrin or food) and then were infused intravenously with one of the prostaglandins. The drug drastically reduced the digestive system's secretion of acid and pepsin throughout the infusion [see illustration on opposite page]. It is believed to have produced this effect by changing the chemical activity within the parietal cells of the stomach. Follow-up experiments have shown further that these two prostaglandins can prevent gastric and duodenal ulcers in rats. It seems well established that ulceration of the stomach and the duodenum is generally caused by prolonged exposure of their mucous membrane to gastric juice of high acidity and peptic potency. The stomach normally produces prostaglandins of the E series, and these may serve to regulate gastric secretion under normal circumstances and thus protect the stomach wall against ulceration. If the studies on dogs and rats are confirmed in man, the administration of E prostaglandins may be a helpful treatment for ulcer pa-

tients who lack this normal protection.

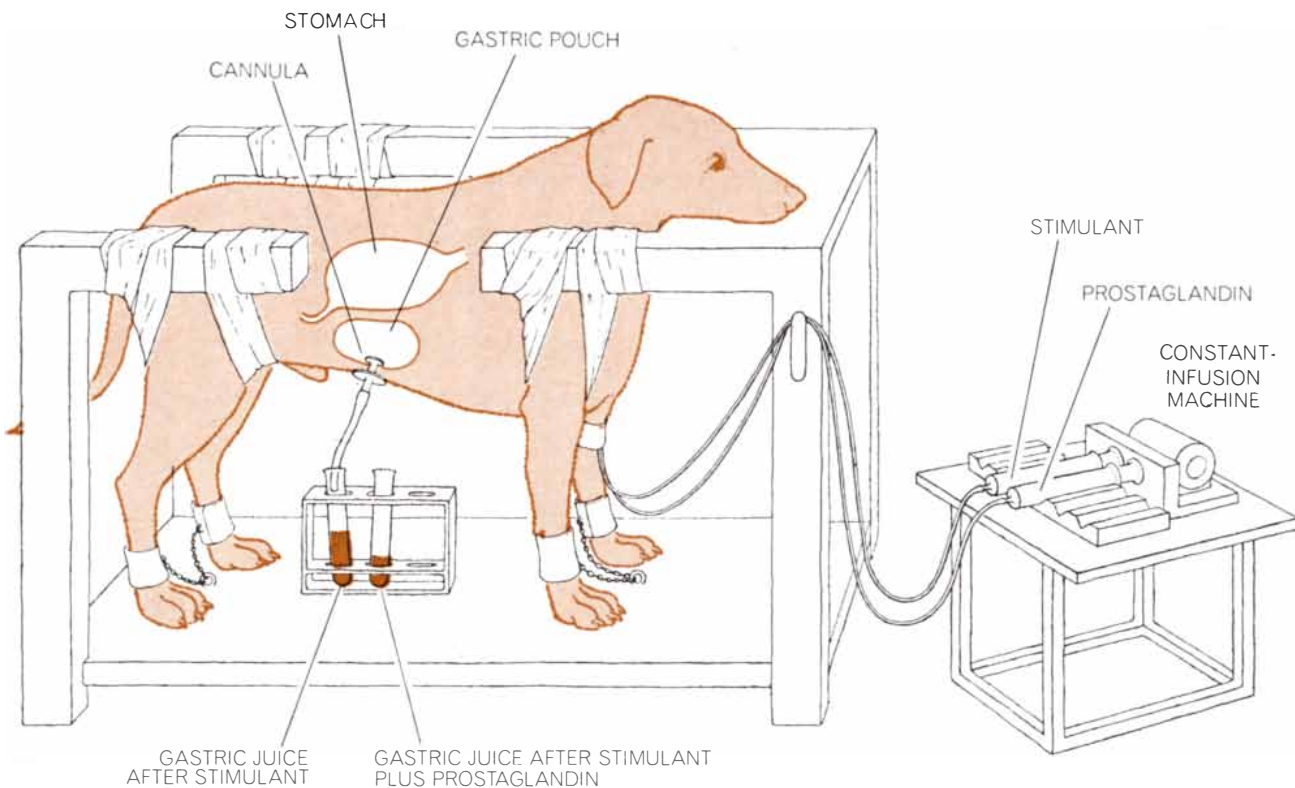
A number of other biological activities of prostaglandins suggesting possible pharmacological uses are under study. Among these potential applications are:

1. Opening the airways to the lungs. It has been shown experimentally in asthmatic subjects that breathing an aerosol preparation of the prostaglandin E_1 can improve the airflow by relaxing the smooth muscle of the bronchial tubes.

2. Regulating blood pressure. In experiments on dogs it has been found that infusion into the kidney artery of a very low dose of PGE_1 or another prostaglandin called PGA_1 produces an increase in the flow of urine and the excretion of sodium ions. This finding and others indicate that prostaglandins in the body normally help to regulate blood pressure. Tests have demonstrated that the infusion of PGA_1 can lower blood pressure in patients with essential hypertension.

3. Clearing the nasal passages. Applied topically to the nose, PGE_1 has been found effective in widening the passages by constricting the blood vessels.

4. Regulating metabolism. PGE_1 has been shown to counteract the effects of



INFLUENCE OF PROSTAGLANDINS on the gastric secretions responsible for peptic ulcers was studied by Andre Robert of the Upjohn Company, who used dogs as experimental animals. The

dogs were first given an intravenous infusion of a stimulant for secretion and then one containing the prostaglandin in addition. The output of gastric juice was reduced during the latter treatment.

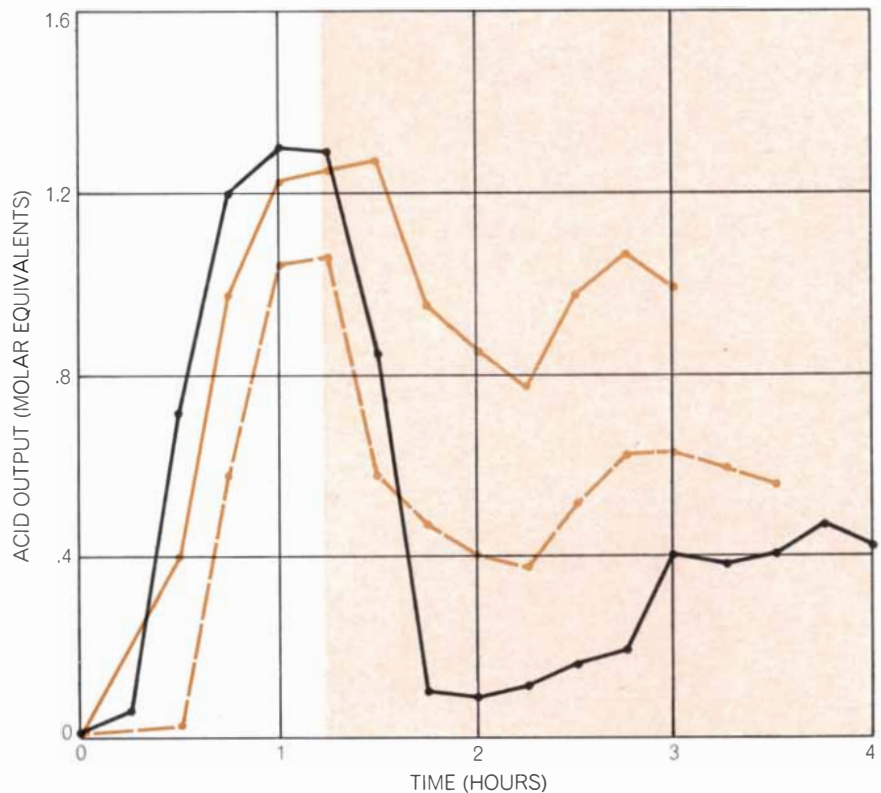
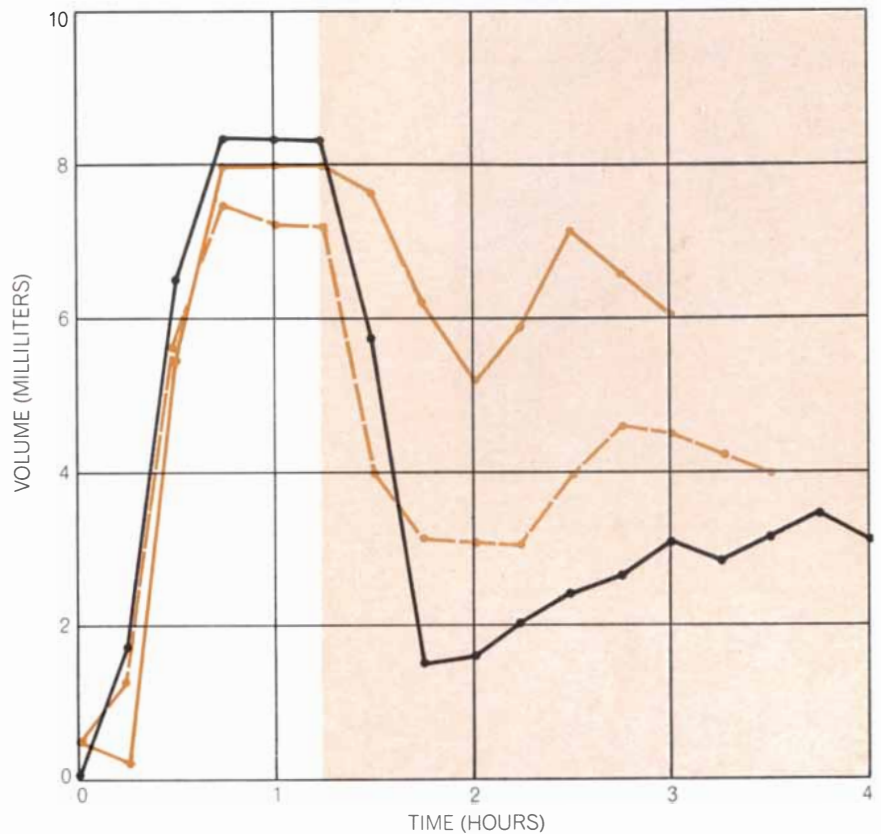
many hormones in stimulation of metabolic processes, for example the breakdown of lipids in fatty tissues.

Many items of evidence now point strongly to the likelihood that the prostaglandins play a fundamental and critical role in the physiology of mammals. Production and release of these substances can be evoked by stimulation of nerves. Recent experiments by a group at the Royal Caroline Institute in Sweden (Per Hedqvist, Åke Wennmalm, Lennart Stjärne and Samuelsson) demonstrated a clear interrelation between the prostaglandins and the substances involved in the transmission of nerve impulses.

Testing preparations of isolated organs (the spleen of the cat and the heart of the rabbit), they found that infusion of the prostaglandin E_2 markedly inhibited the release of norepinephrine in response to nerve stimulation. In other words, the prostaglandin acted as a "brake" on the nerves' action in inciting release of the norepinephrine, a hormone that plays a key part in the transmission of nerve impulses in the sympathetic nervous system. When the preparation was infused, on the other hand, with an inhibitor of the formation of prostaglandins, the consequent removal of the brake from the tissues resulted in an abnormally large release of norepinephrine by nerve stimulation.

These and other results suggest that prostaglandins, playing a negative-feedback role, are part of the mechanism that normally controls transmission in the sympathetic nervous system. The inhibition of the production of prostaglandins in the body obviously invites further investigation. J. R. Vane and his co-workers at the Institute of Basic Medical Science of the Royal College of Surgeons recently conducted such a study and obtained results that suggest the anti-inflammatory action of aspirin and certain other agents may be explainable on the basis that they block the synthesis of prostaglandins.

Prostaglandin formation has been noted in many other apparently unrelated systems. For example, prostaglandins are formed by the lungs during anaphylaxis, by the kidney when its blood supply is restricted, by the surface of the brain when peripheral sensory nerves are stimulated, by the skin during human allergic contact eczema and during certain experimental inflammatory conditions. These diverse situations suggest that prostaglandins may play a fundamental role not only in normal physi-



ABRUPT REDUCTIONS in gastric secretion were observed in dogs as a result of the administration of PGE_2 . In this particular experiment the secretion of gastric juice was stimulated by the intravenous infusion of the histamine dihydrochloride at a dose rate of one milligram per hour. When PGE_2 was added to the infusion (colored band), both the volume (top graph) and the acidity (bottom graph) of the gastric secretion were reduced proportionately to the dose of PGE_2 . In each graph solid colored curve represents a PGE_2 dose rate of 12.5 micrograms per minute, broken colored curve represents a dose rate of 18.75 micrograms per minute and black curve represents a dose rate of 25 micrograms per minute.



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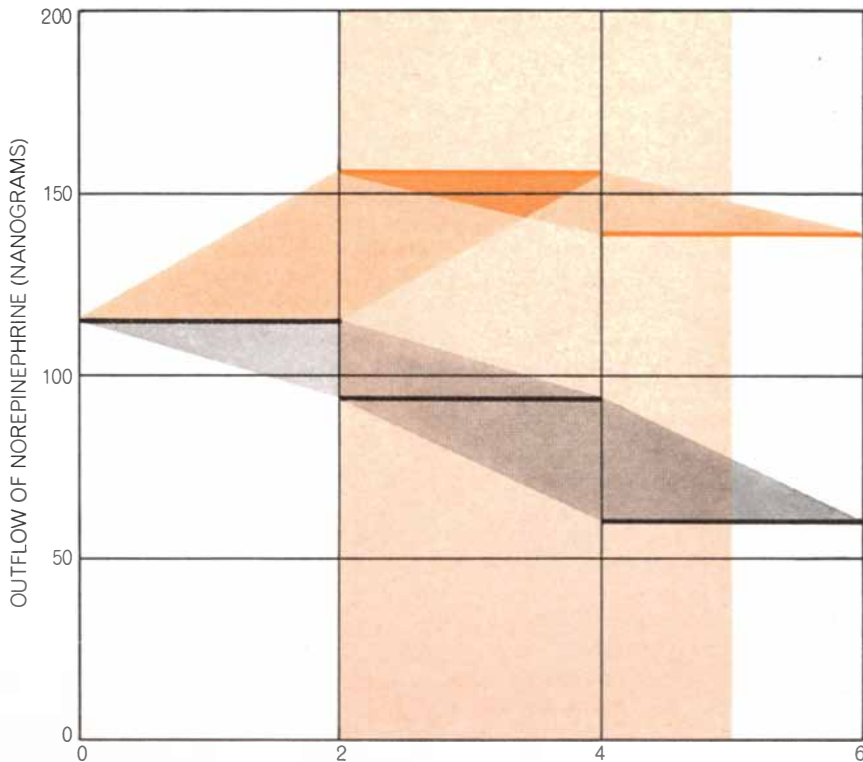
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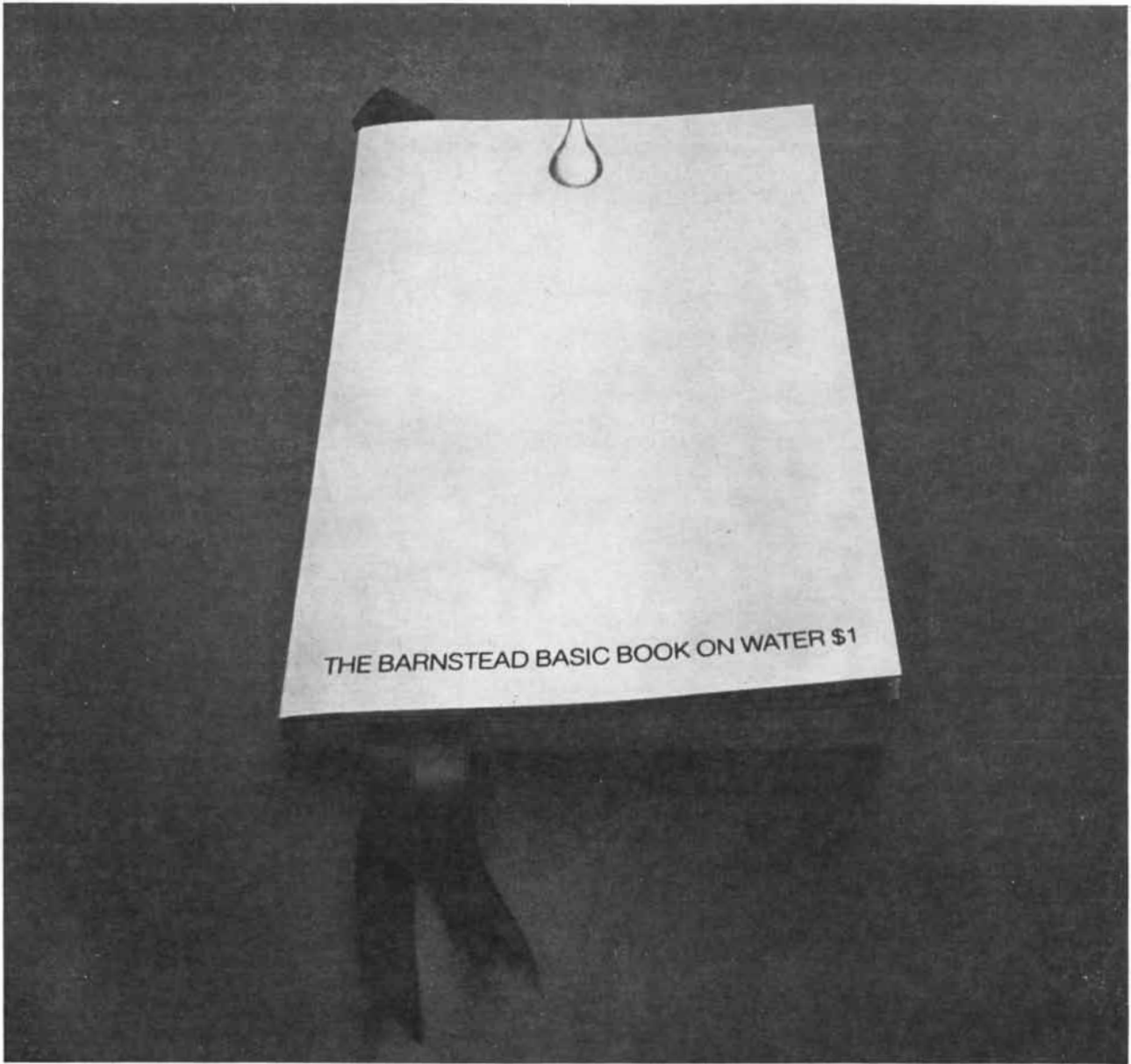
MINUTES AFTER START OF NERVE STIMULATION

INTERRELATION of the prostaglandins with the substances involved in the transmission of nerve impulses was demonstrated by a group of investigators at the Royal Caroline Institute in Sweden. In general they found that PGE_2 acted as a "brake" on the nerve's action in inciting the release of norepinephrine, a hormone that plays a key part in the transmission of nerve impulses in the sympathetic nervous system. In this experiment nerve stimulation of an isolated rabbit heart over a period of six minutes caused an outflow of norepinephrine, the amount of which was measured over three two-minute intervals and declined somewhat over this time span (*black lines*). In separate tests a known inhibitor of the formation of prostaglandin was infused during a three-minute period from the beginning of the second interval, and caused an increased outflow of norepinephrine during the second and third intervals (*colored lines*). Presumably the inhibitor removed the normal prostaglandin brake, resulting in an abnormally large release of norepinephrine.

ological functions but also in certain pathological conditions.

It appears that the prostaglandins are leading us to the meeting ground of the two main systems of communication in the body: the hormones and the nerves. They meet most directly, it seems, in the membrane of the cell. The cell membrane is indeed coming to be recognized as a most important crossroads for a great number of vital activities. Its complex biochemical apparatus controls the selective transport of all kinds of materials into and out of the cell, governs many aspects of the formation of products within the cell and is responsible for cell-to-cell communication, particularly the transmission of signals across the synapses in the nervous system, which is accomplished by chemical means. The discovery of the prostaglandins now lends new significance to the fact that the cell membrane is made up

largely of phospholipids, along with proteins as the other main component. Since phospholipids supply the building materials—fatty acids—for the formation of prostaglandins, it can be supposed that the prostaglandins have a great deal to do with regulation of the functioning of the cell membrane itself. The membrane contains a common medium of communication—the chemical medium—for the chemical agents of the endocrine system and the nervous system. It will be fascinating, therefore, to explore the roles of the prostaglandins in mediating this communication, particularly with regard to their possible connection with the formation of cyclic AMP, the "second messenger," which is increasingly being recognized as a key actor in important functions such as translating the messages of specific hormones and regulating the growth and differentiation of cells.



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SUPERIOR TREES are sought in natural stands as parents of seedlings that are bred for improved traits. The mature loblolly pine at center, growing in the forest of the American Can Company in Alabama, is such a tree. Qualities sought include rapid growth,

good form, superior wood properties, adaptability to various environments and tolerance to pests. Limbs are shot from such a tree with a special gun and used as grafts in an orchard that produces seed, which is grown to determine if offspring have desired traits.

The Genetic Improvement of Southern Pines

These trees are a major source of wood pulp. The best traits of trees in natural stands are now being bred into the trees of commercial forests by the application of genetic principles

by Bruce J. Zobel

Improving domesticated plants and animals by selecting specimens with desirable characteristics and breeding those characteristics into a new stock is a long established practice that has had extraordinary success. A more recent development is the application of similar genetic principles to the improvement of forest trees. Among a number of programs along this line is one that my colleagues and I in the School of Forest Resources of North Carolina State University at Raleigh have conducted with various species of Southern pine. These trees supply the nation with the greater part of its wood pulp and paper. Genetic manipulation has already brought a considerable increase in yields per acre per year, and we foresee even more significant results in the years ahead.

Our program can be summarized under the broad headings of search, grafting, growing progeny and producing seed commercially. Search entails finding parent trees of outstanding characteristics, which include rapid growth, good form, suitable wood properties, resistance to disease and best adaptability to various environments. One cannot always tell merely by looking at a tree that it has the desired genetic qualities; we find trees that appear promising and then see what kind of offspring they produce. The search ranges over a wide area, often involving individual trees that may be many hundreds of miles apart.

When we have found a promising tree, we obtain limbs from it and cut off the ends of the limbs for grafting. Obtaining a limb is not as simple as it sounds, since on a mature pine the limb we want may be 100 feet above the ground. We use a special rifle and bullet and literally shoot the limbs off the trees.

With the grafting material in hand, we proceed to what we term a "seed or-

chard," meaning an area established for the purpose of breeding improved trees and harvesting the seed from them. The seedlings will eventually be planted by companies or individuals who are reforesting areas where trees have recently been harvested. At the seed orchard we graft the cuttings from the parent trees onto young, ordinary trees that are between one foot and four feet tall. The graft is physiologically mature, having come from a mature tree that was producing pollen, cones and seed. Such a graft, when it is established on a juvenile tree, will flower and produce seed several years before a seedling would begin to flower. In effect our procedure brings outstanding parent trees from many places together in an orchard where they can pollinate one another.

In order to make certain that a parent tree will produce offspring with the desired qualities, we conduct progeny tests. Such tests call for controlled pollination. We put bags over the female flowers of a tree so that no foreign pollen can reach the flowers, and at an appropriate time pollen from another parent tree that we want to test is put into the bag. The seeds that result are carefully harvested from the parent trees and are grown in the nursery. The seedlings produced are observed as they grow in the forest. If it appears that they do not have the traits we had hoped to get from the parent tree, the parent is rogued: removed from the seed orchard. Roguing is started about seven years after the establishment of a seed orchard, and it eventually results in the removal of about half of the parent trees from the seed orchard. The ones that remain are demonstrated producers of seed that results in improved genetic stock for planting in the large tree farms maintained by the forest industry in the Southern pine region or by nonindustrial landowners (including

farmers) who obtain seedlings from state nurseries.

Tree farming in the South is an integral part of the concept of the "third forest." The first forest was the virgin stands encountered by the early settlers. The second forest rose mainly on agricultural land that was abandoned around the turn of the century. These trees, which for the most part grew without benefit of the forest-management practices that have now become standard, have been harvested in recent years and replaced by trees grown under careful management practices that often include preparation and fertilization of the site, a high level of mechanization and, increasingly, the planting of genetically improved trees. The objectives of these practices are to increase the yield and quality of the trees and to shorten the time between the establishment of a forest and its harvesting. Associated with the enhancement of growth are better methods of using the timber crop, so that many of the materials formerly wasted—thinings, logging residue and even sawdust—are now used in making paper. The concept of the third forest has spread widely in the Southern pine region, which consists of the Southern and Southeastern states.

The idea of applying genetic principles in the region began to take shape some 40 years ago. It involved a few workers in the U.S. Forest Service, the forest services of several states and the forestry departments of several Southern universities. The efforts of these early workers were not well coordinated and were necessarily oriented toward basic research rather than toward applying genetic principles to growing a crop of trees. Genetic principles could not be applied until it was learned what characteristics of the pine trees were strongly

heritable and how they were inherited.

The major contribution made by the early workers was that they observed and catalogued patterns of variation in commercially important species of pine. In this way they achieved familiarity with the species, which is essential to the success of a breeding program. The early activity resulted in little firm evidence of the improvements possible in pine trees by genetic manipulation of the catalogued variations, even though the investigators drew liberally on methods employed in plant and animal breeding. Hence when the forest industry became interested in large programs of applied genetics about 20 years ago, it had little more than the hope of good returns to justify its investment.

The success of the first large programs was therefore due partly to luck and partly to good guesses about what important characteristics would respond to genetic manipulation. This point is illustrated by the results of including wood properties in the initial breeding programs. Essentially nothing was known about the inheritance of wood quality. What was known well was the pattern of variation of the most important quality of wood: its density, or specific gravity. The information at hand indicated that significant gains might be made through a breeding program. It is now clear that including density in the breeding program was a good investment, because this characteristic has proved to be strongly controlled by genetics and to respond well to a selection program. If

characteristics of unknown inheritance such as wood density had not responded well to breeding, the entire program of genetic manipulation on a large scale might have faltered.

Three circumstances helped to bring about the start of large, well-organized and adequately financed tree-improvement programs in the South some 20 years ago. The first was the publication of a lucid book on forest genetics by Bertil Lindquist of the Göteborg Botanical Garden; the book was translated into English and circulated widely among foresters in the South. Of even more importance was a series of lectures on breeding cereal crops that Ake Gustafsson of the Royal College of Forestry in Stockholm gave in Texas. He predicted that trees would respond to genetic manipulation. The third circumstance was a series of articles on tree breeding published by a newspaper in Texas as a result of Gustafsson's lectures. The articles resulted in a campaign to raise money for a program of tree improvement. On behalf of the Texas Forest Service, and with the participation of 14 industries, I organized such a program in 1951; the working territory included Texas, Louisiana and Arkansas. The major initial task of the program was to convince foresters that it is environment and genetics interacting, and not environment alone, that determines the growth rate and physical features of a tree.

Several years later a similar but larger program was started at the University of

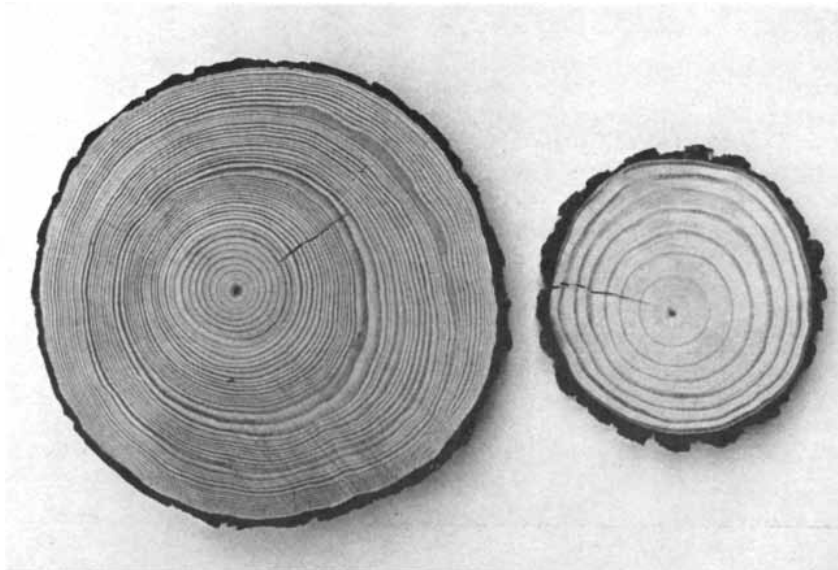
Florida; it dealt primarily with slash pine (*Pinus elliottii*). That program was followed by the large North Carolina State University Cooperative, which I organized in 1956 and have directed since then. Actually two cooperatives are involved. One works on improving pine trees; it is supported by 23 pulp and paper companies, three state forest services, the North Carolina Agricultural Experiment Station and the School of Forest Resources of North Carolina State University. The second cooperative, with one state and 17 companies as members, deals with hardwoods. The industries in the overall cooperative own some 15 million acres of forest land, which are harvested and reforested about once every 25 years.

After a somewhat slow start forest genetics became almost too enthusiastically received. It was regarded by some as a cure for all of forestry's ills. With time it has attained its proper perspective as a powerful tool of the forest manager, provided that he employs it in conjunction with other management practices that increase production.

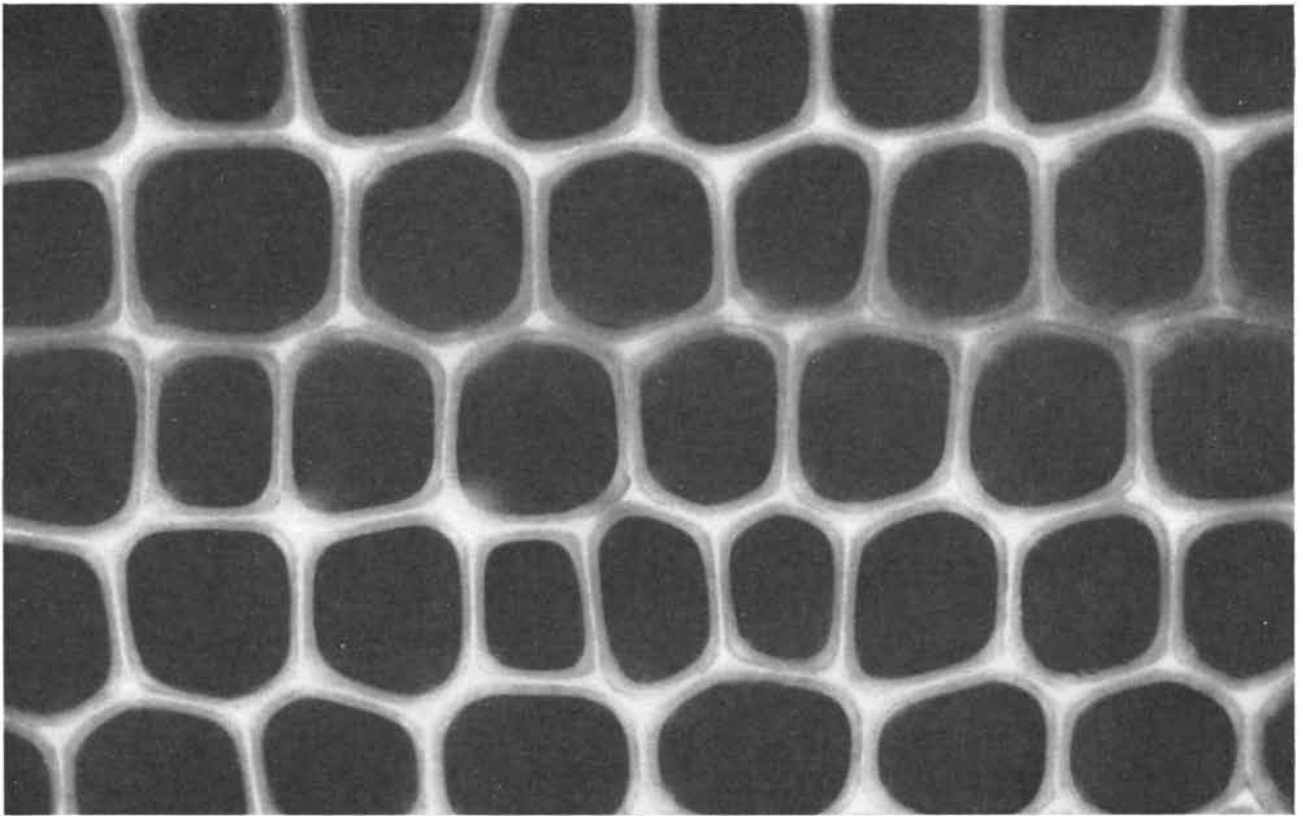
The objective of intensive tree farming can be stated simply as the production of quality timber in maximum amounts and in the shortest time to obtain the maximum economic return. It is simpler to state the objective than to achieve the results. For example, the harvest age of trees can be reduced, but the reduction leads to significant changes in wood quality, harvesting cost and regeneration cost. The job of the tree breeder is to help overcome such problems.

In doing so he has essentially three possible lines of attack. He can breed for improved yields and quality on the more productive forested areas; he can develop trees that will grow satisfactorily on land that is now submarginal for timber, and he can develop strains that are more suitable for specialized purposes. The second and third alternatives are long-term approaches, but they will result in substantial benefits as pressures for land use intensify.

Such pressures are now forcing forestry operations from the more productive sites to areas that have been considered marginal or useless. Hence large amounts of genetically improved seed are needed quickly for the vast forest regeneration programs under way in the South. In our cooperative alone the members need 300 million improved seedlings each year—enough to regenerate 400,000 acres. That goal was about a third realized last year, when enough

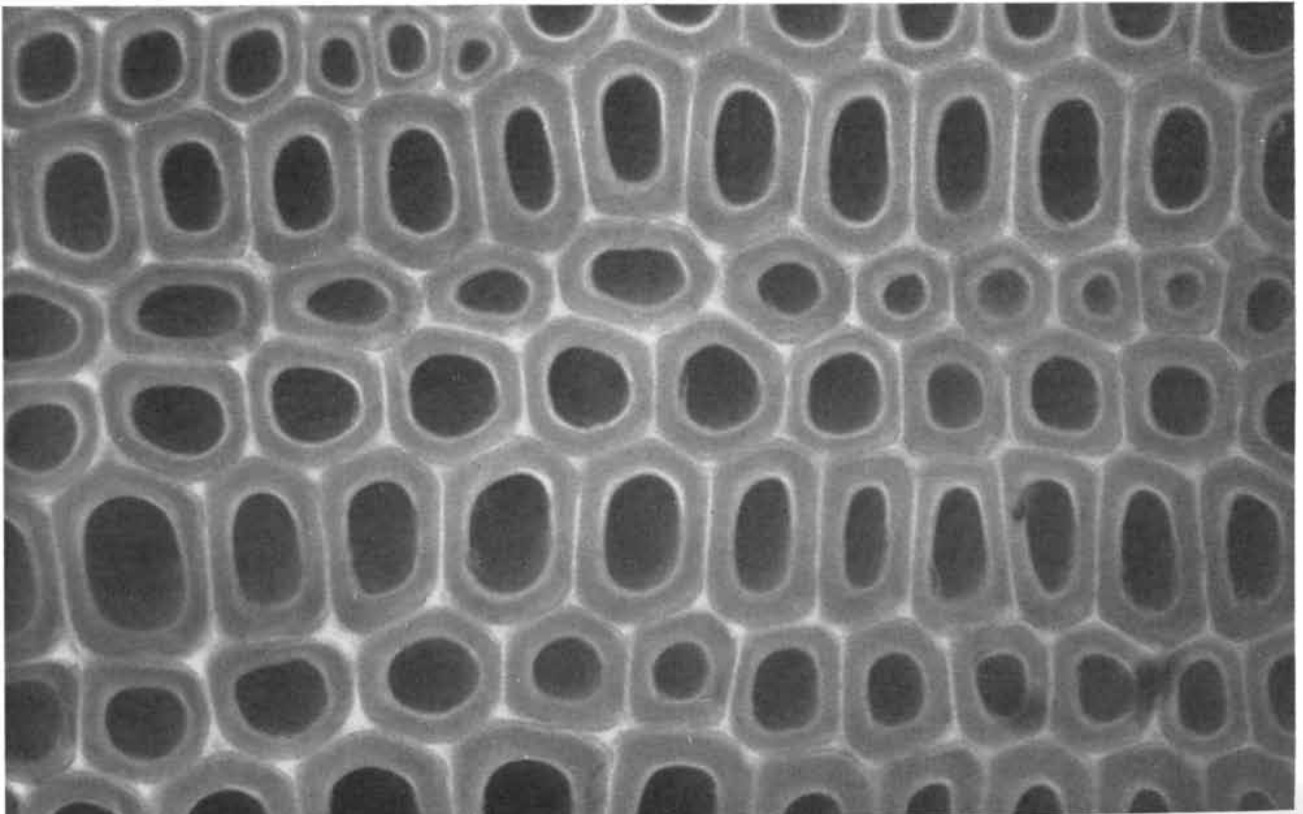


RESULTS OF BREEDING appear in a comparison of cross sections from a loblolly pine from a natural stand (*left*) and one that was genetically improved and grown in a plantation (*right*). As the rings show, wild tree was some 50 years old and grew unevenly from year to year. The improved tree attained substantial growth in eight years and grew quite evenly.



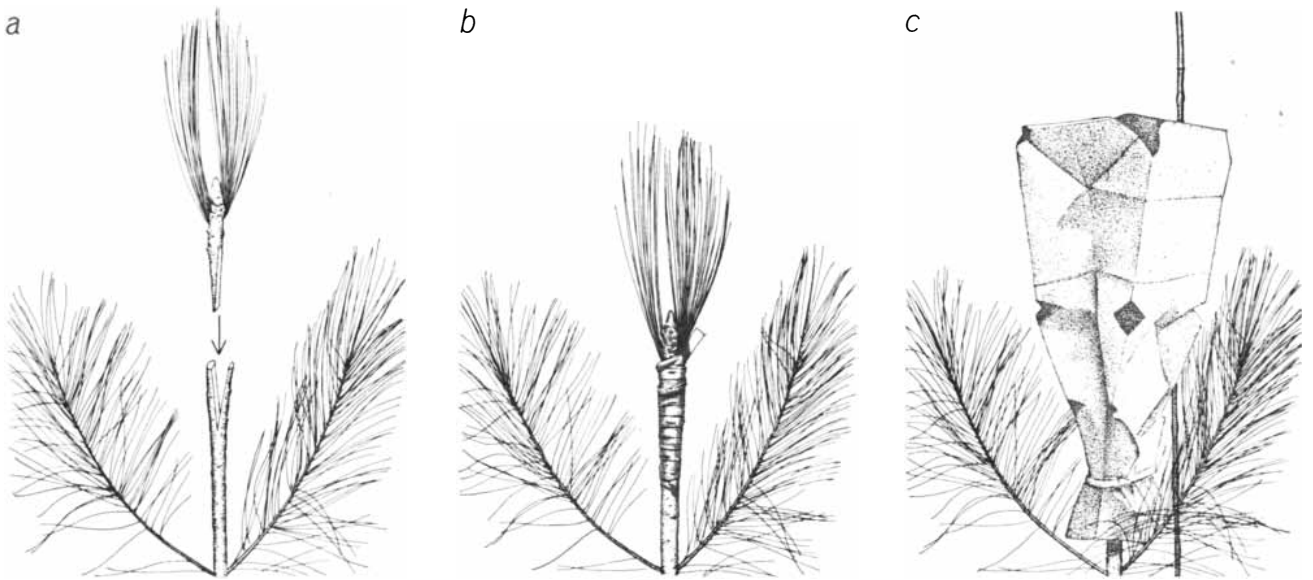
INHERITABLE CHARACTERISTIC of loblolly pine is the structure of its tracheids, which are cells in the wood fiber. In this photomicrograph of tracheids in a loblolly pine that was growing in a

natural stand, the cell walls, which are white, are thin and characteristic of young wood. Wood with thin-walled tracheids is particularly suitable for manufacturing certain high-grade papers.



THICK-WALLED TRACHEIDS appear in a photomicrograph of a young loblolly pine that was used as a parent tree. Wood with

thick cells is good for making bags and cardboard boxes. Enlargement of cells in both micrographs on this page is 480 diameters.



GRAFTING PROCEDURE entails three key steps. A cutting from a superior mature tree is given a V shape on its lower end and inserted in a slit made in a young, ordinary tree growing in an orchard (a). Graft is wrapped (b), and a plastic bag covered by a

paper bag is put over the site (c) to conserve moisture until normal transport of water is established between rootstock and graft. Graft will produce seeds of the kind that would come from the parent tree, so that its progeny will have the parent's desired traits.

genetically improved seed was obtained to produce 100 million plantable seedlings. Within about seven years all the trees planted by members of the cooperative will be of improved genetic stock. When one considers that each acre stocked with improved trees will increase the yield of desirable products from 10 to 20 percent at the time of harvest (15 to 25 years after planting),

it becomes apparent that the gains achieved will amount to millions of cords of wood worth many millions of dollars.

Operating a seed orchard is expensive and exacting, costing on the average about \$5,000 per acre to establish the orchard and test its progeny. Our cooperative alone has nearly 2,500 acres of seed orchards, so that the investment in genetic improvement of the Southern

pine is substantial. One important task is finding suitable parent trees. It often requires several days of intensive search in the best wild stands of trees to find a single outstanding individual tree. To be acceptable a tree must be better than all others in rate of growth, form of trunk and limbs, quality of wood and resistance to disease and insects. We grade it against the five best trees in the stand



GRAFTING BED maintained by the International Paper Company contains several recent grafts, which are identified by the bags. The recipients of the grafts are young trees of ordinary quality. Successful grafts go to seed orchards established to produce seeds result-

ing from the cross-pollination of numerous parent trees that have in effect been brought together in the orchard by means of grafting. Once it is known that the seeds carry desired parental traits, seedlings grown from the seeds are used to establish commercial forests.

and include it in our selection and testing program only if it has a specified degree of superiority to them.

Growth rate is of the first importance. No matter how good a tree is in other characteristics, it must be the fastest grower in the stand. Tree qualities such as straightness of trunk and form of crown are given considerable weight because of the effect they have on yield and ultimately on the quality of the product made from the wood.

Wood quality, as I have already noted, is a characteristic of major importance. Such properties of wood as specific gravity and length of tracheids (long, tubular cells in the wood fiber) have a substantial effect on the final product. No one type of wood is best for all products, so that each of the 85 seed orchards in our cooperative has its own "wood formula." In some orchards the trees have wood that is particularly good for tissue papers; in others the wood is best for newsprint, and still others have wood that is best suited for making high-quality paper, kraft paper or cardboard. A tree that is rejected as having undesirable wood for one seed orchard may be highly desirable for another orchard.

Even though grafting is now fairly routine and successful (members of our group have made more than 500,000 grafts), the road to this point was long and hard. Indeed, it was widely thought at one time that pine trees could not be grafted economically and on a large scale. It took a great deal of effort and time to develop a simple, suitable grafting system. The method we now use entails cutting the scion (the piece of limb from the parent tree) in a V shape at one end, putting it into a cut made in the juvenile tree and covering the graft to retain moisture until union is accomplished and there can be water transport between the roots and the graft [see top illustration on opposite page].

Even with a suitable system a successful graft depends on many things, including the skill of the grafter, the parent tree and seedling stock used, the weather conditions during and after grafting and also a certain amount of luck. Grafting loblolly pine (*Pinus taeda*) has been quite successful, averaging about 85 percent "takes," but several species, such as Virginia pine (*P. virginiana*) and longleaf pine (*P. palustris*), are more difficult to work with. A particularly frustrating problem in grafting has been incompatibility between the root stock and the grafted scion, which often causes the graft to sicken and die. About 20 percent of the parent trees show this abnormality to a degree, some of them



CONTROLLED POLLINATION is the means of testing a parent tree to see if its offspring have the desired traits. A bag is put over the "flowers" of a grafted tree so that no foreign pollen can reach them. At an appropriate time pollen from another parent tree is injected into the bag. The seeds that result are planted for subsequent observation of the progeny.

so significantly that they must be rejected from the seed orchard. Nearly 250 of our best parent selections have been lost for this reason. Much research has been directed toward solving the problem, but success has been limited.

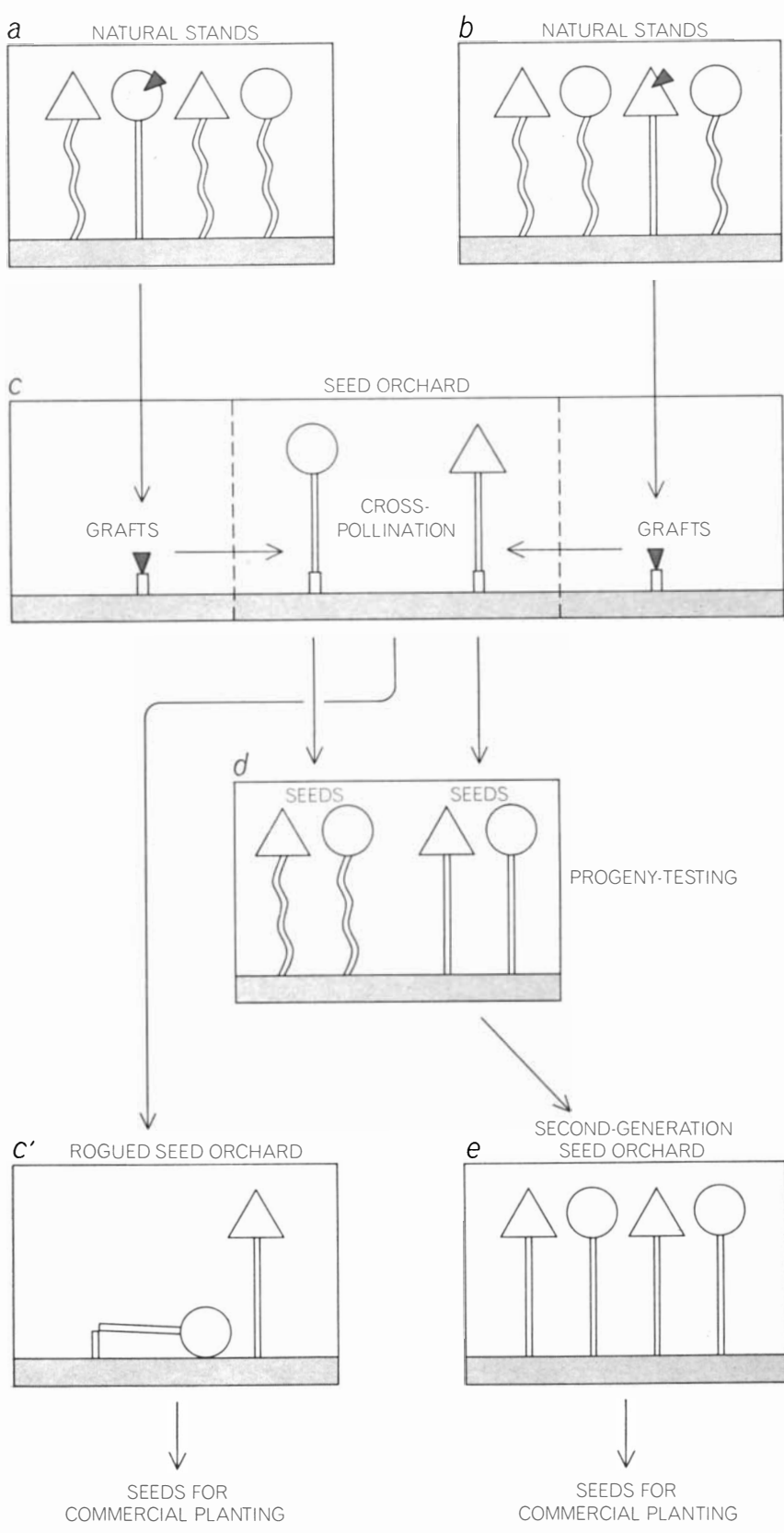
Many other difficulties are encountered in seed orchards. Ice storms, hurricanes and tornadoes can severely damage the trees. Unusual cold often kills the pine flowers or aborts the pollen. Heat and drought take their toll.

The most serious damage, however, is caused by insects. Control of insects is difficult at best. Today, in order to avoid environmental pollution, some of the best sprays and other control compounds can no longer be used. We have yet to find satisfactory substitutes for these compounds. Another problem involving insects is that, as in any concentrated cultivation, managing seed orchards has turned up pests that were formerly unknown or were regarded as being fairly harmless.

A major problem involving the loblolly pine would be amusing if it were not so serious. For years we have awaited the time when loblolly seed orchards would come into full seed production. Now that the time has arrived we are finding it increasingly difficult to collect

the mass of cones during the short period (one to two weeks) when the cones and seeds are mature but the cones have not yet opened, allowing the seeds to fall to the ground. (If the seeds reach the ground, they are exceedingly difficult to collect, although we are developing a vacuum sweeper that we hope will do this work.) The requirement, therefore, is to obtain the cones after they are mature but before they release their seeds. A mechanical tree-shaker works well for dropping the cones of longleaf and slash pine, but loblolly cones cling to the branch tenaciously, and no single system has proved effective in collecting them. We have tried climbing the trees, topping them to keep them short, working with towers and mechanical "cherry-pickers" and even pulling trees over so that they grow horizontally and cones can be collected easily. Eventually we hope to shake the seeds loose after the cones open and collect them with the sweeper. Until this system is perfected we are faced with the problem of collecting some 30,000 pounds of seed from standing grafts, many of which are 50 or 60 feet tall, during a period of two weeks or less.

One result of the seed-orchard system has been the development of specialty orchards for areas where the sites are



BREEDING OF PINES for a particular trait, in this case a straight trunk, begins with the location of trees having that trait in natural stands (a, b). Cuttings from the parent trees are grafted onto ordinary trees in a seed orchard (c) and progeny from the resulting seeds are observed (d) to see if they have the trait. If they do not, the tree that produced the unsatisfactory seed is rogued, or removed, from the seed orchard (c'). Seeds produced by the successful parents and by second-generation trees (e) are used to establish commercial forests.

difficult or unusual products are sought. For example, orchards consisting of parents that produce offspring resistant to fusiform rust, a serious fungus disease of Southern pines, have been established by seven members of the cooperative. Seedlings from these orchards will be planted on the hundreds of thousands of acres where the disease is so severe as to make forestry a marginal operation. Similar orchards produce seedlings for wet sites, and others produce planting stock having special wood properties.

One of our objectives has been to find trees suited to growing in environments from the best to the worst. This work has not been as difficult as we thought it might be, because great differences are found (for a given species of tree) among geographic areas and among trees within an area. For example, loblolly pine from Virginia is much hardier in cold conditions than loblolly pine from Florida, and trees from central East Texas are hardier in drought conditions than trees from southern Georgia. Offspring of trees from the moist coastal plain grow faster than offspring of trees from the heavy clay and the more rigorous environment of the nearby Piedmont, whereas offspring of Piedmont trees are hardier with respect to cold, drought and poor site than offspring of trees from the coastal plain but grow more slowly. Moreover, loblolly pines from the Piedmont produce much heavier and earlier cone crops than the loblolly pines from the coastal plain, regardless of whether the graft is in a seed orchard in the Piedmont or one in the coastal plain.

Because of these strong geographic variations it is essential to select parent trees within a given physiographic area, establish them in a seed orchard and plant the seedlings back into the same physiographic area. Although it is possible to obtain faster growth by moving seed from south to north or inland from the coast, such moves must be made with caution. If the environmental differences are too great or a year with bad weather is encountered, losses may be severe. A move of a limited distance southward causes a loss of growth even though the trees may survive well, and a longer move southward may result in heat damage.

Breeding for trees with rapid growth is a principal objective of all tree-improvement programs. It is difficult to achieve improved growth through a selection program, however, because the two characteristics directly affecting increased volume—height and diameter—are in turn affected by what happens in and above the ground. Differences in

photosynthetic efficiency, rate of respiration and length of growing season have been found among different families. It is also known that some trees utilize fertilizer more efficiently than others. We are now investigating different genetic responses to root infection by mycor-

rhizae, which are useful fungi that are important in determining growth rate because they add to the tree's ability to take in nutrients and moisture.

Gains from breeding programs depend on the type and extent of genetic control and variability. The best gains

are made for characteristics that are strongly under genetic control and have a wide range of variability. For example, tree height is moderately heritable and variable, so that there is a fair amount of room for improving this property. Growth in diameter is much less heri-



NURSERY AND SEED ORCHARDS are maintained in Alabama by the Kimberly-Clark Corporation. The nursery is in the fore-

ground. Behind it are seed orchards of loblolly pine and Virginia pine. In the distant background are areas where progeny are tested.



TREE NURSERY is maintained in North Carolina by the Weyerhaeuser Company for genetically improved seedlings that are trans-

planted to commercial forests. Steps taken to care for the seedlings include irrigation, which is visible in background, and fertilizing.



GRAFTED TREES on the Weyerhaeuser seed orchard in North Carolina are shown on this page at two stages of growth. In this photograph the trees are shown a year after grafting.

table; indeed, much of the variation in diameter of trees in wild stands is a result of environmental conditions. Hence only modest gains can be expected in the first generation from trees selected for diameter.

Because of the inheritance pattern for height and diameter, we originally estimated a growth improvement of only 5 percent in volume after the first generation of selection. It has been a pleasant surprise to find that volume gains in rogued seed orchards are from 10 to 20 percent above those in commercial planting stock. The gains in growth were obtained in spite of the fact that our initial emphasis was on tree form, pest resistance, wood properties and adaptive factors. We foresee an additional gain of 20 to 25 percent in volume from the second generation of breeding, when more emphasis will be placed on increasing volume and less on factors relating to tree quality.

Straightness of trunk, which is important for many products, has responded so well to the first intensive cycle of selection that it will be of minor importance in subsequent generations. Further improvement is possible, but the effect on the final product will be so slight that this characteristic will not be worth much effort.

The main product ultimately desired from tree farming is cellulose in one form or another. The yield of cellulose can be improved directly by breeding trees with higher specific gravity and longer tracheids and indirectly by breeding trees with straighter stems, smaller branches and more resistance to disease. Gains of 4 percent in the dry weight of wood have been made by breeding for high specific gravity. The significance of such gains can be seen in the fact that they increase yields of dry wood by 300 to 500 pounds in every cord (a measure of pulpwood that normally comprises about 2,600 pounds of dry wood). Hence if dense wood is desired, it is possible to increase yields of dry wood by five to seven tons per acre at the time of harvest by planting stock with high-gravity wood.

An interesting application of genetics is the manipulation of tracheids in pine to give the wood qualities similar to those of hardwood fibers. Industries that produce high-quality paper require a high proportion of fibers of the hardwood type. For various reasons hardwoods are becoming scarce in parts of the South, so that the development of hardwood traits in pine wood would be helpful in reducing pressure on this im-



STAGE OF SEED PRODUCTION is reached by grafted trees about four years after grafting. Because the grafts were from mature trees, seed is produced much sooner than the juvenile trees that are the recipients of the grafts would have produced seed on their own.



VACUUM SWEEPER is being developed by the North Carolina Tree Improvement Cooperative for collecting seeds that have fallen to the ground in a seed orchard. The machine is designed for

use in conjunction with a shaker that shakes the seeds loose from open cones on the trees. This machine is a prototype, less rugged than type of machine that will be needed for large-scale collecting.

portant resource. The procedure is to use parents with short tracheids and thin cell walls and to fertilize the plantation heavily with nitrogen. The resulting morphology of pine cells is similar enough to that of certain hardwood fibers so that the requirement for hardwood in producing certain kinds of paper can be reduced.

A true assessment of the gains from a tree-improvement program is not always easy. One can readily measure gains in volume and weight and assign a value to them, but characteristics of wood quality are much more difficult to evaluate. For example, how is straightness of trunk or size of limb to be assessed? We know that the value and utility of the final product are affected by these characteristics, but the economic value of each unit of change is not easy to determine. Another case in point is that increased length of tracheids, which can be achieved through selection, would have no measurable effect on the quality of paper made from older trees. It would, however, be valuable in making the wood of young pine marketable because the short tracheids in juvenile wood make a marginally desirable raw material for manufacturing certain kinds of paper. Similarly, in areas where the incidence of disease is low, resistance to fusiform rust is of little value, but in areas of high incidence resistance may mean the difference between having a

commercial forest and not having one at all.

In one sense all production seed orchards are dead-end orchards. They produce seed in large quantities for commercial planting, but they are restricted in their genetic diversity, and thus in their value for continued breeding, because certain genetic traits have been emphasized in them. Because of the limited parentage, inbreeding will be a problem if advanced generations are produced from production seed orchards. It is thus essential to maintain research orchards to develop breeding stock with a broad genetic base.

With better genetic stock and better basic information than we had originally, we are now free to go in either of two directions. We can breed strains of trees that are particularly well adapted to narrow and specific environments or categories of product, or we can develop trees that perform well over a wide range of environmental conditions and are broadly useful. We have chosen to keep the genetic base broad even though it may be necessary to sacrifice a certain amount of genetic gain. In this way we shall avoid the problems of crop breeders who have developed strains adaptable to highly specialized environments but with a sacrifice of flexibility that has increased the cost and manageability of large-scale operations. The broad base of adaptability possessed by the pines

gives them the ability to grow in different environments while still producing particularly desired characteristics of growth, form and wood quality sought by the breeder. We intend to maintain this broad base.

One way to maintain and broaden the genetic base for future generations is to bring together gene combinations that have not so far been available. We have done this by crossing loblolly pines from widely separated locations. For example, loblolly pine from Texas has been crossed with loblolly pine from North Carolina. A broad base can also be maintained by hybridizing and by specifically breeding individual trees with different genotypes.

It is not necessary at present to increase variability within the pines by using methods such as radiation to induce mutations, because the pines already have much natural variability. Later, as the useful variation is depleted, the problem will become more difficult, and considerable skill will be required to make continued gains possible. It will be necessary to use more sophisticated breeding methods. In a long-lived crop, which trees assuredly are with their harvest-rotation period of 15 to 25 years, it will be essential to make quite certain of the methodology before going into commercial operation. If such caution is not exercised, errors will reduce the production from hundreds of thousands of acres for many years to come.

THE DESERT PUPFISH

More than 20 populations of these hardy fish are found in tiny aquatic "islands" in the vicinity of Death Valley. Isolated for thousands of years, they have evolved into four distinct species

by James H. Brown

The theory of evolution can fairly be dated from Charles Darwin's visit to the Galápagos Islands aboard H.M.S. *Beagle* in 1835, where he observed varieties of finches and other animals he had never seen before. Reflecting on the voyage, he wrote to a friend nine years later: "At last gleams of light have come, and I am almost convinced (quite contrary to the opinion I started with) that species are not (it is like confessing a murder) immutable." Darwin recognized that finches and other organisms that had been isolated on the various islands of the remote Galápagos Archipelago for thousands of generations had gradually evolved in distinctive ways, producing in the case of finches a "perfect gradation in the size of the beaks in the different species."

The isolation provided by remote islands has its counterpart in small springs and small streams that dot the Death Valley region of southern California and adjacent Nevada, one of the bleakest and most arid deserts in the world. These small aquatic "islands," some not much larger than a bathtub, are populated by four species of a tiny fish of the genus *Cyprinodon*. About 1½ inches long when full-grown, they are known as desert pupfish. More than 20 distinct populations of pupfish have been identified in an area of about 3,000 square miles.

Each population is confined to a single, isolated desert oasis, which may be either a warm spring or a small stream. Like other organisms that have been isolated in islands, desert pupfish can tell much about evolution and the response of living things to the selective pressures exerted by various environments. Pupfish can tolerate an unusually wide range of temperatures and salinities. Some populations have evidently survived for thousands of years in small,

restricted habitats where their numbers have never exceeded a few hundred individuals.

The present populations of *Cyprinodon* are the descendants of an ancestral pupfish that once had a broader and continuous distribution. At intervals during the ice ages of 10,000 to 30,000 years ago, when glaciers covered the northern part of the continent, the climate of southwestern North America was much cooler and wetter than it is today. Death Valley then contained a large body of fresh water, Lake Manly, fed by several rivers and numerous streams. The ancestral pupfish lived in Lake Manly and were undoubtedly distributed throughout most of its large drainage system. As the climate became hotter and drier most of the watercourses disappeared, leaving small populations of *Cyprinodon* to survive to the present time in isolated oases where the supply of water has never failed.

Thus isolated, the populations have gradually evolved into four distinct species and several subspecies. The classification has been done principally by Robert R. Miller of the University of Michigan. As a result of evolutionary divergence the species have distinctive shapes and markings [see illustration on page 106]. The four species and their habitats are as follows. *Cyprinodon radiosus* is found in Owens Valley, which lies to the northwest of Death Valley. *C. salinus* inhabits Salt Creek and Cottonball Marsh at the northern end of Death Valley. *C. diabolis*, the smallest and most distinctive species, is found only in Devil's Hole, a long-isolated spring to the east of Death Valley. *C. nevadensis* inhabits a number of springs and streams in the Amargosa River basin to the south and east of Death Valley.

The most differentiated and longest-isolated populations of *C. nevadensis*

have been recognized as subspecies, and nearly all populations of this species have some distinctive characteristics. The species and perhaps some of the subspecies have been isolated for at least 10,000 to 30,000 years. The less differentiated populations are still only partly isolated; aquatic connections are available to them at times of heavy flooding [see illustrations on page 107].

Desert pupfish survive in radically different kinds of environment. In fact, about the only requirement for their existence seems to be an unfailing supply of water. Their habitats can be divided into three basic types. The first consists of shallow streams and marshes fed by ground-water springs. The temperature and the amount of water in these habitats fluctuate drastically with the season; the salinity ranges from the equivalent of seawater to about a fourth of that value. The second type of habitat is represented chiefly by thermal springs, which are fed by water from depths where it has been heated by layers of warm rock. Some of these springs have no outflow; in others most of the pupfish are confined to the source pool where the salinity is low and the temperature is warm and virtually constant throughout the year. The third basic type of habitat consists of hot artesian wells that have been dug by man. Water emerges from these wells at temperatures above 105 degrees Fahrenheit and discharges into shallow streams, where it gradually cools to the ambient air temperature. Two such wells were dug near the town of Tecopa, Calif., in the 1960's. Their outflow streams reached the Amargosa, and they were colonized by the natural population of pupfish that inhabited the river.

My experience with desert pupfish began in early 1969 when C. Robert

Feldmeth and I visited a number of the oases and began a comparative study of thermal tolerances in *Cyprinodon*. We wanted to define the limits of temperature that can be tolerated by the populations of pupfish inhabiting the thermally variable streams and marshes and the outflows of hot artesian wells. We also wanted to find out if these populations are more tolerant of extreme temperatures than those populations that live in the constant-temperature environments of thermal springs. We reasoned that populations that have evolved for thousands of years in springs of constant temperature might have lost some of their ability to tolerate extreme temperatures, in the same way that cave fishes living in absolute darkness have lost their "useless" eyes and skin pigment.

We learned that pupfish in their natural habitats readily survive at temperatures as low as 38 degrees F. and as high as 108 degrees. Such extreme temperatures, however, are always separated either in time or in space, so that an individual fish would never experience the entire 70-degree range within a period of a few hours or even a few days. Thus shallow desert streams and

marshes are often covered with ice on cold winter nights and the temperatures in parts of these same habitats can rise to 100 degrees F. on hot summer days. Even during the winter, however, some fish may be swimming in water of 108 degrees near the outflow of a hot artesian well while others just a few hundred yards downstream are swimming under ice. Of course, the fish are free to move up and down in the outflows of the artesian wells, and they tend to regulate their movements so as to remain at a relatively constant temperature.

By testing in the laboratory the thermal tolerances of fish from habitats where the temperature varies, we found that at any given time an individual pupfish can withstand temperatures over the full range of approximately 70 degrees [see lower illustration on page 108]. The actual temperatures the fish can tolerate depended on the temperatures the fish had recently experienced. Thus if a fish had just come from a cold environment in the field or had been kept at a low temperature in the laboratory, it might be able to tolerate temperatures ranging from 32 to 102 degrees F. If it had just come from a warm environment, its range of thermal

tolerance would be shifted upward, so that it might be able to survive temperatures between 40 and 109 degrees F. From these results it can be seen that the ability of pupfish to endure extreme temperatures in their natural environments depends on a combination of two phenomena. On the one hand there is an inherent, genetic capacity to withstand a wide range of temperatures; on the other there is the process, usually called thermal acclimation, that enables the fish to shift its tolerance to higher or lower absolute temperatures depending on its recent thermal history. The combination of these phenomena enables the pupfish to occupy environments where thermal variation is extreme as long as the temperature changes do not come too rapidly.

A thermal tolerance involving both a genetic component and an acclimation component is typical of nearly all organisms. What is unusual about pupfish is that their temperature tolerance is exceptionally broad for an aquatic organism, particularly for a fish. Many freshwater fishes, such as some species of trout, can tolerate a thermal range of only about 40 degrees F., and some ma-



HABITAT OF DESERT PUPFISH is one of about 20 along the southern reach of the California-Nevada border. The photograph shows a portion of the Amargosa River that contains water and

pupfish in the winter and spring but dries up completely in summer. In the dry season the population of desert pupfish (*Cyprinodon nevadensis*) retreats to a number of headwater springs.

rine and tropical fishes are much less tolerant than that. The wide thermal tolerances of desert pupfish have enabled them to persist in the shallow desert streams and marshes where temperature variation approaches the extreme for any aquatic habitat. The pupfish share these habitats with only a few equally hardy kinds of plants and invertebrates.

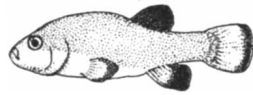
Quite to our surprise we found that pupfish inhabiting thermal springs of constant temperature are just as tolerant of extreme temperatures as their relatives that occupy habitats where the temperature varies tremendously. Even *C. diabolis*, which has lived at 92 degrees F. in Devil's Hole for at least 30,000 years and has evolved consider-

ably in other respects, is capable of tolerating a 66-degree range in temperature (from 43 to 109 degrees) when just removed from water of 92 degrees in its native spring. Pupfish from thermal springs also have the same capacity for thermal acclimation as fish from environments where there is great variation in temperature.

These unexpected results are difficult to interpret. Why should so many organisms gradually lose characteristics that no longer have a function, yet pupfish retain the ability to tolerate extremes of temperatures they have not experienced for thousands of years? Perhaps part of the answer is that the ability to tolerate extreme temperatures is differ-

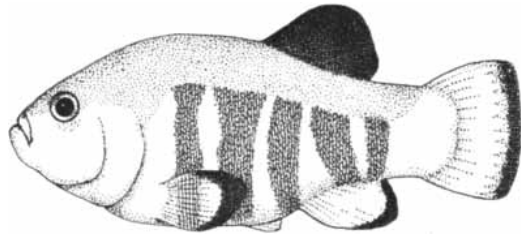
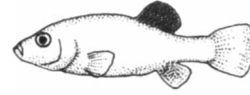
ent from those "useless" characteristics that are generally lost during evolution. It is easy to see how organs such as the eye, once they are completely unable to function in the absolute darkness of caves, might actually become disadvantageous. Since they would be subject to injury and infection, it would be beneficial to the organism if they were eventually eliminated by natural selection. There appears to be no corresponding disadvantage for the pupfish to retain the ability to tolerate a wide range of temperatures even though it is living securely at some constant temperature. Part of the explanation may be that the genetic or biochemical basis of thermal tolerance in desert pupfish makes this at-

MALES

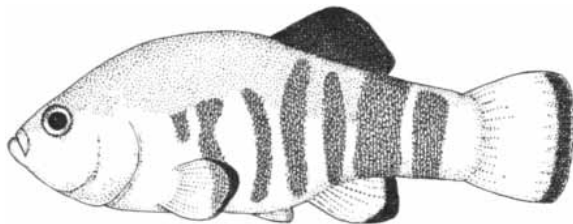
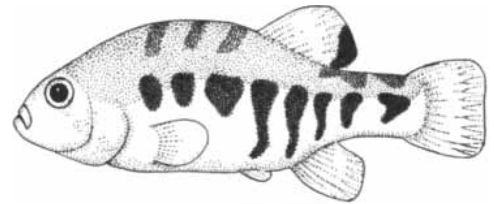


CYPRINODON DIABOLIS

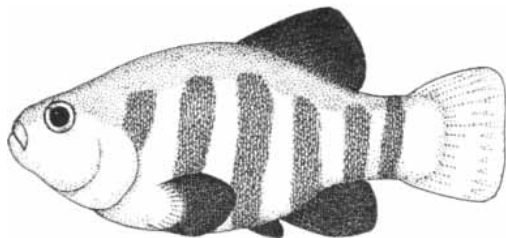
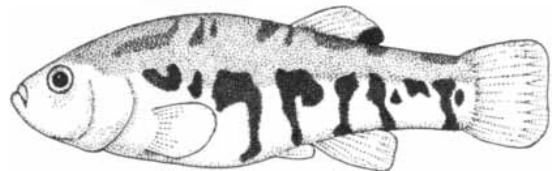
FEMALES



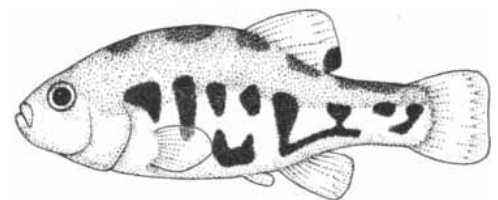
CYPRINODON NEVADENSIS



CYPRINODON SALINUS



CYPRINODON RADIOSUS



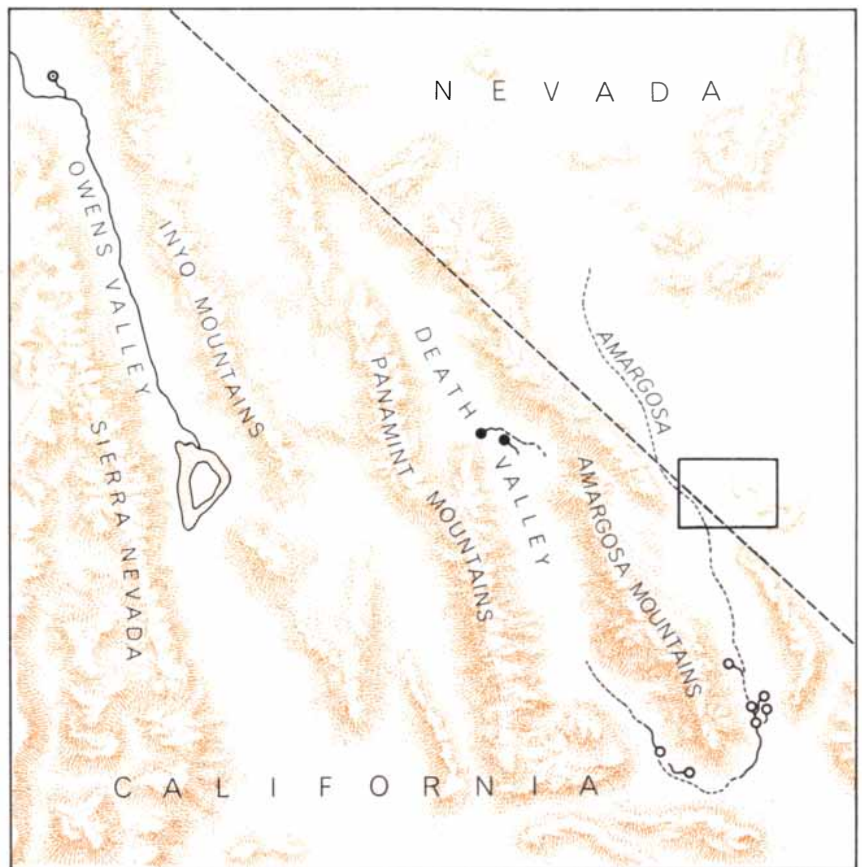
FOUR SPECIES OF PUPFISH have evolved in the streams and thermal springs of the Death Valley region. The smallest, *Cyprinodon diabolis*, is found only in Devil's Hole, a thermal spring in a rocky mountainside (see maps on opposite page). *C. nevadensis* populates a number of springs and streams in southwestern

Nevada and eastern California. *C. salinus* is found in Salt Creek, a marshy desert stream that is sometimes as salty as seawater. *C. radiosus* inhabits warm springs in Owens Valley. The species can be distinguished by their size and markings. Males are a bright, iridescent blue; females are greenish with black markings.

tribute resistant to evolutionary change.

Granted that the pupfish has an unusually broad thermal tolerance, one would also like to know if it has thermal preferences and if it is able to avoid stressfully high temperatures. I have investigated the matter by studying the behavior of pupfish in the outflows of hot artesian wells. In one of the wells the water is 117 degrees F. at the source and gradually cools as it moves down the outflow stream [see illustration on page 110]. Fish are found in all parts of the stream where the temperature is less than 108 degrees, but they rarely enter water that is hotter than that even though they can tolerate temperatures up to 111 degrees for several minutes. Moreover, a sizable portion of the population can always be found where the temperature is between 107 and 108 degrees. As the outflow stream cools at different rates (depending on ambient wind and temperature conditions) these fish move up and down the stream and stay within the 107-to-108-degree temperature range. In this habitat one of the main foods of the pupfish is a blue-green alga that can grow at higher temperatures than the fish can withstand. Every time the outflow cools more rapidly and the 107-to-108-degree band retreats upstream, the fish encounter large mats of algae that have been growing un-molested.

The pupfish are able to sense the critical temperature of 108 degrees F. with remarkable precision in both steep and gradual thermal gradients. In the main part of the stream the temperature changes only one degree in several yards, yet it is possible to identify the place where the temperature is 108 degrees by finding the greatest upstream aggregation of pupfish. A quite different state of affairs is observed in small shallow pools to the side of the main channel. Sometimes fish get trapped in these pools when the outflow cools more slowly and intolerably hot water moves downstream. The temperature in such a pool often remains below 108 degrees (largely because of the high rate of evaporation from its surface), but the temperature increases abruptly at the edge bordering the main stream where hotter water is flowing past. In a distance of an inch or less the temperature may go from 105 degrees to more than 112 degrees. The fish dart about the pools to within a fraction of an inch of lethal temperatures but normally never enter them. If the fish get a bad scare, one may occasionally dart out into the hot



○ *CYPRINODON RADIOSUS* ● *CYPRINODON SALINUS* ○ *CYPRINODON NEVADENSIS*

POPULATIONS OF DESERT PUPFISH are sparsely scattered throughout an area of about 3,000 square miles straddling the California-Nevada border. During the ice ages of some 30,000 years ago there were aquatic connections among the various habitats. As the climate became drier, isolating the habitats, the pupfish evolved into four separate species.



○ *CYPRINODON NEVADENSIS* ■ *CYPRINODON DIABOLIS*

ENLARGEMENT OF AREA designated by colored rectangle on the map at top of page shows Devil's Hole, home of *C. diabolis*, and a number of spring-fed streams populated by *C. nevadensis*. Mexican Spring, hardly bigger than a bathtub, holds about 30 *C. nevadensis*.

stream; there it dies within seconds. The ability of pupfish to detect and avoid critically high temperatures enables them to live for weeks and even to reproduce in these pools where they are literally inches from instant death.

The ability of pupfish to inhabit waters of varying salinity is almost as impressive as their thermal tolerance. In the Death Valley region the salinity in pupfish habitats varies from very low in the thermal springs to near the concen-

tration of seawater in parts of some streams and marshes. A related *Cyprinodon* that inhabits the Gulf coast of Texas can tolerate salinities several times the concentration of seawater. Populations from both freshwater and saline habitats can survive for long periods in a wide range of salinities.

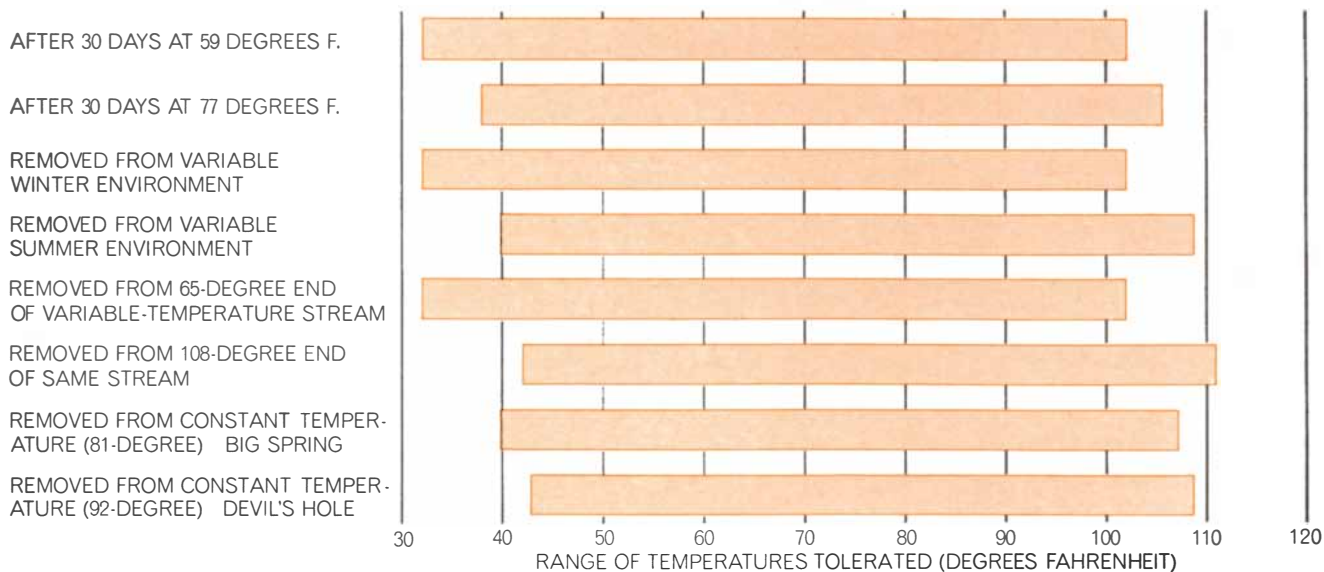
Other attributes of desert pupfish are just as interesting as the adaptations that enable them to live in pools and streams with extreme temperatures and salini-

ties. The size and constancy of the pupfish habitats vary greatly, and so do the size and constancy of the various populations of *Cyprinodon*. Populations that occupy streams and marshes fed by ground-water springs usually fluctuate greatly in numbers in response to seasonal changes in temperature, salinity and amount of water available. The Death Valley region receives most of its scanty rain in winter and early spring. In the rainy seasons the marshes fill with

HABITAT	GENERAL DESCRIPTION	SIZE	TEMPERATURE	SALINITY
Salt Creek	Marshes and stream fed by ground-water springs.	Stream varies in length from at least five miles in spring to one mile in summer.	Fluctuates from freezing to at least 100 degrees F.	Varies from concentration of seawater to half that value.
Big Spring	Large thermal spring; discharges water at 1,500 gallons per minute.	Source pool 50 feet in diameter and 30 feet deep. Outlet stream runs about two miles.	Constant 81 degrees F.	Fresh
Devil's Hole	Thermal spring in deep cleft in rocky mountain-side; no outlet.	Rectangular pool eight by 60 feet; more than 200 feet deep.	Constant 92 degrees F.	Fresh
Mexican Spring	Tiny spring; discharges a trickle of water that flows only a few feet.	Pool 12 feet long, 18 inches wide and one or two inches deep.	Fluctuates from 40 to 95 degrees F.	Fresh
Tecopa Bore	Hot artesian well; dug in 1967 and colonized by pupfish from nearby marsh.	Outlet stream runs about 3/4 mile to marsh.	Gradient: 117 degrees F. at source; marsh may freeze in winter.	Fresh

REPRESENTATIVE HABITATS OF PUPFISH are small streams and pools, mostly fed by springs. Pupfish have also found their way

into the outlet streams of recently dug hot artesian wells. More commonly populations are being destroyed by human activities.



THERMAL TOLERANCE OF PUPFISH is approximately 70 degrees Fahrenheit. The tolerance range is shifted up or down several degrees depending on the temperature the fish had most re-

cently experienced. The two top bars show the result of acclimation in the laboratory; the other bars show the temperature tolerance of fish that had recently been exposed to the conditions shown.

water and the streams flow far out onto the desert floor. Then as the temperatures rise in late spring the pupfish population increases explosively. The fish become so numerous that the Shoshoni Indians used to travel to the marshes to harvest the inch-long fish. The population reaches a maximum in midsummer just before large areas of the habitat begin to dry up.

In July, August and September hundreds of thousands of fish become stranded in shallow pools and perish as the temperature and salinity increase and the remaining water rapidly disappears. A fraction of the maximum population survive in the permanent waters of the source springs. The survivors are often further decimated by the scouring action of winter floods, but with the coming of spring the remnants begin reproducing to repeat the cycle. Some of these populations, such as the one inhabiting Salt Creek, probably fluctuate more than a hundredfold each year, and literally millions of pupfish perish each summer.

In contrast with the streams and marshes, the source pools of the thermal springs provide one of the most constant environments to be found in the Temperate Zone. There is essentially no variation in temperature, salinity or size of habitat. There is, however, some fluctuation in the growth of algae, the principal food of the pupfish, as a result of seasonal variations in the number of daylight hours. Even in these habitats the populations of *Cyprinodon* fluctuate, apparently in response to the availability of food, but the changes are small compared with those that regularly take place in streams and marshes. Variations in population size of more than a few fold are rare; the source pools of the larger springs, such as Big Spring, always contain a few thousand fish. The smaller springs support smaller populations. Devil's Hole, which is located in a deep fissure in the side of a mountain, receives only a few hours of sunlight a day. The limited supply of algae supports a population of only 200 to 800 pupfish.

The ultimate in small population size is attained in Mexican Spring, a long narrow pool that is only one or two inches deep in most places. The entire spring contains an estimated 80 gallons of water, barely enough to fill a bathtub. The spring is separated from the nearest other pupfish habitat by hundreds of yards of desert. Its inhabitants have been isolated for many generations, perhaps for hundreds or thou-

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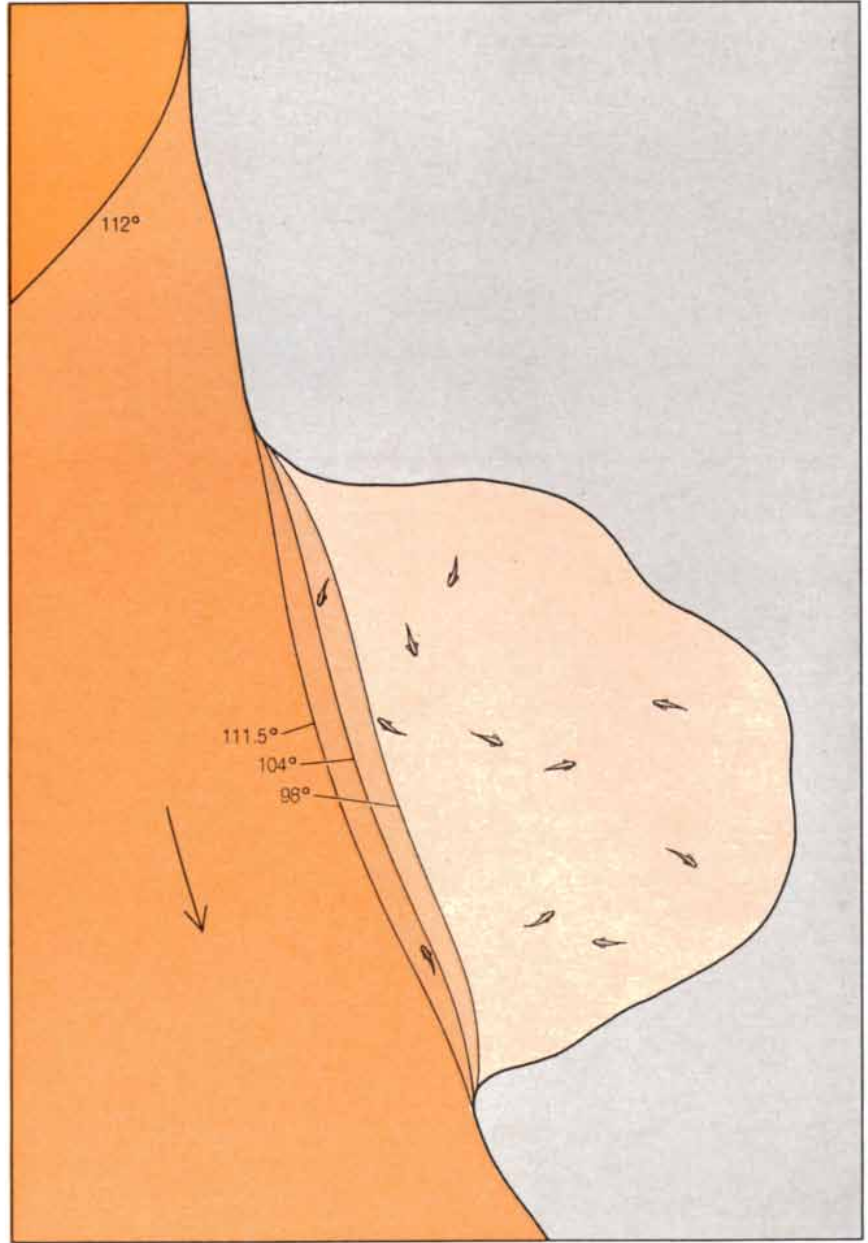
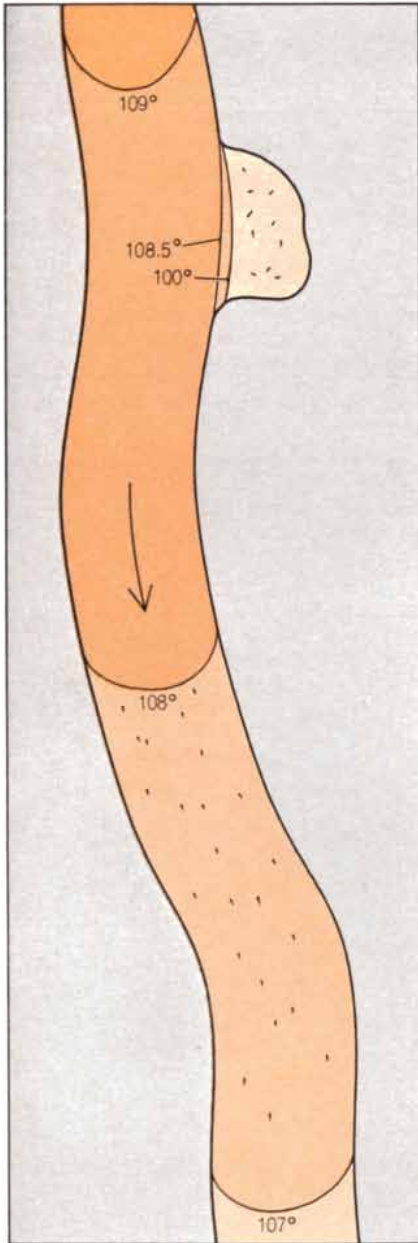
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sands of years. No more than 20 to 40 fish constitute the entire population of the spring. Of these only four or five are mature males, five to 15 are mature females and the remainder are young. This must certainly approach the minimum size for any self-maintaining population of organisms. Only the constancy of the spring environment and the reproductive capacity of the pupfish have enabled the tiny fish to survive.

The desert pupfish of Death Valley offer manifold opportunities for studies whose results should be every bit as interesting as those reported here. Some

of the work is in progress but most of it remains to be done. Unfortunately the pupfish habitats are extremely vulnerable to the activities of man. Since the 1940's at least eight populations of desert pupfish have been exterminated, at least half of them since I began working in the Death Valley area in 1969. These extinctions can be attributed directly to the introduction of predatory fishes, to the construction of bathhouses over the sources of thermal springs and to the filling or draining of springs for agricultural purposes. As this article is written, pumping of water from the nat-

ural underground reservoirs is lowering the water level in several springs and threatening the extinction of several additional populations, including the *C. diabolis* of Devil's Hole. Each population of pupfish is the unique product of a long period of evolutionary history, and the creation of thousands of years of natural selection is now threatened by a single generation of human activity. Both man and the pupfish require water to survive in the desert; unfortunately the absence of water is one environmental condition to which this amazing little fish has not become adapted.



ACUTE TEMPERATURE SENSITIVITY is exhibited by desert pupfish in the main outflow of an artesian well (*left*), where they concentrate in regions below 108 degrees F. By swimming as close as possible to the 108-degree boundary they improve their access to

blue-green algae, which can grow at a higher temperature than the fish can stand. Pupfish are sometimes trapped in small, shallow side pools (*right*), where one can see them swimming within a fraction of an inch of temperatures that could kill them in seconds.

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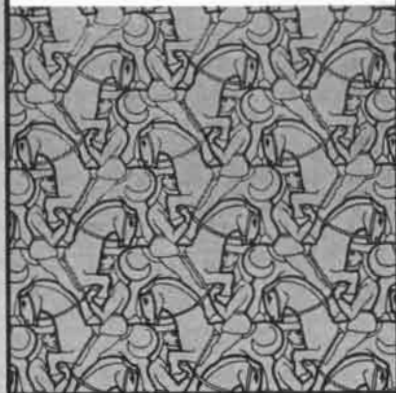
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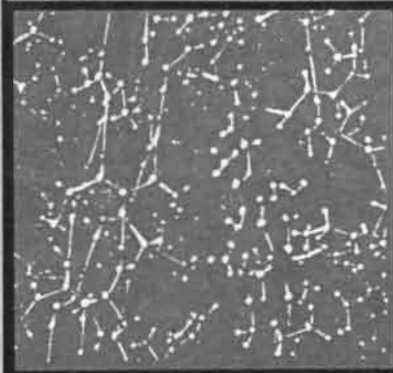
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MATHEMATICAL GAMES

*Advertising premiums to beguile the mind;
classics by Sam Loyd, master puzzle-poser*

by Martin Gardner

The giving away of inexpensive advertising premiums is a clever and popular means for attracting the attention of consumers. Many giveaway premiums are based on mathematical puzzles, and I have described a number of items of this kind in earlier articles. A paper "map-folding" premium was depicted in May, for example, and other articles have described tetraflexagons and hexaflexagons that are now providing curious advertisements for a variety of products. This month we consider some of the classic mathematical premiums that have not already been discussed here.

One of the oldest and best is the T-puzzle [see illustration below]. The reader is urged to trace or photocopy the four pieces, paste them on cardboard, cut them out and try to fit them

together to make a capital T. I know of no polygon-dissection puzzle with as few pieces that is so intractable. The number of giveaway premiums based on this puzzle, particularly in the early decades of the century, runs into the hundreds.

Less well known, although equally ancient and charming, is the Pythagorean-square puzzle [see top illustration on opposite page]. The task is to arrange all five pieces into a square slightly larger than the square that is dissected into four pieces. I have not seen this as a die-cut premium in recent years, although several plastic versions are now on the toy market. The handsomest is called Madagascar Madness, which points out in its instructions that the puzzle nicely illustrates the Pythagorean theorem. If the big and little squares are on the sides of a right triangle, the square formed with the five pieces will, of course, be the square on that triangle's hypotenuse.

This country's most prolific creator of mathematical premiums unquestionably

was Sam Loyd (1841–1911), the famous Philadelphia-born puzzlist and chess-problem inventor. In his cluttered, musty office in a decaying Manhattan building occupied by *The Evening Globe*, Loyd concocted hundreds of puzzles of fantastic variety and ingenuity. As described in a 1911 magazine article, his small office "would be dark even if the one window were washed, a cataclysm of which there seems no immediate prospect. There are two desks, a typewriter and a printing-press in it, and countless shelves loaded with papers, pictures, magazines, stereotype plates and one thousand other things which have spilled out upon the floor and risen like strange, dirty snowdrifts breast high in the corners. Sam Loyd says he does all his business on a cash basis and keeps no books. The reason probably is that he couldn't find the books. That would be too much of a puzzle even for him."

Loyd's first big success with a premium came with his invention, at the age of 17, of the Trick Donkeys. The task is to arrange three cardboard rectangles so that two riders are astride two donkeys. The puzzle is still widely used as a giveaway item throughout the world. Loyd's original version, which P. T. Barnum distributed by the millions to publicize his circus, is reproduced in the chapter on Loyd in *The Scientific American Book of Mathematical Puzzles & Diversions*. Modernized versions can be found in the article "Problem-solving" in *Scientific American* for April, 1963; on page 124 of *The Mind* (a Life Science Library book), and in an American Can Company advertisement in *Time* for March 22, 1968. Loyd once related in an interview that Barnum used to make periodic treks to his office saying, "Hang it all, Sam, show me how to do my puzzle. I've forgotten again."

Another of Loyd's early premium hits, even more widely used today than then, is nothing more than a pencil with a short loop of string on its eraser end. Loyd designed the trick for agents of the New York Life Insurance Company, who would attach the pencil to prospective customers' coats with the promise to remove it if a sale was consummated. The loop is placed around a lapel buttonhole, then the cloth is pulled forward through the loop until the pencil goes back far enough for its point to enter the buttonhole from behind. When the pencil is pulled forward through the hole, it is fastened in such a way that it seems impossible to remove the pencil without cutting the string.

Loyd produced numerous geometric



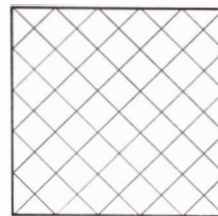
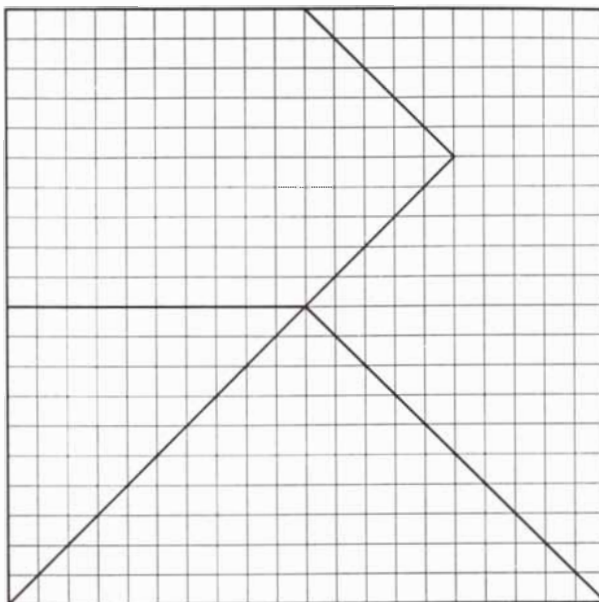
The classic T-puzzle

puzzles, but none with a more unexpected solution than his Pony Puzzle, shown in the bottom illustration on this page exactly as he himself originally drew it. The problem is to rearrange the six pieces to make the best possible picture of a trotting horse. In his *Cyclopedia of Puzzles* Loyd claimed that over one billion copies of the Pony Puzzle had been sold.

The most spectacular of all Loyd premiums, by all odds, was his mind-bending "Get off the Earth" paradox. He patented the device in 1896 and first sold it as a premium to advertise Bergen Beach, a resort that had just opened in New Jersey. Copies of the original are now rare collector's items. The art, based on Loyd's sketches, was done by Anthony Fiala, then a cartoonist on *The Brooklyn Daily Eagle*. (Later Fiala was commander of the Ziegler Polar Expedition of 1903–1905 and wrote a book about it, *Fighting the Polar Ice*.) The puzzle consisted of a cardboard disk fastened by a central rivet to a cardboard rectangle. A tab attached to the disk projected through a curved slot in the backing so that by moving the tab up or down the disk could be rotated to two positions [see illustrations on next page]. In one of the positions you can count 13 Chinese warriors. When the disk is turned to the other position, there are only 12 warriors. Which man vanishes, the premium asked, and where does he go?

For more than a year Loyd filled his weekly puzzle column in *The Brooklyn Daily Eagle* with letters from readers attempting to explain this astonishing phenomenon. In Loyd's own lengthy, mock-serious explanation (January 3, 1897, page 22) he called attention to a curious feature easily overlooked by a person unless he has tried the difficult task of drawing human figures properly around the rim of a disk. "The grotesqueness of the figures and a necessary legerdemain feat of changing a right leg for a left one between the fourth and fifth men does the trick. If it were not for that particular acrobatic feat, all of the men on the left side would come down head end first. Some pirates, who brought out the puzzle in different parts of Europe, with different figures, found it absolutely necessary to retain that flop over of the legs."

At that time Americans were aroused over the "yellow peril," a fact that explains the premium's unpleasant racist connotations. As if not to be partial to either China or Japan (the two nations had been at war in 1894), Loyd provided the Metropolitan Life Insurance



The Pythagorean-square puzzle

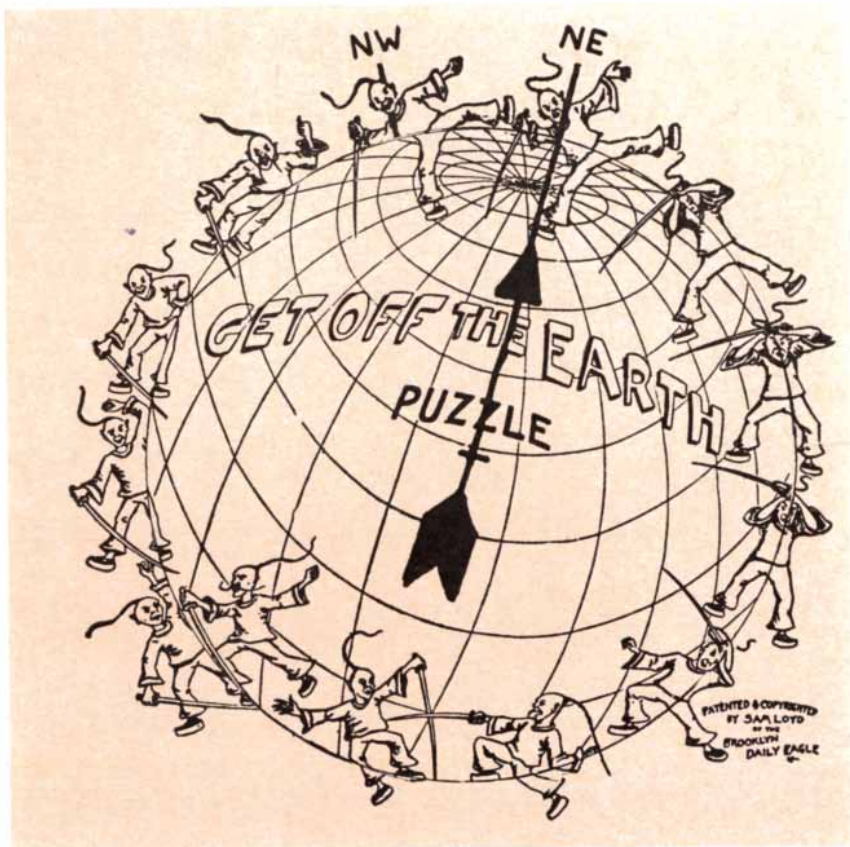
Company in 1897 with a more elaborate Japanese version of his paradox. Nine Japanese men alternate around the circle with eight lanterns. When the disk is turned, one man vanishes and a ninth lantern appears, giving the impression that a man has turned into a lantern. The premium announced a contest with 20 prizes, from \$5 to \$100, for the best explanation. Although the names of the winners were printed, none of the prize-winning letters were published. Perhaps the reason is to be found in a typical "explanation" that was quoted: "When the handle is down I find nine Japanese, but when the handle is up there are only eight, as one has disappeared." In 1909 Loyd issued a third version of the para-

dox called Teddy [Roosevelt] and the Lions, in which an African native seems to turn into a lion. It too is reproduced in the chapter on Loyd in *The Scientific American Book of Mathematical Puzzles & Diversions*.

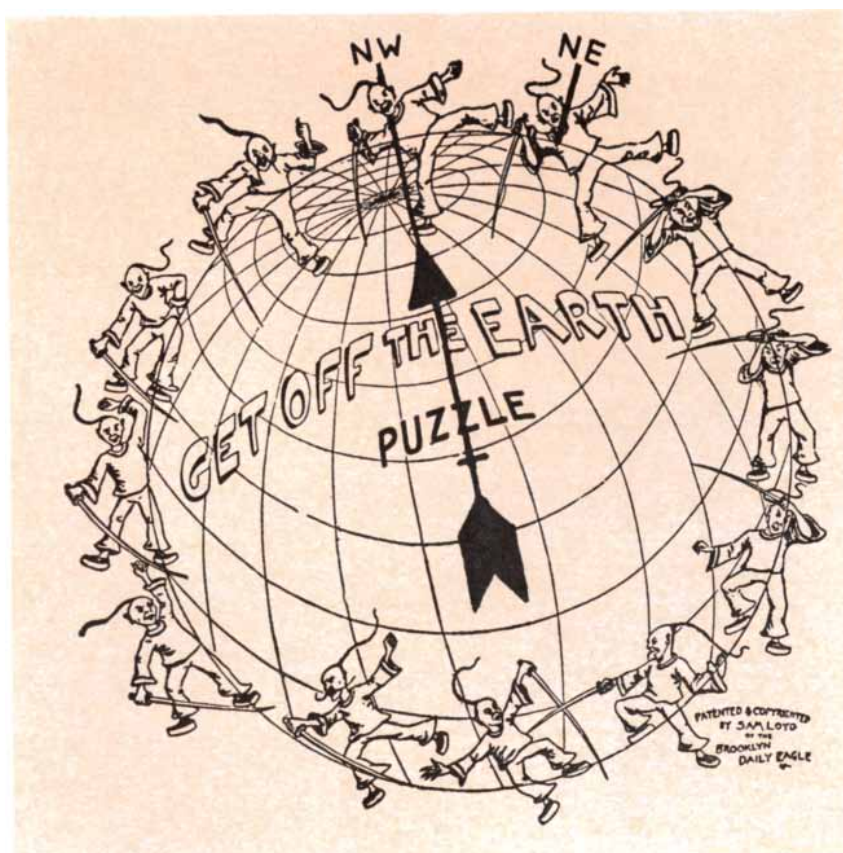
The basic principle behind Loyd's three versions was not original with him. He simply took earlier linear forms of the paradox and bent them into circular shape. I have seen in a private collection of advertising cards an 1880 premium, copyrighted by Wemple and Company of New York, called The Magical Eggs. A rectangular card is cut into four smaller rectangles. Different arrangements of the pieces produce eight, nine or 10 eggs. Scores of varia-



Sam Loyd's Pony Puzzle



Loyd's greatest puzzle starts with 13 Chinese warriors



Now there are only 12 warriors. Which one disappears?

tions on this paradox have since been used in the U.S. and abroad. The latest and funniest version, in three pieces, is *The Vanishing Leprechaun*, skillfully drawn by Pat Patterson, a Toronto graphic designer, and issued in Canada by William Elliott, a producer of puzzles and magic tricks. The paradox is reproduced in the top illustration on page 119 with Elliott's permission. An eight-by-19-inch two-color print on paper-board can be obtained postpaid by sending \$1.50 to W. A. Elliott Company, 212 Adelaide Street West, Toronto 1, Canada.

From hundreds of other mathematical premiums I select as a final specimen a card that advertises a brand of Scotch whisky [see *bottom illustration on page 119*]. This seemingly trivial addition problem trips most people whether they have had a drink or not. To obtain the correct sum the use of an adding machine is advised.

Next month I shall give answers to the dissection puzzles, but the reader will be left to himself to decide which warrior and which leprechaun vanish, and where they go.

The answers in August to July's "quickie" problems brought more surprises by mail than any previous collection. Readers caught ambiguous phrasing, indulged in amusing quibbles, found alternate and sometimes better answers, spotted some errors and argued that one problem was meaningless. I shall comment on these recalcitrant problems in numerical order.

4. C. C. Cousins and others noticed that five of the court cards in the illustration on page 104 of the August issue were drawn with heads facing in the wrong direction. Readers can try to identify the reversed-face cards before examining a deck of cards.

8. Larry S. Liebovitch, instead of using a decimal point, solved this problem by using "ln," the symbol of "natural log of." Thus $2\ln 3 = 2.19+$.

12. James A. Ulrich was the first to argue that the probability of the string's being knotted is 1 because there is no way a closed loop of string can exist without its ends being tied.

13. "House" remains the best answer, but less familiar words such as "ye" and "el" allow other solutions. George A. Miller sent a computer print-out of 269 alphabeticized answers, and all the words (from "abhor" to "wavey") are found in standard dictionaries.

14. Martin Kruskal provided a photocopy of the *New York Times* account (February 22, 1938) of Samuel Isaac

When I say Chrysler gives every Imperial a road test, I don't mean they just drive it around the block.



They give it a road test.

I've seen the way Chrysler builds cars; they really care about their product. And when it comes to the Imperial, they don't stop with just building it. They run it through a road test that gives it over 100 different checks. From the windshield wipers to the transmission.

If it's not right, they don't want you to have it. That's nice to know when you spend that kind of money for a new car.



Look inside an Imperial. Examine some of the things they check during the road test. The way the seats work. The fit of the glove box door. The operation of the windows.

Then, feel the carpeting and the upholstery. Sit behind the wheel and look around you. I think the things you can see will tell you something about the way this car's put together.

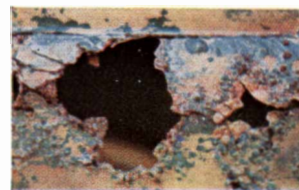


If everybody would do as much as the automobile industry is doing to clean up our environment, we'd be well on the way to solving many of our problems.

Chrysler has already done a lot to cut down pollution.

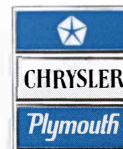
And now they've developed a new electronic ignition system that does away with the points and condenser that can wear out. You can order it on every Chrysler.

It helps keep the engine tuned longer. And a tuned engine means a cleaner exhaust.



You're washing your car, you poke at a little spot and a chunk of rust falls off. Ever have that happen to you?

Well, the Chrysler people have been doing something to help keep that from happening. They dip their car bodies in special solutions to help prevent corrosion.



Coming through with the kind of car America wants.

That's their slogan this year. And I think that's the kind of car they're building. One that lasts longer and works better than anything they've ever built before.

I drive an Imperial. What else? It's big and beautiful and plush . . . and my snooty friends love to sit back in it.

But the important thing to me is the way Chrysler puts these cars together. They want this car to last. And I think that's the kind of car America wants.





Now, the oil with EDP

Over ten years ago, Texaco introduced 'Stop Loss'—an organized lubrication control system with limitless application.

Taking a lubrication system and adding EDP should be simple. But Texaco had to do more. You see, every company's system is unique. Computerize a paper mill's lubrication system and you've done one. Now you have trucking firms, pharmaceutical houses and cotton mills. And each system is different.

What Texaco did was to put our

lubrication engineers and computer experts together to come up with a system which would easily adapt to any company, any plant, any process. And work exceptionally well.

And they did. We call it Texaco COMPUTEX. It took two years to complete.

Texaco COMPUTEX is a computerized lubrication control program that easily adapts to every industry.

Written in COBOL for the IBM System 360, the program matrix can be used

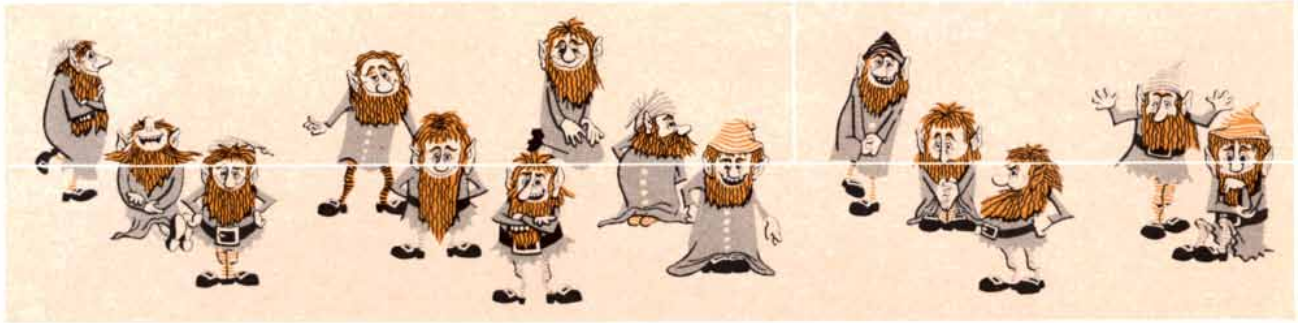
Scheduling under the program can be done for all machinery by either date, mileage, time usage or throughput.

Texaco's unique knowledge about industries it serves now creates an interface of lubrication and computer technology. One more step to better service.

At Texaco it happens every day.

We're working to keep your trust.





Which leprechaun vanishes?

Krieger's preposterous claim to have disproved Fermat's last theorem. He had saved the clipping since he had seen it as a small boy.

15. Solomon W. Golomb proposed "underfund" and "underwound" as alternate answers.

16. The probability of $1/2$ that a distant viewer will see three sides of the Pentagon is correct only as a limit as the viewer's distance from the Pentagon building approaches infinity. My solution ignored the fact that there are five infinitely long strips, each crossing the building, inside of which both the viewer and his *Doppelgänger* can see only two sides (and if very close to the Pentagon, only one side). This was pointed out by David J. Abineri, Warren Buell, Jerry Griggs, Thomas E. Jensen, Bruce P. Kirk, David Lupo, H. Don Park, David E. Peterson, Stephen H. Rich and many others who wrote later. The probability is zero, commented P. H. Lyons, "if the smog in Washington is anything like what it is here in Toronto."

17. Walter C. Eberlin added two strokes to 11030 so that when it is viewed in a mirror it spells "peon."

23. When George said that Feemster "owns fewer than that," I meant him to mean fewer than the amount specified by Albert. If "that" is taken to refer to "a thousand" instead of "more than a thousand," however, Feemster could own exactly 1,000 books as well as none. So many readers reported this that listing their names is not feasible.

24. Howard J. Frohlich passed along

a friend's view that a date such as 8/8/71 could also be called "ambiguous" because you do not know whether the first 8 refers to the day or the month.

25. Since I failed to ask why manhole covers *and holes* are round instead of square, scores of readers sensibly replied that the covers are round to fit the holes. John W. Stack cited as his authority for this answer M. A. Nhole's *Comprehensive Review of Equilateral Rectangular Beams and Circular Receptacles*, pages 31-4207, published in 1872 by the Sewer and Street Company, Inc. P. H. Lyons had another answer: To reduce the decisions a sewer worker has to make in replacing the cover. Some covers and holes *are* square, according to John Bush, who told of a recent explosion near his home in Brooklyn that blew off a Consolidated Edison square manhole cover. After the smoke cleared the cover was found at the bottom of the manhole. "*Geometria invincibilis est*," Bush concluded.

28. The Hamlet rebus, "To be or not to be," was invented by Golomb, a fact I did not know when I gave it.

32. "Can you answer this?" Golomb wrote. "No, U Thant!"

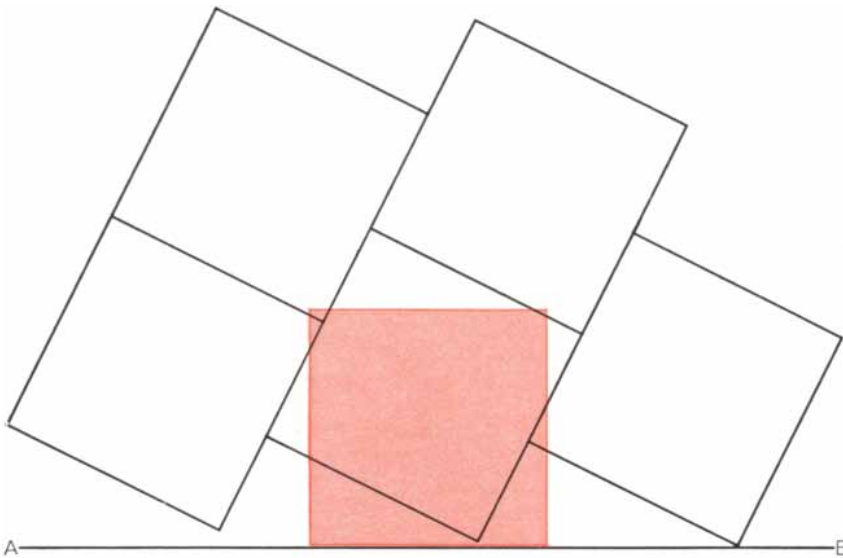
33. The problem of the touching cubes was one I thought of several years ago and had answered with 20 cubes. I was staggered to receive two different solutions, each with 22 cubes. The top illustration on the next page shows how five white cubes can abut the top side of the red cube. Since none extends beyond line AB, this formation can go on four

sides of the red cube [see bottom illustration on next page]. Two more cubes plug up the holes on face A and its opposite side. This solution was first received from Kenneth J. Fawcett, Jr., senior research scientist at Scope Electronics, Inc., Reston, Va., and later from Rudolf K. M. Bergan, Michael J. and Alice E. Fischer, Leigh Janes, K. B. Mallory, Allen J. Schwenk and George Starbuck.

Can you add this column of figures? Place your hand over all but the top number and move it down the column, revealing one number at a time. Add all the numbers, as you go along. When you get the total, turn over for correct answer.

1 0 0 0
4 0
1 0 0 0
3 0
1 0 0 0
2 0
1 0 0 0
1 0

An advertising giveaway card

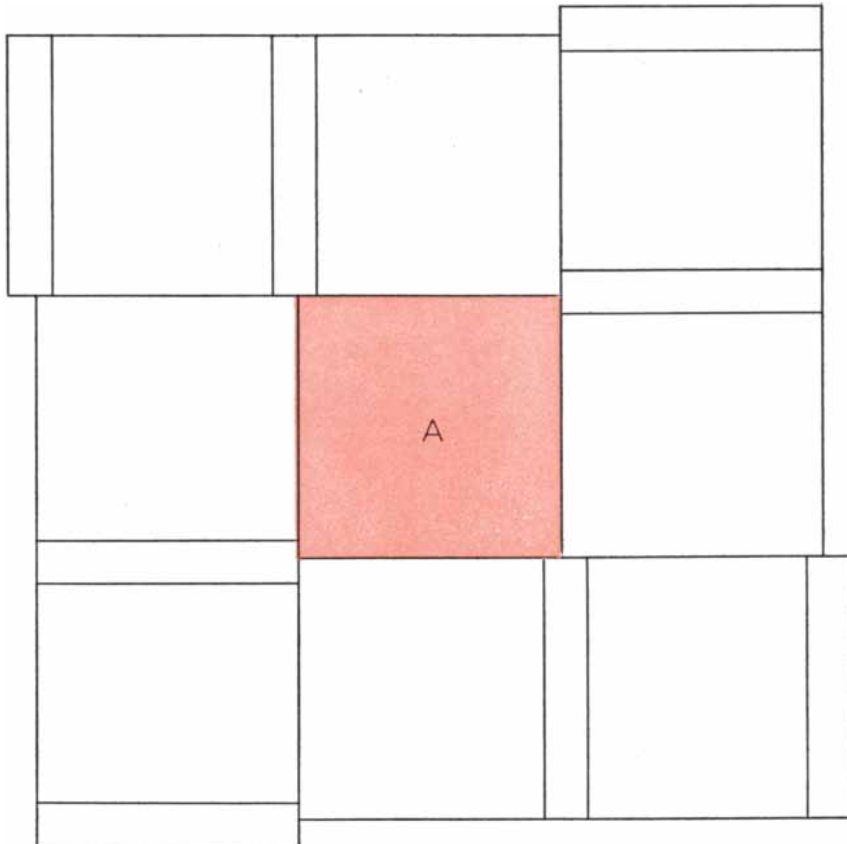


Five cubes about one side of the red cube

The other solution, found independently by Bergan, Rudolph A. Krutar and Robert S. Holmes, is shown as drawn by Holmes [see illustration on opposite page]. Eight cubes go on two opposite faces of the red cube, and six about the red cube in the middle layer. Even the fact that as many as eight nonintersecting unit squares can overlap one unit

square is, as far as I know, a previously unknown result.

While I was still recovering from the 22-cube solution, Holmes (who is working for his doctorate in particle physics at the University of Rochester) delivered the knockout punch: a 24-cube solution! Later Janes, in collaboration with Michael Bradley, reported a 23-cube solu-



Arrangement for 22-cube solution

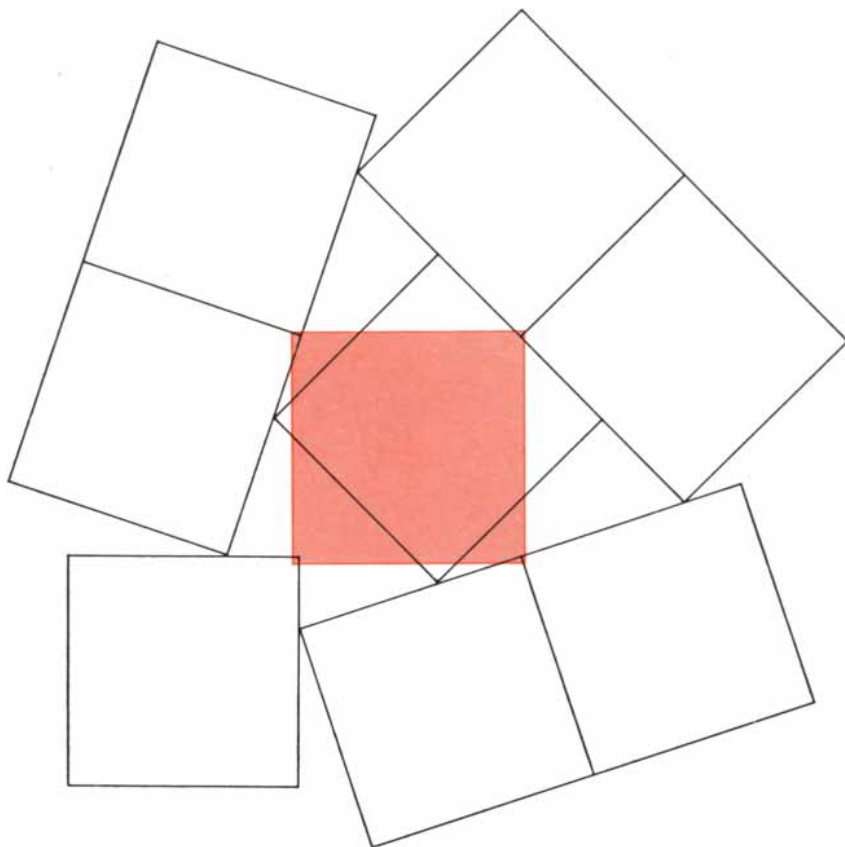
tion. Since the 24-cube solution takes considerable space to explain, I must postpone disclosing it until next month.

35. If the rope is hemp, wrote Lyons, the nonswimmer could smoke it and fly.

36. This question (about the boy, the girl and the dog) stirred up a hornet's nest. Some mathematicians defended the answer as being valid, others insisted the problem has no answer because it is logically contradictory. There is no way the three can start moving, it was argued, because the instant they do the dog will no longer be between the boy and the girl. This plunges us into deep waters off the coast of Zeno. The issue will be discussed in detail next month.

John C. Comfort and Ken Rosenbaum were the first of numerous readers to point out that the proof given in August, that the second player cannot have a winning strategy in go-moku, applies to finite boards only when the game is played without the rules prohibiting forks and six-in-a-row wins. The first player, who in Japan always plays black stones, is unable to steal a second-player strategy by making an irrelevant first move because either of the restrictive rules could make this play a liability. "White-stone players of the world, take heart," concluded Rosenbaum. "There is yet hope." I also neglected to add that traditional go-moku rules allow violation of the fork rule when such a play is necessary to block an immediate win, a qualification involved in the solution of David L. Silverman's problem.

Exciting new discoveries have been made concerning John Horton Conway's game of Life, discussed in this column in October, 1970, and February of this year. R. William Gosper, Jr., of the Massachusetts Institute of Technology's Artificial Intelligence Laboratory, has found a new glider gun, more compact spaceship factories, a puffer train that puffs out stationary blinkers while it moves with half the speed of light, and a puffer train that puffs out gliders. His associate Roger Banks has discovered what is probably a Garden of Eden pattern inside a nine-by-13 rectangle. The M.I.T. group has also discovered a variety of remarkable new Life forms: periodic objects, glider-eaters, glider-reflectors, and so on. An extremely fast program for Life oscilloscope displays has been written by Steve Root of the Digital Equipment Corporation. (It tracks the R-pentomino through its 1,103 generations in 19 seconds!) The group has completed a 17-minute film that should be much in demand. For de-



Another 22-cube solution

a biography
by Cornelia V. Christenson

Kinsey
kinsey
kinsey
kinsey

tails on these and other developments readers can consult the current (third) issue of *Lifeline*, a newsletter about Life issued by Robert T. Wainwright, 1280 Ederis Road, Yorktown Heights, N.Y. 10598.

Last month's six Halma problems can be solved as follows, but none of the solutions is unique:

1. Counter 6 steps diagonally up and right, 8 (or 4) steps diagonally down and left, 5 jumps all counters to end at the center.

It is possible in three all-jump moves (no steps) to end on either a corner cell or a side cell of the original pattern, but when steps are not allowed, four moves are necessary (they were given last month) to reach the center. Two moves suffice to remove eight counters but the survivor will be outside the original pattern.

2. Counter 4 steps up, 3 jumps 8, 9, 4, 1, 2, 5, 6, then 7 jumps counter 3.

3. Counter 6 steps up, 8 (or 4) steps down, 5 jumps all counters to rest on the center cell. This pattern and its solution are equivalent to the first problem, with each diagonal move changed to vertical and each vertical move to diagonal, all horizontal moves remaining

the same. There are similarly equivalent patterns and solutions on the checkerboard and the Chinese checkers board.

4. Counter 6 can jump all counters in one move, returning to its original cell at the center. The problem is equivalent to a 10-counter equilateral triangle on the Chinese checkers board.

5. Counter 11 hops diagonally up and right (eliminating counter 8), 6 jumps 10 counters and returns to its former cell, then 5 removes 6 as it leaps to the center.

6. Counter 8 steps diagonally up and right, 14 jumps 9, 1, 3, 11 and returns to its former spot, then 8 jumps 11 counters to end on the cell originally occupied by 11.

Another problem, a three-by-four rectangle on a five-by-six field, not given last month, can be solved in three all-jump moves, the final counter resting on any of the 12 cells of the original pattern. In two moves the board can be cleared but the last counter will be outside the original pattern.

If readers find shorter solutions for any of these problems, or for the three diagonal-transfer Halma problems given last month for square boards of orders 6, 7 and 8, I shall report the results in a later article.

"Gentle, witty and full of quotations. There is no chutzpah as effective as plain, unshocked, Quaker-style frankness. That was Kinsey's secret weapon."

Alex Comfort, *Book World*
"A thoroughly interesting portrait of Kinsey as a scholar and painstaking man of science."

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Conducted by C. L. Stong

Several years ago Michael E. Meichle, who was then a student at Skyline High School in Idaho Falls and is now a freshman at the University of Montana, set out on an unusual line of experimentation: smashing glass. He broke old window glass, new window glass and occasionally lamp bulbs. In 30 months of experimenting he destroyed some 200 pounds of glass. In addition he made more than 4,000 high-speed photographs of glass-smashing and compiled a report of the experiments that won a top place for him at the 21st International Science Fair. The experiments demonstrated that glass fractures in predictable patterns and that the strength of the material can be altered by fairly simple procedures. Meichle discusses his experiments as follows:

"Three years ago a small telescope mirror that I had been grinding and polishing for nearly a year accidentally slipped from my hands and landed on the concrete floor. Instead of shattering as I expected, the glass simply cracked. Moreover, it continued to crack for several days. I could see the fracture advancing steadily toward the edge and thought the glass would eventually fall apart in my hands. Instead the growth rate of the crack decreased as the internal stresses gradually approached equilibrium. The disk remained intact. It was useless as a telescope objective, of course, but it was not a total loss. It introduced me to an engrossing new hobby: making experiments that show the basic fracture patterns of glass and demonstrate that various surface coatings influence the resistance of glass to fracture by impact.

"I started the project by making a number of assumptions about fracturing and then testing each assumption with

THE AMATEUR SCIENTIST

*An amateur breaks glass with a purpose:
to determine the patterns of fracture*

an experiment. For example, it seemed reasonable to suppose the strength of glass would depend in part on its chemical composition. In other words, the strength of soda-lime glass might reasonably differ from that of lead glass or borosilicate glass. Similarly, it seemed reasonable to suppose the size and thickness of a specimen would influence its strength, as would the condition of its surfaces. A small, scratched specimen might tend to break more easily than a large specimen with unmarred surfaces.

"One important assumption was made in the interest of minimizing the cost of the project. It seemed reasonable to suppose glasses of all kinds might fracture the same way even though each kind differed in its resistance to fracture. For example, a piece of relatively costly borosilicate glass might be more resistant to fracture than a comparable specimen of inexpensive soda-lime glass, but both pieces would fracture similarly when subjected to an appropriate impact. On this assumption most experiments were made with specimens of window glass. The experiments demonstrated that window glass fractures in predictable patterns. Subsequent experiments proved that costly glasses fracture the same way.

"Most specimens consisted of new window glass cut into squares that varied in size from one inch to four inches. Distributors of window glass routinely fill orders for panes of specified dimensions by cutting narrow strips from sheets of standard size. The strips are discarded. When I explained my project to our local hardware dealer, he invited me to help myself from his scrap barrel. I chose strips of appropriate width and sliced them into squares with a glass cutter of the wheel type.

"I learned to choose the glass with care. The strength of the material is altered by the condition of the surface. Old glass tends to be unpredictably weaker than new material, particularly if it has been exposed to weather. The strength of new glass is reduced by surface defects, including minute scratches that may be almost invisible.

"Window glass is available in at least two thicknesses: standard and double weight. When making tests, the specimens must be grouped according to thickness. Indeed, I segregate all specimens that are cut from the same sheet and test them in sequence so that account can be taken of manufacturing variations in the quality of the product that occasionally arise from differences in composition, annealing and handling.

"I assumed that the apparent strength of a sheet of glass would be influenced by its supporting structure. For example, a sheet that is supported by a solid anvil and receives a fracturing blow in the center might break differently from one clamped at the edges so that it can bend and thus yield in the direction of the force. To check this assumption I made a simple test fixture [see illustrations on opposite page]. It consisted of a slab of plate glass six inches square and 3/8 inch thick and two strips of the same glass two inches wide and six inches long. The square slab could be supported over a hole in the top of a strong box that contained a xenon flash lamp for making high-speed photographs. A specimen to be broken could be put directly on the slab for support over its full area. Alternatively, the two strips could be put on the slab and spaced at any distance, so that the specimen could be placed across the strips, like the span of a bridge, for support on two sides but not in the middle. A force directed downward at the unsupported middle would cause the specimen to bend more or less depending on the spacing of the slabs. Nonuniform bending can be induced by placing the strips at an acute angle.

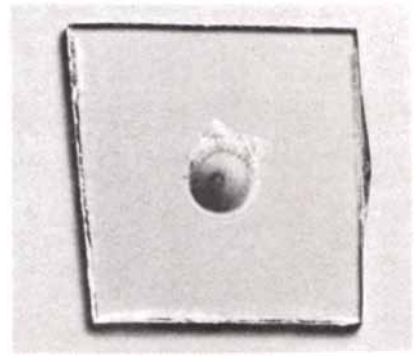
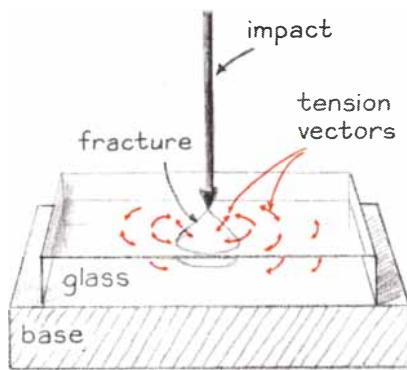
"All specimens were broken by impact. The scheme used most frequently for developing reproducible impacts entailed dropping a steel ball of known mass onto the glass. I assumed that the minimum force of impact required to break the specimen gave a measure of the relative strength of the glass. Because impact varies with the height from which the ball is dropped, the relative

strength of a specimen can be recorded as the minimum distance through which a ball of known mass must fall to break the glass.

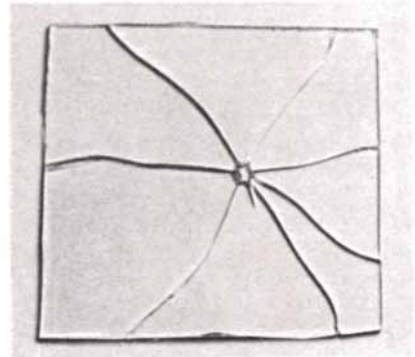
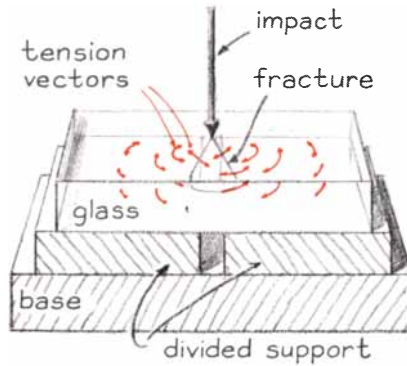
“Several devices were built for dropping the ball. The simplest scheme worked best. It is a wood clothespin of the coiled-spring type fitted with a peep sight made of wire. The ball is clamped in the jaws of the clothespin. To break a specimen I hold the assembly above the glass at the desired height, take aim and release the ball by squeezing the handles of the pin. As an aid in aiming the ball I place a rectangular grid behind the fixture that supports the specimens. The force of impact varies with both the mass of the ball and the height from which it is dropped. I used ball bearings in a range of diameters from 1/4 to 15/16 inch. Most specimens were broken with 3/4-inch and 15/16-inch balls.

“A few specimens were broken by placing a steel rod vertically against the glass and striking the top of the rod with a hammer. This scheme was particularly handy for making high-speed photographs of fractures, although the force of the impact could not be closely controlled. The rod and the head of the hammer are connected to the trigger circuit of an electronic flash lamp [see top illustration on next page]. They function as an electric switch that closes when the head of the hammer hits the rod. The lamp can be triggered in advance of impact by fastening an extension of aluminum foil to either the top of the rod or the head of the hammer. The interval of time between the flash and the impact varies with the length of the foil extension. By adjusting the length of the foil one can photograph the fracture at various stages of development.

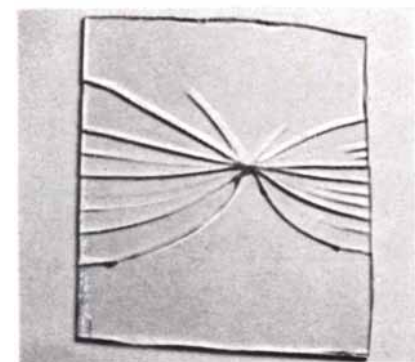
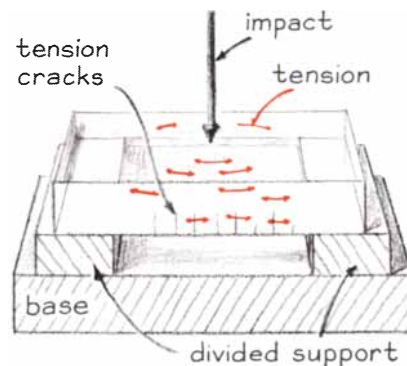
“I also built an apparatus for breaking lamp bulbs. It consists of a weighted



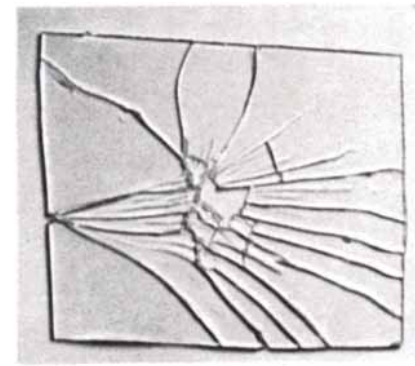
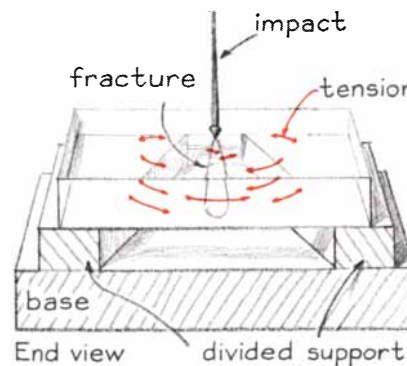
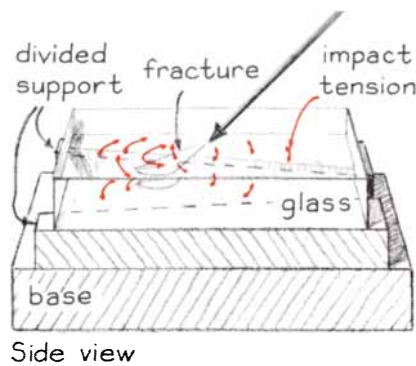
A "Zone 1" fracture plotted (left) and photographed (right)



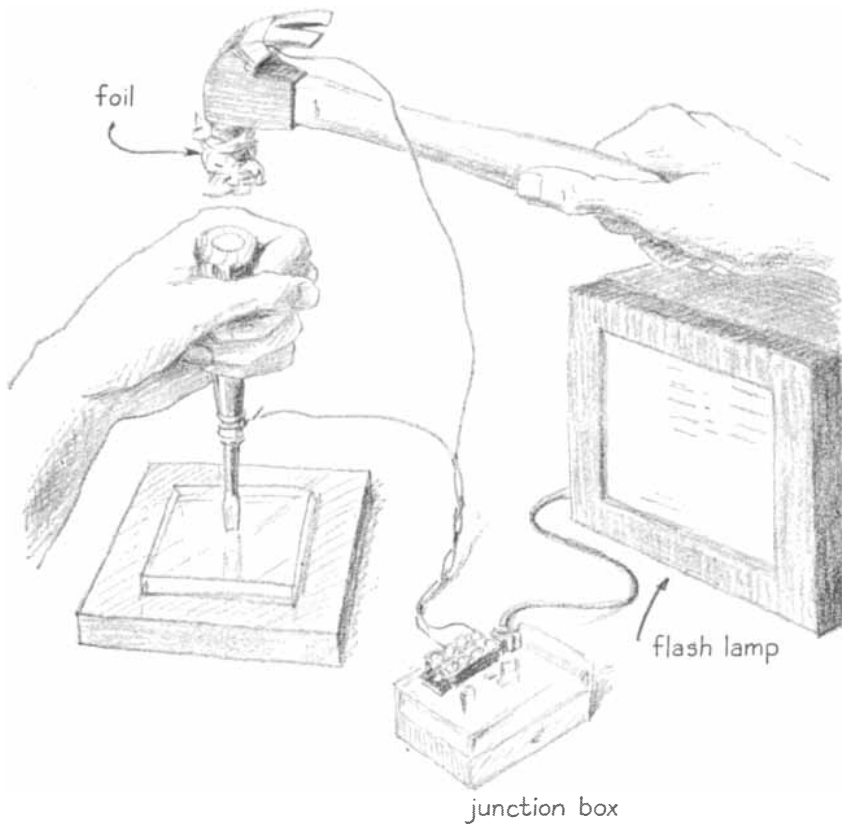
A Zone 2 fracture



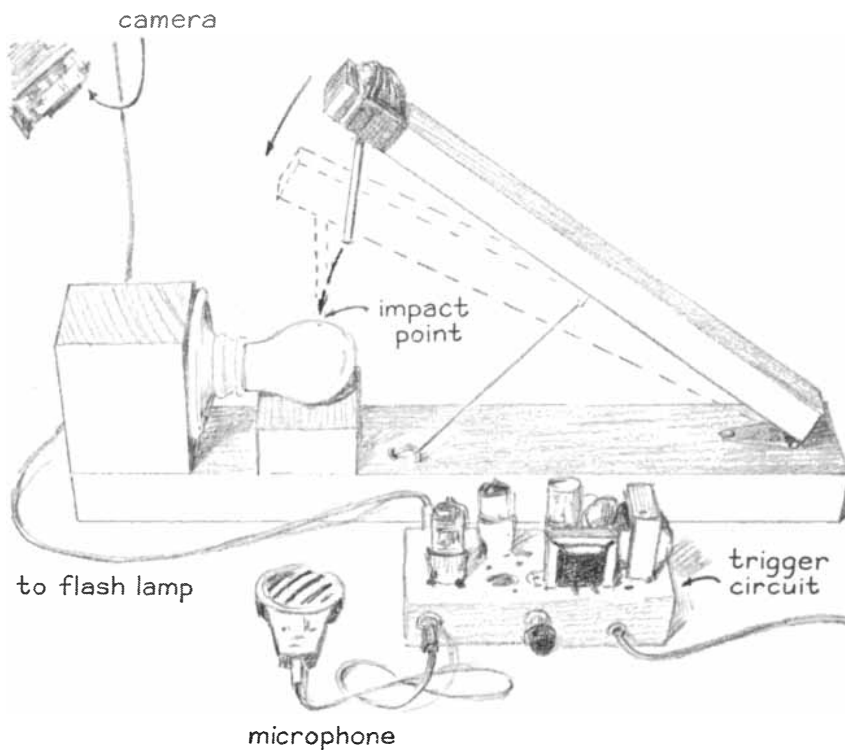
A Zone 4 fracture



Oblique impact (left) and vertical impact (center) producing a Zone 3 fracture



Michael E. Meichle's arrangements for photographing fracturing glass



Bulb-smasher with "sound slave" apparatus for triggering a flash lamp

arm hinged to a horizontal base [see bottom illustration at left]. The arm swings in the vertical plane and carries a steel rod at its free end. When the arm falls, the end of the rod strikes the bulb perpendicularly to its upper surface. The bulb is supported horizontally by a socket. The lower surface of the glass rests on a block of wood that is solidly mounted to the base.

"It is possible to determine the final pattern of fracture by reassembling the fragments of a broken specimen, but the operation is tedious and time-consuming. My observations were made with high-speed photography. I used a 35-millimeter camera and a \$15 electronic flash lamp.

"Although the camera has an electric switch for synchronizing the flash with the operation of the shutter, I did not use it. Instead I set up experiments in a room that can be darkened. After the camera has been focused on the specimen I darken the room, open the shutter for a time exposure and trigger the flash by one or another of three devices that are actuated by the experimental apparatus. The shutter is then closed by hand. Light reaching the film is provided solely by the flash. The exposure time is determined by the duration of the flash. The flash of my lamp persists for about .0005 second. A flash duration of .001 second or less is adequate for photographing most experimental events, including the fracturing of a lamp bulb.

"One of my three schemes for triggering the flash consisted in wiring the flash unit to a steel rod and the head of a hammer. In another scheme the trigger circuit is connected to a pair of narrow strips of aluminum foil separated by about an eighth of an inch. The strips are placed in the path of the falling ball. The ball bends the strips into contact, thus closing the circuit that flashes the lamp. A thin strip of wood cemented between the foils at one end supports the structure.

"Switches of this general kind can be constructed in various obvious ways. All such switches close the triggering circuit in advance of the moment of impact. Electronic flash lamps do not reach full brilliance at the instant the triggering circuit is closed. The characteristic time lag that separates the two events can be determined experimentally.

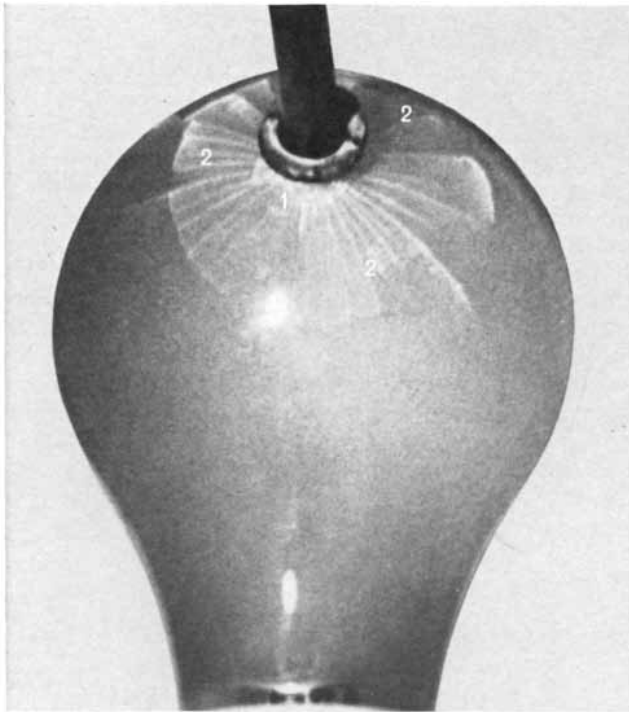
"Most of my photographs were made with a third device, which triggers the flash after impact. The apparatus is known as a "sound slave." Noise made by the impact triggers the lamp.

“Sound slaves can be bought for \$20 and up from dealers in photographic supplies. I made one that is described by Ray E. Pafenberg in the January 1965 issue of *Popular Electronics*. It consists essentially of a microphone that picks up the sound of the impact. The result-

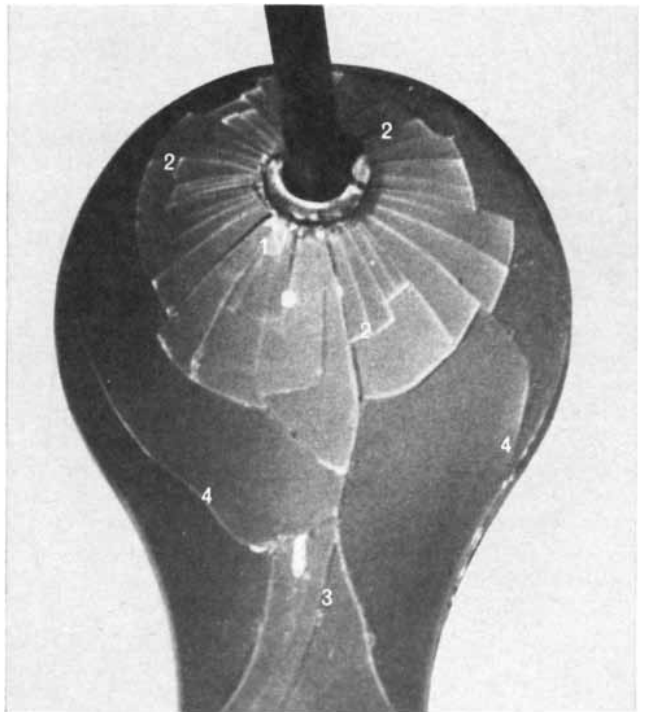
ing electrical pulse, after amplification, operates a fast electronic switch. The switch closes the triggering circuit of the flash lamp.

“The interval of time between the impact and the flash varies with the distance between the microphone and the

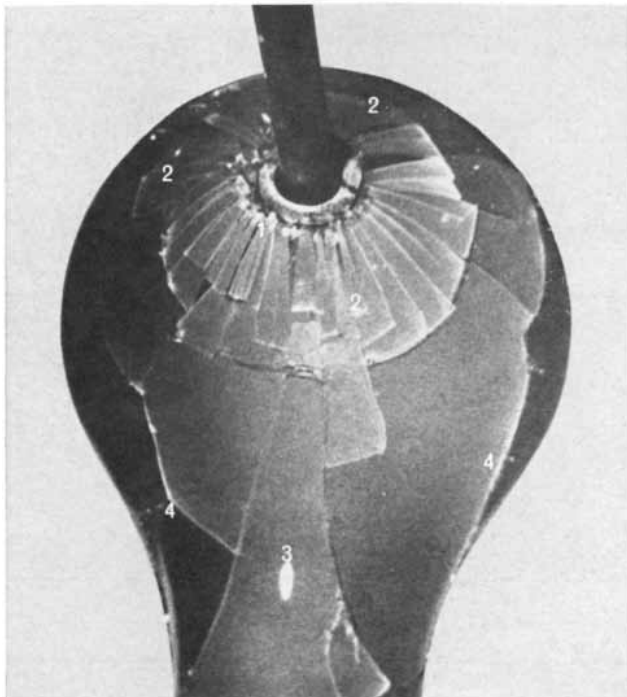
specimen. Sound waves travel at a velocity of about 1,100 feet per second. This delay must be added to the characteristic interval between the instant when the triggering circuit is closed and the moment when the flash develops maximum intensity. Care must be taken



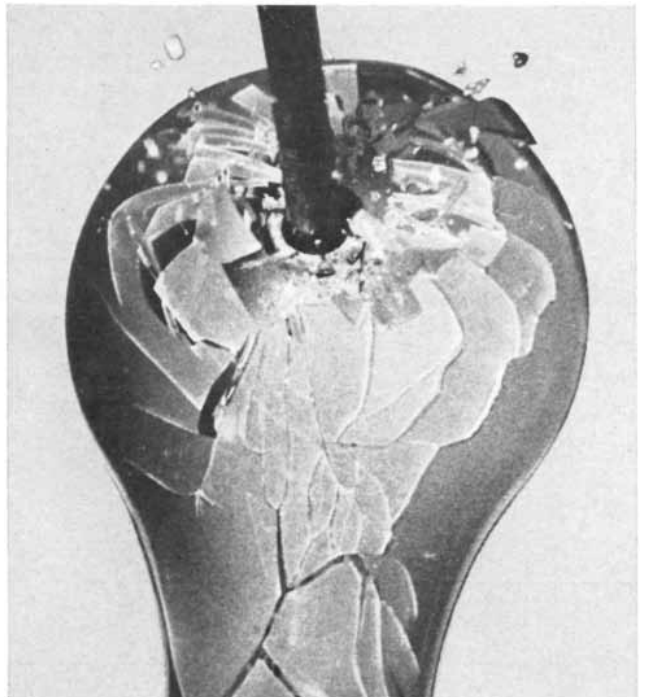
Bulb fracture at .001 second



Bulb at .002 second, zones numbered



Bulb at .003 second



Bulb at .004 second

to avoid spurious or unwanted flashes.

"The microphone should be placed on a soft pad for insulation against vibration. I learned to walk softly and breathe quietly. Fortunately flash units require a few seconds to recharge after delivering a flash. I take advantage of this interval to perform noisy operations that would otherwise trigger unwanted flashes.

"For example, after placing the specimen on its fixture and loading the clothespin with a ball I turn off the room lights. I then move to the position from which I shall release the ball. Next I turn on the power and test the flash lamp by snapping my fingers. As the flash unit recharges I open the shutter of the camera and wait for the 'ready' light to appear. The ball is released. If all goes well, the apparatus makes a photograph of the fracture automatically. I then close the shutter, turn off the photoflash apparatus, turn on the room light and prepare for the next experiment.

"From what height should a ball of known mass be dropped to break a given specimen? How far should the micro-

phone be placed from the specimen to photograph the event? The answers must be determined by experiment. The ball is dropped from increasing heights until the specimen breaks. Another specimen of identical size is then placed on the fixture and subjected to the same final impact. It may fail to break. (The first specimen may have been marred and thus weakened by repeated impacts.) The height of the drop is increased and the ball is dropped again. Eventually the experimenter finds the minimum height for breaking most identical specimens. Enough specimens are then broken to compile a statistically valid result.

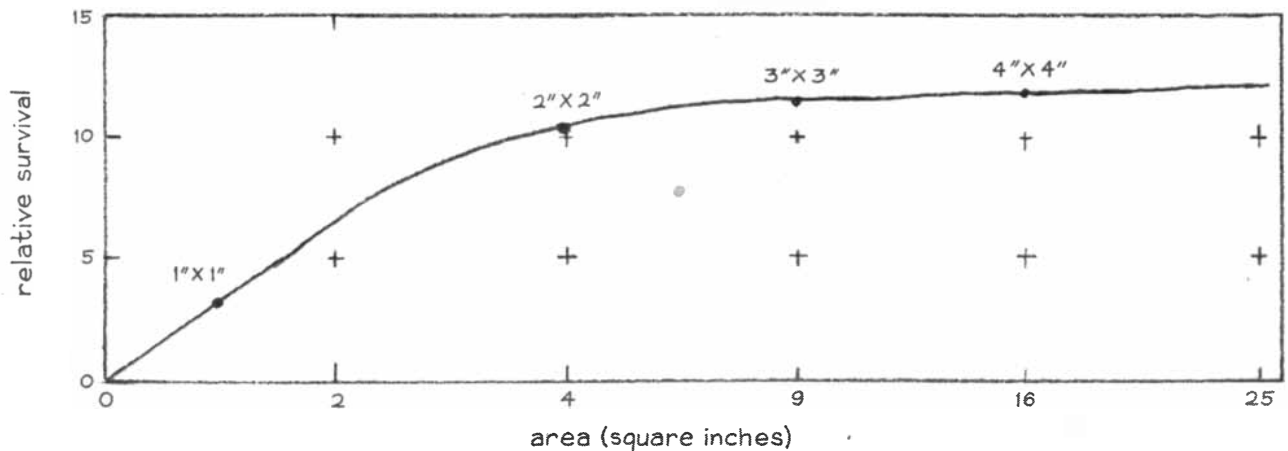
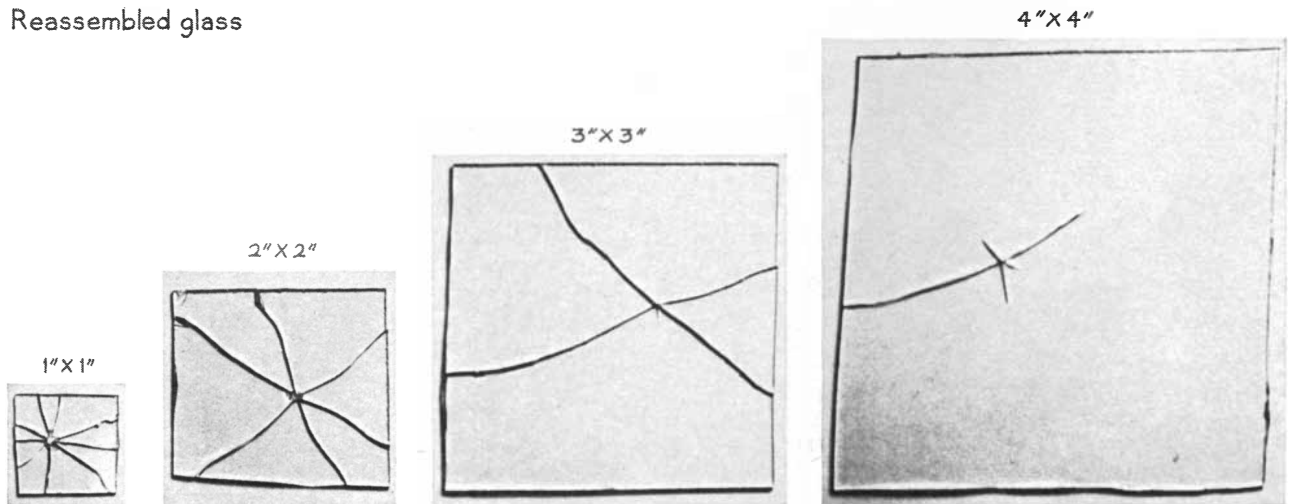
"Little can be learned by fracturing a sheet of glass unless the event is photographed. At first it appeared as if the cost of photographic supplies might exceed the limit of my pocketbook. I found several ways to reduce the cost. For example, I used 35-millimeter film because it costs less than larger sizes. Moreover, it can be bought in bulk rolls and hand-loaded into cassettes at a saving of al-

most 75 percent over the cost of pre-loaded cassettes. In addition 35-millimeter film in bulk is available on the surplus market at a fraction of its retail price. The surplus material is outdated and inferior in quality to new stock, but it is adequate for testing apparatus and making nonessential records that will not be printed.

"I also made substantial savings by developing my negatives at home. It is not necessary to master the art of making prints or to invest in a projection printer. I judged the results of experiments by examining the negatives directly. Prints were made of relatively few exposures, primarily for use in my final report. Learning to read the negatives has a secondary advantage. The results of an experiment can be examined as soon as the wet film comes out of the fixing solution, usually within less than 15 minutes.

"Although fracture patterns of many kinds were recorded during the course of the experiments, four basic types were observed in every experiment, ei-

Reassembled glass



Resistance to fracture related to size of glass

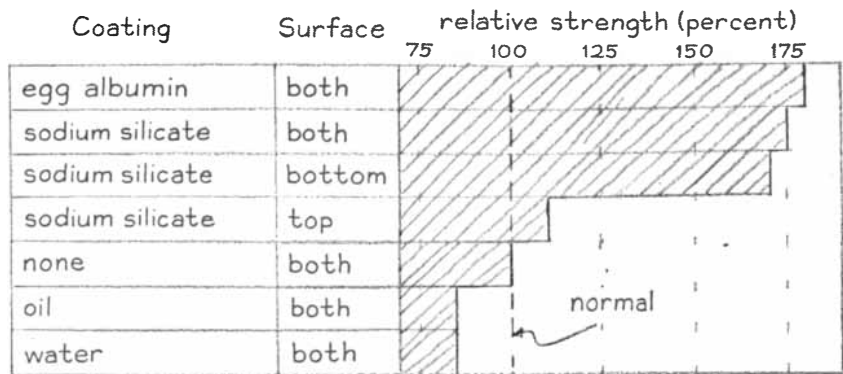
ther singly or in combination, and their causes were identified. The basic patterns of fracture can be produced at will by establishing appropriate experimental conditions. For want of a better term I refer to the basic patterns as fracture zones, primarily because I originally supposed that the basic patterns were confined to limited areas of the glass. The assumption was subsequently disproved, but I retained the name nonetheless.

"The experiments demonstrated that a sharp blow by an object of low mass and high velocity will create a cone-shaped fracture at the point of impact on the surface of a sheet of glass that is rigidly supported. I refer to the break as a Zone 1 fracture. It is the first fracture to appear after impact and seems to be caused by shear stress.

"To confirm this assumption I made a model of clear plastic that represented the cross section of a glass sheet and loaded it at a certain point to simulate an impact. When the loaded model was examined with a polariscope, shear stress could be seen in the pattern of a Zone 1 fracture. (Incidentally, a small pellet at high velocity that strikes a thick sheet of glass, such as an unsupported slab of 1/4-inch plate glass, can transmit a shock wave through the material from the Zone 1 fracture that detaches a smooth cone of glass from the rear surface. The detached cone leaves a clean tapered hole through the slab that diverges from front to rear. I am told that such holes frequently appeared in the windshields of automobiles in the days of gravel roads before the introduction of shatterproof glass.)

"Zone 2 fractures consist of a radial pattern of cracks that spread from the point of impact. The pattern originates in the Zone 1 fracture and appears to be caused by a shock wave that radiates from the impact. I recorded the shock wave by making high-speed color photographs of breaking specimens through crossed sheets of Polaroid. One polarizing sheet was placed in front of the flash lamp so as to direct polarized light upward through the specimen. The second sheet was placed in front of the camera lens and was rotated to the position where minimum light is transmitted by the unstressed specimen. The apparatus therefore acts as a polariscope.

"Fractures of the Zone 3 type appear when the glass is not supported evenly or when the impact is applied at an angle with respect to the surface of the glass. As with all fractures, the glass fails under tension. Tension may develop when



Influence of surface coatings on strength of glass

an area of glass is pushed in the direction of the impact or bent in the direction of least support. Stress patterns that accompany Zone 3 fractures were also photographed in polarized light.

"Fractures of the Zone 4 type appear when glass is caused to bend substantially under impact. The deformation creates tension in the lower surface. The fracture is explosive when the force exceeds the strength of the material. The fractures radiate from the point of impact in the direction of least support. For example, if opposite edges of a square specimen rest on a pair of parallel supports and impact is applied at the center, the fractures radiate in the form of an hourglass. Zone 4 usually develops as the final pattern of a complex fracture.

"The four zones appear either singly or in combination when soda-lime glass is broken by impact. Their distribution can be predicted if the physical conditions under which the break occurs are known. By taking zone characteristics into account one can predict how a glass object of complex shape will break. For example, a Zone 4 fracture can be expected in an area of the object placed in tension by a bend. Similarly, one would expect to find Zone 3 fractures in a region of glass that is stretched by impact.

"I found it interesting to predict the patterns into which a lamp bulb would fracture and then check the accuracy of my guess by experiment. First I examined the shape of the bulb and took into account its supports as well as the point where the impact would be applied. I then broke the bulb and several others so that fracture patterns could be photographed at various stages of development. I would have preferred to break a single bulb and photograph the developing fracture with a high-speed motion-picture camera, but this equipment was beyond my means. I satisfied

myself by experiment that similar lamps fracture the same way, as depicted in the four accompanying photographs [page 125] with superposed numerals that indicate fracture zones by type. Impact was applied to the upper surface of the bulb by the falling rod. The glass did not bend at the top of the curve. A Zone 1 fracture developed at the point of impact. Primary shock at this point initiated Zone 2 fracturing that radiated as needle points from the Zone 1 fracture. The shock of inrushing air created a force that tended to tear the lamp from its socket and stretched the triangular area at the top of the bulb near the base. As a consequence needle-shaped fractures of the Zone 3 type developed in that area. As the action continued Zone 2 fractures were stressed inwardly by the moving air, putting the sides of the bulb in tension. The bending caused Zone 4 fractures to develop randomly in the sides. Finally, Zone 2 fractures broke off and were pulled completely inside the bulb. The zones continued fracturing and the fragments separated. The bulb collapsed.

"During the course of the experiments I observed that the resistance of sheet glass to fracture by impact increases with area. When a series of specimens are broken under identical conditions, including equal impacts, the size of the fractures varies inversely with the area of the glass [see illustration on opposite page]. Surface coatings also influence the resistance of glass to shock. A soiled or wet window of soda-lime glass will fracture more readily than a clean window. Conversely, window glass that is coated with a film of egg albumin or sodium silicate and then dried is substantially more resistant to fracture by impact than clean glass. My investigation of the influence of such coatings was limited. The accompanying chart [above] displays the results of a few experiments."

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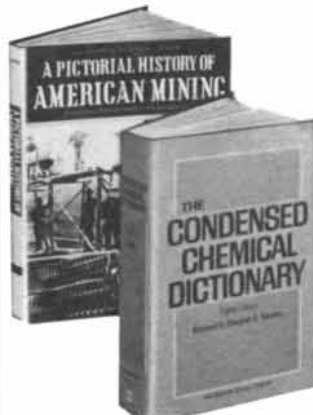
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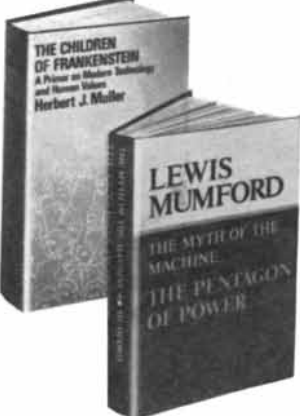
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BOOKS

Attitudes toward dying, the iridescence of animals and the work of G. I. Taylor

by Philip Morrison

THE DYING PATIENT, edited by Orville G. Brim, Jr., Howard E. Freeman, Sol Levine and Norman A. Scotch. Russell Sage Foundation (\$10). Five thousand Americans will die tomorrow, and tomorrow, and tomorrow. Out of New York toward the new graveyards that ring the city 30 or 40 miles away the cars of mourners race, "streams of headlights, incongruously glowing in the daylight," past the trucks and the travelers. A car or two can become detached from "the proper object of its grief" and follow a stranger to the grave. Each day several score of such headlong corteges form and scatter. The volume and the bureaucratic centralization of these funeral rites are characteristic of our times. But the dying itself, the inevitable terminal act of all our lives, has not yet been managed: "What was once a natural event is emerging as a social problem."

There are three trends that prescribe the issues; they each form a motif around which some papers of this sober volume gather. The first is the present nature of American mortality: gone are the frequent deaths of childhood, the result of contagious disease. In our small families many people will encounter no one's death intimately until they are gripped by the death of a parent. The second trend is the clear shift of the place where people die. Once only the friendless and the poor died in the hospital; now two-thirds of all Americans die in general hospitals. Among the major causes of death only the quick ends—by accident, by stroke, by diseases of the heart—yield at least an even chance of death at home. (In New York City fewer than 3 percent of all deaths occur neither in an institution nor in the home.) The third trend is that the terminal business of life becomes more and more protracted, and the physician has an increasing power to fix its length.

Yet doctors and nurses are by instinct

and training poorly prepared to deal with the dying. The poet W. D. Snodgrass, who served as an orderly in a Veterans Administration hospital, expressed the resentment of the young forced to attend to a whimpering old man who would not die:

*They'd say this was a worthwhile job
Unless they tried it. It is mad
To throw our good lives after bad;
Waste time, drugs, and our minds, while
strong
Men starve. How many young men did
we rob
To keep you hanging on?*

The heroic act of life extension, with its intravenous administration of food-stuffs, drugs and blood, its antibiotic prevention of the familiar fatal pneumonia in the incurably ill, its beating back of malignant tumors by radical therapy, its mechanical and chemical means of maintaining breath and heartbeat in patients with loss of consciousness, is profoundly costly. It calls not only for money but also for will, energy and devotion.

In a county hospital the poor rarely receive such attention; it is easier there for a doctor to write off any patient as hopeless. In a middle-class hospital the private physician will not want to be regarded as having "given up." In such a hospital the audience for the doctor's prediction of death is the family and his colleagues; in the public ward there is no one to listen, and strong measures, say of surgical repair, are withheld unless they promise results of medical interest. "The patient continued downhill to death." There particularly death is social, not merely physical; the institution determines to treat the dying person "as if he were already dead." One nurse spent two or three minutes trying to close the eyelids of a dying woman. It would be more difficult to do that after muscles and skin had stiffened in death, and more efficient to act now than when it would be time to wrap and prepare the body. Body disposal has been organized with deftness and skill

in nearly all hospitals. The 60-year-old practice of a clinical review of each death, made before the report of the pathologist's autopsy findings, gives hospitals a strong feedback signal; an accredited teaching hospital must autopsy at least 25 percent of its deaths. This claim on the pathologist's time for the much increased laboratory work now needed for therapy and diagnosis deserves a new examination.

Elisabeth K. Ross, a Chicago psychiatrist, has become a field ethnographer of the dying. Her sensitive and attentive interviews with dying patients point a way to a meaningful training and a hopeful approach to dying patients, "enabling them to die in peace and dignity." In her seminar medical and theological students interview terminal patients, learning from the patients about dying and learning even more about themselves. One careful study of signal-response times reports: "Nurses were startled to learn how much they delayed answering the ring of the dying."

The Dying Patient, 16 papers by a variety of professionals, is written with little cant or jargon (an economist's chapter is the least accessible) and is certainly of interest to many general readers "in a period of social activism." Dying is part of living—an inescapable part; surely it demands from us a social response more intelligent than our present mixture of sentimentality, sensationalism and neglect. We shall not solve the problems; they belong among the eternal paradoxes of deep truth. We can nonetheless come to recognize where we have drifted.

THE SPLENDOR OF IRIDESCENCE: STRUCTURAL COLORS IN THE ANIMAL WORLD, by Hilda Simon. Illustrated by the author. Dodd, Mead & Company (\$25). Hilda Simon is a professional illustrator of birds and insects, with both an artist's devotion to the eye and a scientist's curiosity. She thanks her late father, a physicist at Zeiss, for encouraging her widespread interests. How much she is involved with color is suggested by a fact she is too modest to mention

that appears in the publisher's jacket biography: she prepares her color drawings, which are not merely the illustration of this handsome book but its essence, neither in colored inks nor in paint but in black pencil alone. She makes a separate pencil drawing for each of the four or five plates used for the superposed halftone impressions that make up the full-color printed picture. Her selection of the relative values of gray at any point in her several pencil drawings is what determines the final subtle color made up by the many tiny halftone dots in the colors of printer's inks. Color arises anew out of the structure of her drawings in black and white.

This is the theme of her book. The halftone structures she describes, however, are not the flat planes of printed dots, each 100 microns across. Instead they are the breathtakingly intricate three-dimensional lattices of protein that make feathers and scales and give structural color to the animal world.

After a couple of chapters that provide a simplified account of physical optics and of the evolutionary history of color in the living world, Miss Simon reaches her central interest. Birds that are blue have color by structure, not by pigment. If a blue feather is crushed, it becomes dark; even if it is only soaked in a transparent liquid that fills its interstices, it loses its blueness. A red feather, on the other hand, is a set of hollow tubes filled with a carotenoid pigment; grind it and it stays red. A white feather is transparent under the microscope; its whiteness is the multiple-reflection whiteness of snow. A blue feather resembles a white one in that its texture scatters light; it preferentially scatters blue light because there are dark absorbing cores of the black pigment melanin within its horny keratin structures. Green birds add a yellow pigment to a structural blue; thus does a green shell parakeet produce mutant offspring that are blue or yellow. In birds that are blue the yellow pigment has been lost; in birds that are yellow the subtle "blue" structure is missing. (Green bird pigments are known; one pigmented green bird is the African plantain-eater the touraco.)

The peacock feather is the paradigm of intricate color-producing structure. Electron micrographs show that the entirely modified barbules of the feather hold a regular space lattice of parallel rods of melanin, arranged in a square array with a sixth of a micron between elements. At each molt the lattice must grow again; it takes seven months for this marvelous pattern to form. In the

immature bird the melanin is randomly scattered through the feather. Different tiny structures differ in the number of melanin-rod layers; the brown of the eyespot is an intimate mixture of multi-layered violet and gold barbules that looks brown at a distance. The green-gold plumes of the sacred quetzal have a microstructure marked by layers of elliptical platelets of melanin separated by clear layers of keratin. Other birds of the same family, the trogons, have a simpler feather microanatomy: one bird, the Ecuadorian peacock, has barbules formed of close-packed hollow tubes of melanin, the smaller tubes in blue-violet zones and the larger ones in coppery places.

The blue butterflies, the *Morphos*, are perhaps the most striking. That the color is surface-generated is plain; transmitted light never shows those marvelous blues of the upper wing, only the concealing browns of the lower surface. The butterfly's beauty is skin-deep—a depth of less than half a micron. These wings gleamed for the naturalist Henry Bates, watching the butterflies in the sun "from a quarter mile." The colors are purer and brighter than those of the subtler birds; this is light scattered from a regularly carved surface, not from the more complex partly absorbing space lattices of the feather. The tiny butterfly-wing scales are lined with long ridges whose cross section resembles a Christmas tree or perhaps some magical microwave antenna. Every ridge has on each side some eight or 10 regularly spaced branches; they produce their interference blues with an air spacing of about a quarter of a wavelength.

Gold bugs and ground beetles, sword-tail fish and the rainbow boa, abalone shell and hummingbirds—all are quite beautifully depicted here. To be sure, flat absorbing ink spots, however cunningly arranged, cannot fully represent colors formed in space, colors whose play of motion and variation with angle add so much to iridescent reality. These approximations are nonetheless vivid and generally satisfying; a few of them, mostly showing the small beetles and the *Morphos*, closely evoke their source.

Structural color is unfading in the collector's cabinet, but pigments often do not last. Of course pigments too are structural. Their structure is on a scale even the electron beam cannot reach: the scale of the atom. A structure so delicate does not last because it is responsive to the impact of light and of the atoms of the air. On that scale the structural colors appear gross and static.

Miss Simon is no scientist, but she is

an ally worth having. She sees what too many have overlooked, both the critics of the laboratory and the preoccupied workers within it. The world is indivisible, and knowledge and feeling interact. The wonder of the *Morphos* wing is not made commonplace by an understanding of its elegant fabric.

THE SCIENTIFIC PAPERS OF SIR GEOFFREY INGRAM TAYLOR. VOLUME IV, MECHANICS OF FLUIDS: MISCELLANEOUS PAPERS, edited by G. K. Batchelor. Cambridge University Press (\$35). G. I. Taylor is in his 86th year, still lively, still reflective, still a man who finds joy in the strengths and flows of the world about him that he has done so much to explain. This last of the four volumes of his collected scientific papers is both too expensive and too mathematical to attract a great many readers. One can nonetheless celebrate the man by describing his work. His is all the 20th century has to match the high tradition of the great Victorian natural philosophers, the few exalted amateurs who, like Lord Rayleigh, laid the foundations of more than one specialty and were equally at home with differential equations, electrostatic machines and playing fields. This is not to say that G. I. Taylor is an amateur; he is a pro, a research worker or a professor all his life. All the same he retains the catholicity of interest, the free acceptance of both theory and experiment, the concern for the profound without any diminution of the wonder in the commonplace that seemed to go with that older and less organized epoch.

The first paper he ever wrote is here; it is one page long. G. I., then a research student of J. J. Thomson's, took photographs of the shadow of a needle cast by the light of a gas flame, and step by step he reduced the light intensity with a series of smoked-glass screens. The diffraction pattern remained sharp even in light so weak that an exposure took three months. (The story goes that young Taylor, an enthusiastic yachtsman then and now, spent the summer of 1909 cheerfully sailing while the image formed to prove his simple and important thesis!) In this way he first demonstrated that interference did not depend on the simultaneous presence of large numbers of "the indivisible units of light." (We call them photons now.) Even coming slowly, one long after another has passed, they manage to achieve exactly the interference called for by the wave theory.

Another nonmathematical paper, written in 1934, tells how anchors work.



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They must dig in as soon as a pull comes on the chain, and that digging-in state must be stable in the ground. Taylor designed a new form of anchor for small craft, devised a scaling test for anchors, developed his design by tests of tiny models weighing no more than a pound, and showed that weight for weight his new form held twice as strongly as the conventional design. He then shipped one of these anchors aboard his 19-ton cutter *Frolic* and cruised off. He is typically at work in this paper, setting out the essence of the physics, testing his views with deft experiments (often carried out with his own hands and tools) and then pressing this new quantitative knowledge into the service of the art. This paper is meant for a yachting readership; it is without mathematics.

There are 49 papers in this volume. One treats of the swimming of microscopic organisms, such as spermatozoa, that must exploit viscosity in order to move; another deals with the thin sheets of fluid, called water bells, that form when a jet strikes a flat plate; a third, published in 1969, treats of jets drawn out of fluid surfaces by electric fields. The volume lists all the publications of the four-volume collection. The first volume collects Taylor's work on the mechanics of solids, including the path he first mapped toward an understanding of the plastic behavior of crystal lattices through the concept of dislocations and their motion. That was in the 1920's and early 1930's. In the second volume he addresses the statistical nature of turbulent flow and finds methods for handling it to perceive order in the flow of the atmosphere and the ocean. In the third volume we find his papers on aircraft (generally rather early) and on explosion waves (his main topic during World War II). He applied his own theory to the first test of an atomic bomb, a paper that was first published after a delay of five years. In the 1960's, "retired" as a research professor, he sought out problems that could be studied with inexpensive equipment. He has appeared in a couple of fascinating films, one showing model spermatozoa swimming about in obedience to his scaling relations. He has given a number of witty and pointed talks and papers reminiscing of the days when "aeronautical science was young." He has written—no one has written better—on amateur science and on diversions in science; for him the most advanced problems were at once urgent and diverting. He has even written of his remarkable kinsman George Boole and of one or two other relatives, includ-

ing one splendid lady who published her spare-time mathematical studies on multidimensional polygons when she came to read mathematics, once her housewifely duties had decreased with age, to learn that the professionals were finally getting around to rediscovering her old results.

The typography of these papers is worthy of the subject matter; the astute editor, a student of G. I.'s and himself a major contributor to the science, has managed to improve on the originals with a few notes and figures here and there in correction, amplification and context. That is no small achievement, even with the advantage of hindsight.

If you would like to understand just how it is that water falls out of an inverted tumbler even though atmospheric pressure can support a column of water tens of feet high, you can look it up in Volume III. You will find a definitive paper, with fast-action photographs, published in 1950. This simple process has analogues all over the universe: in stars, in explosions, in cold fronts, in snowplows, in plasmas of charged particles. It is the sense of unity that Taylor's work can convey that lets his readers share the zest of a happy man.

A GUIDE TO NEW ENGLAND'S LANDSCAPE, by Neil Jorgensen. Barre Publishers, Barre, Mass. (\$8.50). The two aerial photographs of the wide U-shaped valley of Crawford Notch, first looking south and then north, can stand for the whole of this small book, a graceful and engaging "balance between a scientific text on the aspects of the landscape and the conventional organization of a guidebook." The book consists of brief, clear, perceptive sections on the chief features of the complex and beautiful surface of New England, each followed by a page or so telling just where to see good examples of the features described. The work is not geology alone, any more than the photographs of Crawford Notch are pure geology. Three levels of the landscape "suggest the plan of the book." These are the bedrock forms that are the bones of the land, the mantle of glacially worked material that covers the bedrock some 20 feet deep and smooths out most of New England, and the shady forests and other vegetation that color, enliven and fur the green land. (The sky and its climate are all but overlooked.)

The story of the level peneplain in the south—the ancient plateau whose memory is preserved in the even tops of the hills of all Massachusetts west to the Berkshires—begins the book. You can

see the peneplain from Mount Monadnock, the prototype of the monadnock: a resistant prominence above a peneplain. The mountain ranges are described and are well annotated for visitors, both the hardy climbers and weaker folk. The Taconics, where all the little brown bats of New England winter in one dark cave, are the residue of a great fold that broke off the crease of the Green Mountains and slid westward a dozen miles, according to "the present consensus among geologists." New England bedrock is very thinly mineralized; you can still pan for gold in the Swift River near Byron, Me., but the wonderful tourmalines of the Mount Mica pegmatites have petered out. Hundreds of such local bodies of large-crystal granite dot the finer granite of the region. They have been worked for more than a century, mostly as open pits for mica and feldspar, beryllia and some gems. Since the richest material is now gone, they are a poor investment for industrial working. They will richly repay the amateur who wants to scratch or hammer one sunny day in hope and in fresh air. Dinosaur tracks mark the river lowlands of the Connecticut Valley "frequently enough to reward a diligent search." The dinosaur habitat is detailed here, both in dinosaur days and now.

Glacial landforms are obvious in New England. The lakes and the bogs, the cirques of the hills, the drumlin mounds and the erratic boulders clearly distinguish this land from the southern piedmont it otherwise resembles in a broad way. They are proud of a glacial boulder of 5,000 tons in Madison, N.H., and Bunker Hill, like the little hill between M.I.T. and Harvard, is a glacial drumlin.

New England is far more forested than it was a century ago, when more than three-quarters of the southern half of the region had been cleared for field and pasture. The northern spruce-fir forest has been logged at least once or twice almost everywhere. There is a virgin stand near Pittsburg, N.H. The last few New England acres of virgin hardwood, held by Harvard University near Winchester, N.H., were almost totally leveled by the hurricane of 1938. There white pines about 250 years old stood 150 feet tall and four feet in diameter. The New England timber industry, based on white pine ever since the King's broad arrow marked pines more than two feet in diameter for ships' masts, has never recovered from that hurricane. A single day wrecked decades of careful management; half-grown pulpwood is less risky, so that private

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forests will be immature and even-aged from now on.

The careful list of readings and the guide for getting the maps indispensable in going beyond the mere armchair use of the book are very good indeed. The book is marred only by its rather high price. A set of a dozen or two less expensive books, dealing with all regions of the U.S., would be a public scientific investment of high merit, recalling the WPA guides of the 1930's. Jorgensen has set a high standard; he is a teacher, a trained geologist, a wildflower enthusiast and a man who can write. Maybe there are others like him in the West! The mountaineering and serial photographs by Dick Smith deserve special praise; there are many other useful maps, photographs and diagrams in the book.

IN THE MATTER OF J. ROBERT OPPENHEIMER: TRANSCRIPT OF HEARING BEFORE PERSONNEL SECURITY BOARD AND TEXTS OF PRINCIPAL DOCUMENTS AND LETTERS. United States Atomic Energy Commission. Foreword by Philip M. Stern. The M.I.T. Press (\$5.95). One small paperback volume selected from the 43 volumes of the Pentagon papers on Vietnam has been a best seller. It holds a set of secret, mostly signed documents of analysis and planning, collected and glossed by a group of Pentagon researchers, mostly unnamed. The entire corpus was made publicly available this summer through novel channels after many years of delay. Those papers appear in careful prose, running from Pentagonian to a few quite brilliant evocative pieces. From their pages there rises the smell of burning huts in a poor country a long way off.

This volume, much thicker than the newer one, has a very different form. It hews close to the unities of classical tragedy. It is the verbatim transcript—only a few phrases are deleted in the entire volume—of oral testimony given day after day one month long ago by some dozens of men, most of them close to power. They testified in candor under oath, given assurance of secrecy. What they said was published within a couple of months as a legal “leak,” one must judge, of material deemed to support the decision. The smoke of war here is potential, not real, but it is pervasive. Behind the case lie the ashes of Hiroshima and ahead of it the hazard of the cratering of the great cities of mankind. The prose is spoken and hence is direct and personal, even awkward; power and the professors had not been intimates for long. The case reflected an

internal crisis of power, a desperate contest for the longest levers of American military strength and political decision. The volume is a facsimile of the long-out-of-print 1954 Government Printing Office version, helpfully augmented by the formal charges and decisions of the various boards, excellent indexes of names and subjects (the strategic and the tactical Pentagon overlap little, although one can find the names of John McCone and McGeorge Bundy in both books) and a perceptive if somewhat narrow foreword by Philip Stern, the closest student of the case itself.

EPHEMERAL FOLK FIGURES: SCARECROWS, HARVEST FIGURES, AND SNOWMEN, by Avon Neal. Photographs by Ann Parker. Clarkson N. Potter, Inc./Publisher (\$10). It was the Opies, those penetrating ethnographers of the play of children, who made it plain that no city street was so modern or so neglected that the classic games, the legacy of untold generations of children, did not go on, if perhaps covertly. This book touches the same theme: the preservation of old ways in the crevices of a new society, out of a confluence of residual usefulness, dimly felt tradition and ever flowing psychological wellsprings of art. Here are 125 plates, many in color, that exhibit simple effigies of the human form and its cognates, each adapted to one phase of the seasonal round, all made in our own industrialized and alienated land within the past decade, mostly in or near our big cities. A scarecrow? Look at “Kali of the fields,” a porcelain-pot face concealed by a tall conical straw hat, shown in season and in snow with her six gloved arms made up of three sticks. Scarecrows are a realized tradition; it appears that most are in fact made by old people in the farmlands who recall the customs of the old country. A harvest figure? They of course arise around Halloween, our own national secular harvest holiday. They are syncretized from many strands, particularly from the jack-o'-lantern tradition brought here by the Irish after the potato failure. Commercialization cannot defeat the spirit; forms of polyethylene can be used as integrally as any empty pumpkin.

The thoughtful text by Avon Neal, artist and writer, and the evocative photographs by his wife, Ann Parker, are well matched. They have given us a volume not only of pleasure but also of hope. May many photographers follow their lead to record such transient expressions, art forms inherently more fleeting than life itself.

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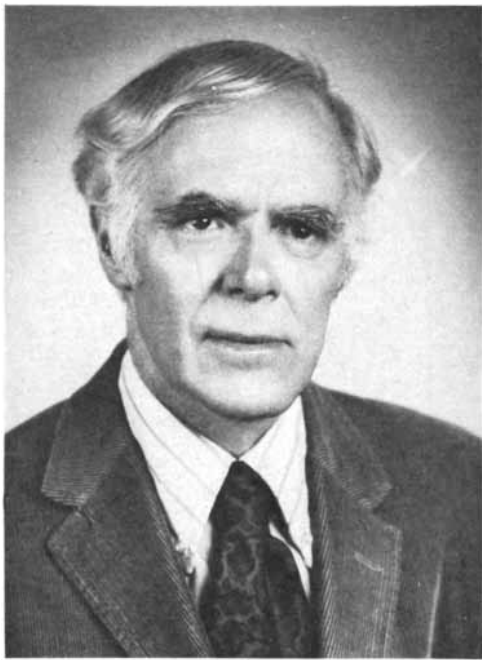
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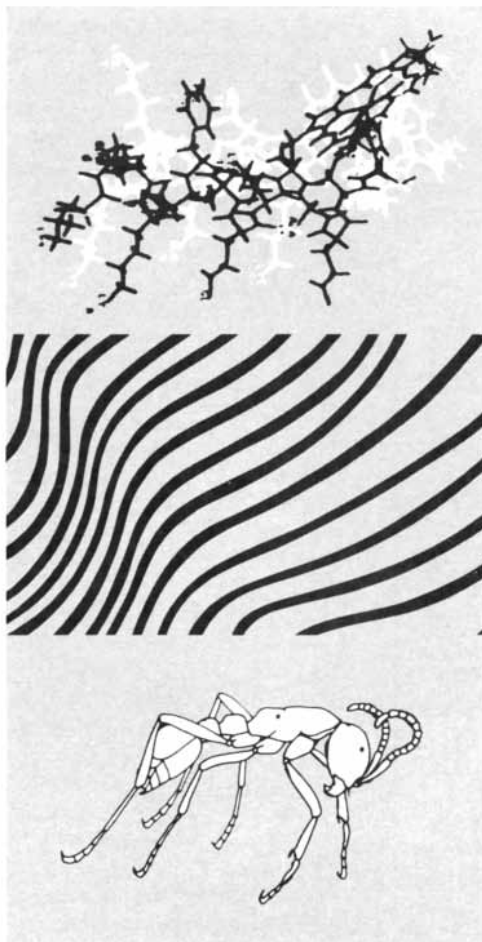
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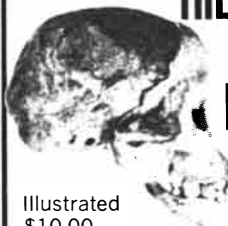
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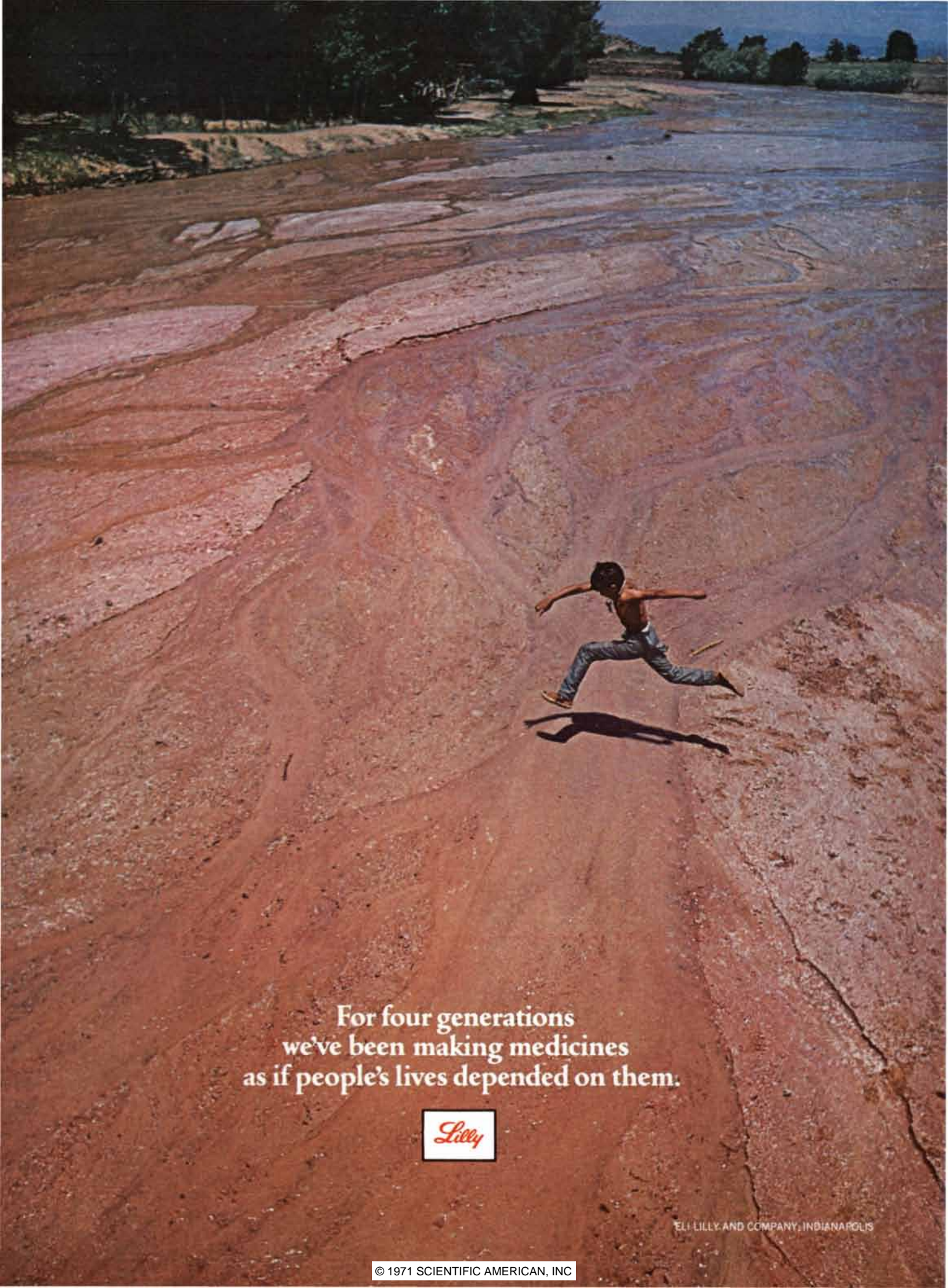
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