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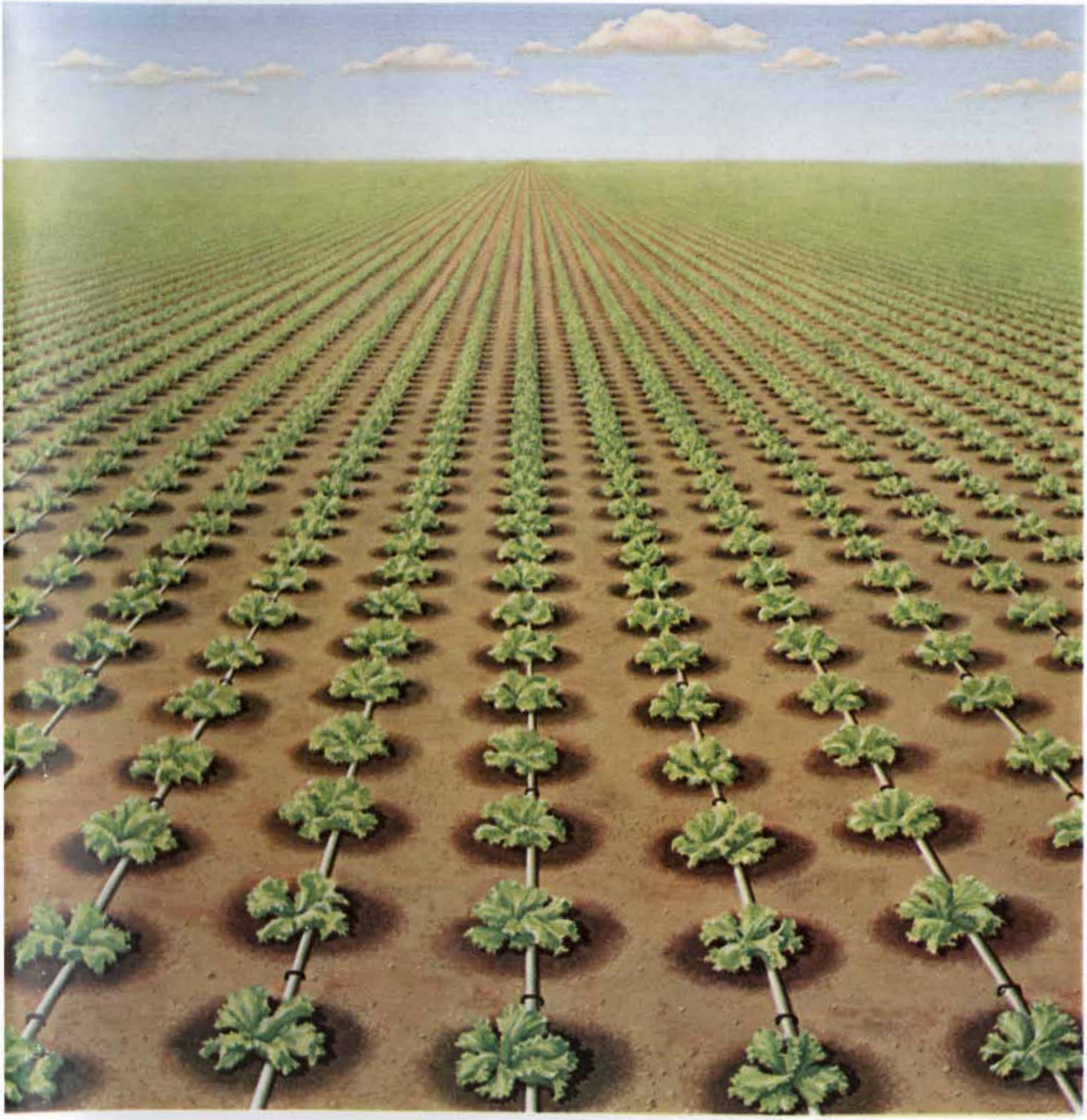

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Should you be looking for a sleek, personal car this year, make Chrysler LeBaron your choice. It's the first of a totally new class of automobiles. LeBaron 2-door comes with many personal appointments of luxury. Overhead lighting. Velour seats. And soft leather seating is available on the Medallion model. In short, LeBaron gives you the pleasures of a luxury car at a price that makes it a pleasure to own.

LeBaron 4-Door

Luxurious and affordable.

The nice thing about LeBaron is the way it satisfies your taste for luxury but still has regard for your budget. LeBaron 4-door, for example, is elegant both inside and out. The luxurious LeBaron pictured at your right is equipped with a padded vinyl roof, available wire wheel covers, plush velour seats, and much more. In fact, it comes with many of the same comfort and convenience features you'd find on $12,000 sedans. But LeBaron can be yours for many thousands of dollars less.

LeBaron Town & Country

There are many new wagons, but there is still only one Chrysler.

If you have a family, or just like the feel of a wagon, this could very well be your choice for 1978. LeBaron Town & Country is a lighter, more efficient size luxury wagon. But don't let that fool you. It has 90 percent as much passenger space as last year's full-size Town & Country. And though LeBaron is smaller outside, it's still big on luxury inside.

Chryslers. such a luxury of choice.

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ARTICLES

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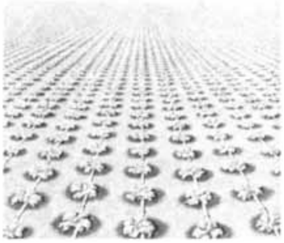

THE COVER

The painting on the cover shows a field of lettuce growing under drip irrigation, a system designed to deliver water slowly but frequently and in precise amounts to the root zone of each plant. The water is transported at low pressure through plastic pipes and is delivered to each plant, almost literally drop by drop, through holes or manufactured emitters (see "Drip Irrigation," by Kobe Shoji, page 62). Compared with other methods of irrigation the system reduces stress on the plants and conserves water. The absence of weeds in the field of lettuce is also partly due to the drip-irrigation system, since the areas between plants and between rows are dry and weeds are unable to flourish there.

THE ILLUSTRATIONS

Cover painting by Tom Prentiss

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LETTERS

Sirs:

You will no doubt be receiving many letters from history-conscious auto buffs, particularly partisans of the Lincoln Zephyr and the Volkswagen, anxious to set the record straight as to who influenced whom in the development of the Chrysler Airflow ["The History of the Airflow Car," by Howard S. Irwin; SCIENTIFIC AMERICAN, August]. Dr. Irwin implies that but for the Airflow the Lincoln Zephyr and the Volkswagen would have been quite different. This is not probable.

To be sure, the Airflow was a seminal development in automotive design whose influence was very great. It is always tempting, however, to consider the first manufacturer to bring an idea to public view as being the sole originator of that idea, and to assume that apparent followers in time were necessarily copiers in thought.

Chrysler gets the credit for the concept of redesigning the automobile from the passenger compartment out, shared perhaps with R. Buckminster Fuller's Dymaxion car of 1933. (Both cars were conceived and developed more or less simultaneously. Fuller produced only three prototypes for the Chicago world's fair of 1933 and had no mass-production considerations to delay the unveiling of his product.)

Much research was going on at that time in various countries into the optimum air-penetrating shape for a land vehicle. Most pertinent to the story is the research conducted independently by Ferdinand Porsche, which led to the Volkswagen, and by John Tjaarda, which led to the Zephyr.

John Tjaarda was an engineer with the Briggs Manufacturing Company. His experimental body design was exhibited by Ford at the 1933 world's fair. That body featured a short, bug-eyed, rounded nose not too unlike the Airflow's; it was a smaller car with a more tapering tail, intended for a rear-engine configuration. The Airflow was still in the works, but its ultimate form was in sight; Walter P. Chrysler and his staff kept an eye on public reaction to Ford's exhibited car, hoping to learn what to expect on the introduction of their own machine. It was from the Tjaarda car's shape, and from structural research paralleling Chrysler's, that Ford engineers developed the Lincoln Zephyr for the 1936 model year.

It is worth noting that as the Zephyr evolved, stress analysis of its steel body framework compared with the figures for the Airflow designs revealed an error: the Airflow bodies had been built fully twice as strong as necessary. As a result the Zephyr's body structure, although sufficiently strong, was made only half as heavy as the Airflow's, and the thinner members allowed more glass area and better vision for the driver.

The influence of the Airflow on the Zephyr was to a large extent a negative one; the placement of the engine over the axle and the passengers between axles, the wind-cheating rounded shape, the all-steel body structure and the great interior width were all in the cards for the Zephyr regardless of the Airflow. Chrysler's mistakes—the unnecessarily heavy structural members, the small windows, the unorthodox front end and the awkward headlight placement—appeared in the marketplace soon enough for Lincoln to witness their effect on sales and counter them in Lincoln's own offering two years later. As a result the Zephyr carried into styling art—and sales—the promise offered earlier by the Airflow's technological advances. Yet the Lincoln people did not merely refine ideas taken from Chrysler; they had their own research, dating back to 1928 and earlier with Tjaarda's explorations into streamlining, on which to build.

The Volkswagen story also does not hinge on the Airflow. The Volkswagen concept and overall shape were crystallized before 1934, when Dr. Porsche, then of NSU Motorenwerke, displayed a small-car prospectus for Germany's new chancellor Adolf Hitler, who

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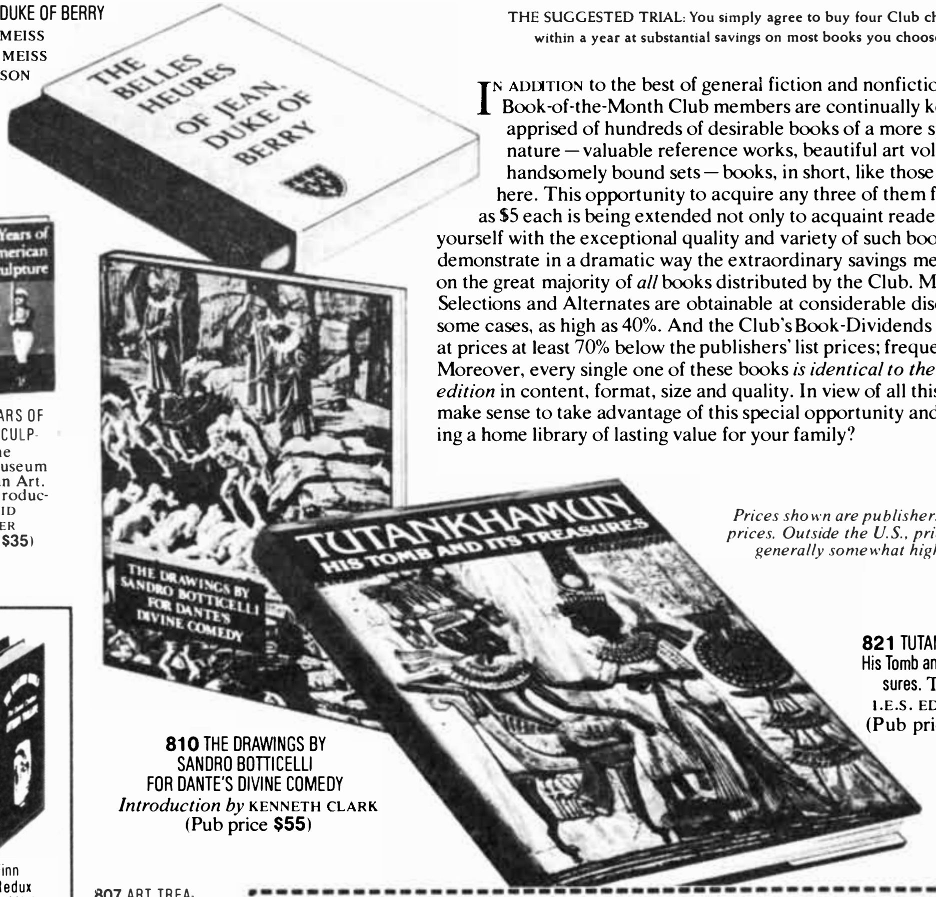

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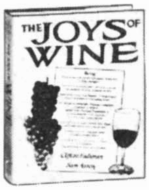

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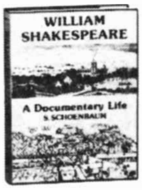

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Alexander Leaf, M.D.:

ON THE PHYSICAL FITNESS OF MEN WHO LIVE TO A GREAT AGE

PUBLISHER'S NOTE: *Alexander Leaf, M.D., Jackson Professor of Clinical Medicine, Harvard Medical School and Chief of Medical Services, Massachusetts General Hospital has traveled the world to examine people who are living to a great age in vigorous health, free from the infirmities and debility which plague so many of our elderly. What he has learned can help you if you want to enjoy living a long, long time in sturdy health.*

—Richard Stanton

In the Caucasian village of Duripshi I found myself running, jumping and slithering down the rocks to keep abreast of Markhti Tarkhil, age 104, as he descended to the cold mountain stream where he had his daily bath. Markhti had related that as long as he could remember he bathed each morning in this fresh stream. We got into our car at Markhti's house to drive down to the stream where we would take pictures. Halfway down the rough road the driver stopped and refused to go further. "If I proceed further down this road I'll never get the car back," he claimed. While we were arguing Markhti jumped from the car and asked, "What are we waiting for?" Whereupon he started down the hill with me in pursuit. It proved to be a difficult and rough descent, but Markhti moved so quickly and agilely over the rocks and down the river bank that I had difficulty keeping beside him, frightened at what might happen were he to stumble and fall. Knowing how fragile the bones of most of our old people are, I had terrifying visions of picking up the pieces were Markhti to trip. Fortunately, no such mishap occurred and Markhti reached the bottom of the hill ahead of me.

Later I asked the Russian doctors there how often the old people suffered fractures. They shrugged and claimed there rarely were fractures. The constant physical activity of these vigorous elders keeps the balance between bone formation and destruction such that the bones remain mineralized, dense and strong.

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STATE/COUNTRY____________________ZIP__________SA-8 quickly adopted the car as the model for his promise of a "people's car" to revitalize the German economy and society. The prototype is recognizable as a near-ancestor of the modern "beetle." Technical problems remained to be worked out. A fleet of more advanced, still more beetleish prototypes was produced in 1936–37, but production was again delayed. The war turned the people's car into a successful jeeplike wagon, but the civilian sedan did not reach production until after the war, when the British occupation was looking for a "make work" project for refugees and found the plans and tooling for the people's car. The rest is history.

The Volkswagen itself borrows little from the Airflow; the resemblance is superficial only, as mechanically and structurally the Volkswagen pursued a track entirely different from the Airflow's. Chrysler cannot even be credited with paving the Volkswagen's way into the American marketplace; the Airflow was not fondly remembered, and the early Volkswagens did not sell well here until the middle 1950's.

Although the development of the Zephyr and the Volkswagen was essentially independent of the Airflow, the Airflow's influence was strongly felt in the industry, and quickly. Stylists rejected it in detail, but they soon enough accepted it in principle. Engineers were quick to see that the Airflow was right. The 1936 models of most major manufacturers began to take on lines suggestive of the Airflow's philosophy—broad rounded curves, smooth angles, slippery shapes, clean surfaces.

Let the record show that the Airflow was first with the most. But let it also show that the Zephyr and the Volkswagen, among others, although they were introduced later, were developed right alongside the Airflow and made their own contributions to the development of the modern automobile.

PAUL CAVINESS

Lawrence, Kan.

Sirs:

In my article on light-wave communications ["Light-Wave Communications," by W. S. Boyle; SCIENTIFIC AMERICAN, August] the subtitle incorrectly referred to the Bell System's light-wave communications evaluation as the "first commercial test of light-wave telephone service." The light-wave communications system described in the article was announced on May 11, 1977, and is the first such system to provide a wide range of telecommunications services. It is carrying voice, data and video signals on pulses of light, as the article points out, over one and a half miles of underground cable. Other companies, here and abroad, conducted earlier commercial tests of light-wave systems carrying voice signals.

For example, on April 25, 1977, the General Telephone and Electronics Corporation announced that "the world's first 'optical' communications system to provide regular telephone service to the public [has been] placed in service in California." This test system transmits telephone conversations between two telephone offices. Moreover, in February, 1977, a Japanese firm, Fujitsu, installed a light-wave communications system to transmit telephone conversations between telephone offices in Singapore.

W. S. BOYLE

Bell Laboratories
Murray Hill, N.J.

Sirs:

Jearl Walker suggests ["The Amateur Scientist," SCIENTIFIC AMERICAN, August] that Ph.D. candidates in physics test their faith (as a prerequisite for the degree) by striding across a bed of hot coals. When the future Kaiser Wilhelm was a student, his chemistry teacher explained the Leidenfrost effect to the class and asked Wilhelm if he had "faith in chemistry." The answer was yes, and the future Kaiser was allowed to demonstrate his faith. He washed his hands with ammonia, whereupon the teacher poured molten lead into his cupped palms.

Considering the effects if anything were to have gone wrong, I would say that the teacher himself had demonstrated incredible faith in chemistry.

ANDY POOR

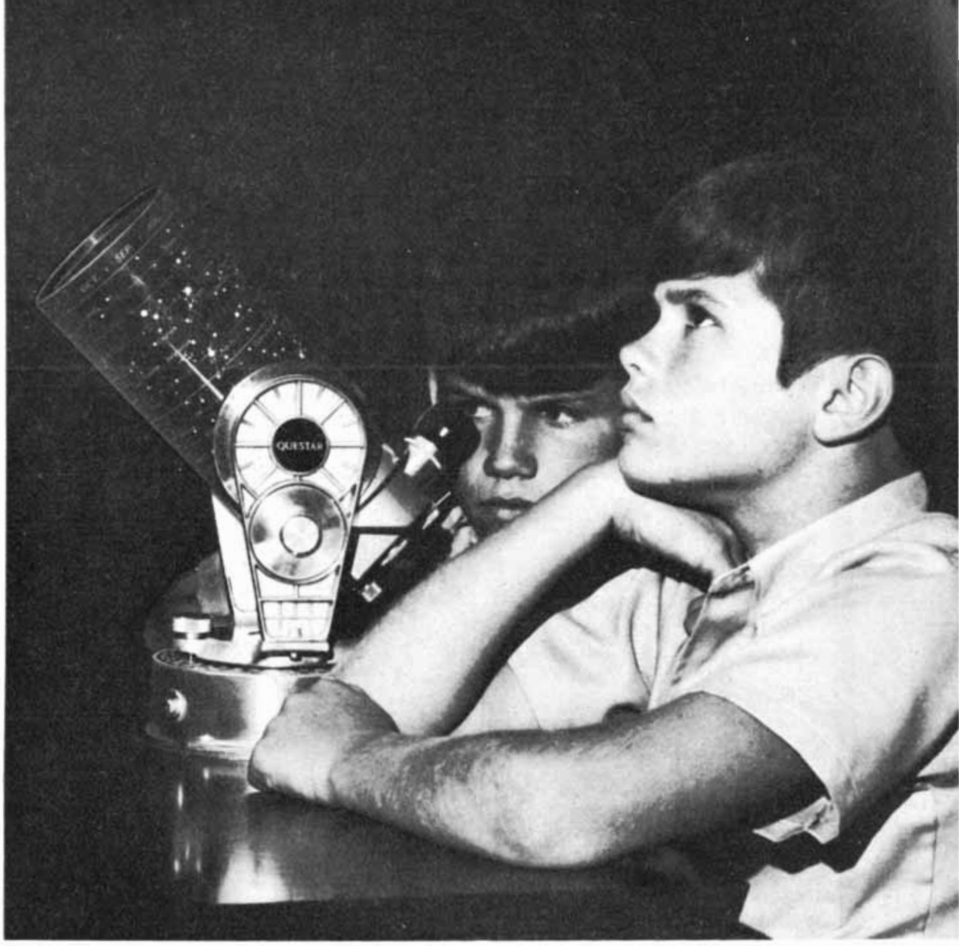
The Institute for Advanced Study
Princeton, N.J.

Sirs:

Considering the bravado of our fearless Walker, who strode across burning embers, I am surprised he did not build his bed of coals at the edge of a lake or swimming pool. Then, believing in the inverse Leidenfrost effect and knowing that his feet were quite hot, he could have compounded his earlier feat by walking across water. (Or would he have skittered across?) Even if the second leg of his journey was something less than an uplifting experience, he would have cooled his feet in a gratifyingly short period of time.

BOB WAIT

Cincinnati, Ohio



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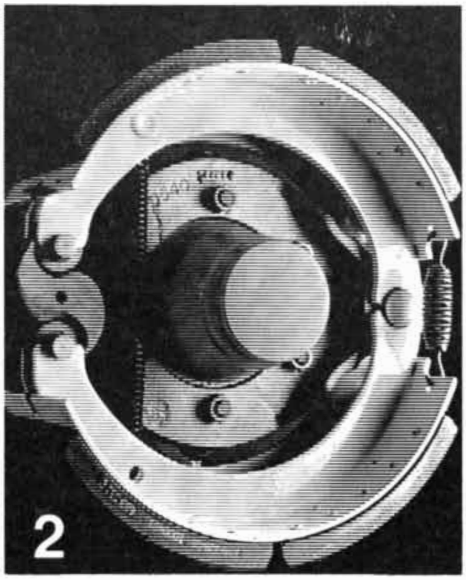
50 AND 100 YEARS AGO

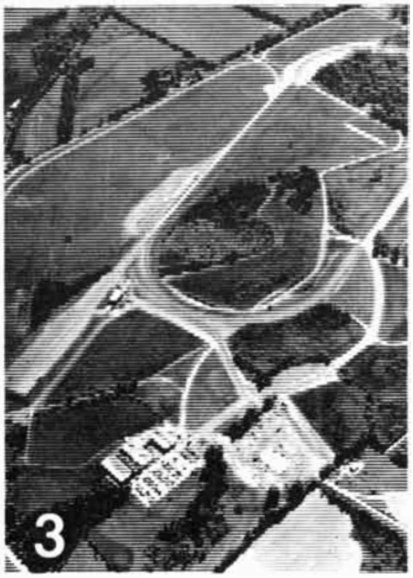
SCIENTIFIC AMERICAN

NOVEMBER, 1927: "Photographs show that the visible portion of the Andromeda Nebula is but the central and brighter region of a vast spiral mass of faint light whose extreme diameter is almost three degrees, or six times the apparent size of the moon. The outer parts of the nebula have been resolved on E. P. Hubble's photographs into countless thousands of tiny stars, and by the discovery of variable stars among them it has become possible to find the distance and size of the entire stupendous system. Hubble's latest data make the distance 870,000 light-years and the extreme diameter 45,000 light-years. Until a few years ago it was supposed the entire universe of stars was not nearly as big as this. With the 100-inch telescope and long exposures under good conditions it should be possible to distinguish the image of a nebula as faint as the 18th magnitude from that of a star and thus to reach objects at the distance of 140 million light-years. Nebulae twice as far away might be photographed, but they could not be distinguished from faint stars unless and until a larger telescope than we now possess is provided."

"Less than six years ago the first synthetic-ammonia plant in America started operation. Since then our progress along the line of nitrogen fixation has been commendable. At the end of last year eight plants in the United States were either producing or were ready to produce synthetic ammonia. Notwithstanding the possibility of supply surpassing demand, expansion and construction are continuing without sign of abatement. The Allied Chemical and Dye Corporation, for instance, has recently announced plans for a large plant to be erected at Hopewell, Va. It is understood that the output of this plant will go into fertilizers."

"Radio this season is in a transition period. The fall styles reveal a distinct trend from the battery-operated receiver to the light-socket set, which dispenses with all batteries and takes its power from the house-lighting mains. A few circuits of this type appeared on the market last year, but this season many more manufacturers have introduced batteryless equipment because of the further development of alternating-current tubes and improved rectifiers. The filaments of the new tubes obtain their power from the light socket through a





Eaton Update:

1 Getting the power around the corner

Eaton hydrostatic transmissions offer designers of agricultural equipment great flexibility by replacing awkward mechanical linkages with hydraulic lines that can go around or through other components. They allow the equipment to work more efficiently because operators have an infinite selection of operating modes.

Eaton's commitment to hydrostatics started in the mid-sixties. A new plant in Spencer, Iowa, is operating at maximum capacity, and we are planning another expansion to serve this growing market.

2 The advantages of being single

With Eaton's Single Anchor Pin brake system you can reline a truck brake in just two minutes—and the only tool you need is a screwdriver. With conventional double anchor pin systems the job can take hours, even with special tools.

This Eaton exclusive is saving down-time for truckers all over the country. But it's only one of our many contributions to trucking efficiency. We're a leader, worldwide, in axles and heavy-duty transmissions, and we're winning an ever-stronger position in components like brakes and anti-lock systems, fan drives, and air conditioning.

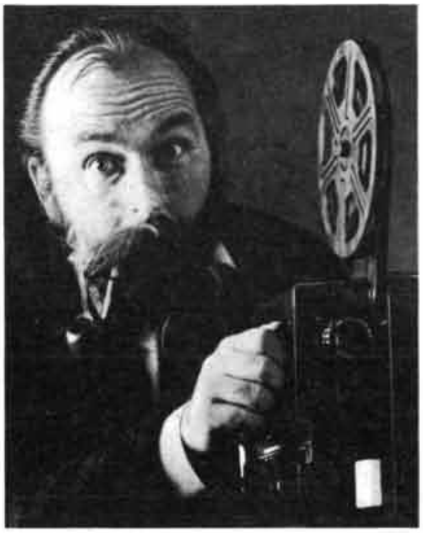
3 636-acre survival course

The Eaton Proving Ground at Marshall, Michigan, subjects truck and automobile components to horrendous treatment. The facilities include a 1.6 mile oval track for sustained endurance testing; road surfaces that are just plain hostile; a salt bath for corrosive brake lining tests; and a 1200-foot skid pad that can simulate any skid condition.

It's all part of Eaton's total commitment to quality. We market new engineering ideas only after having proved that they excel at surviving in the real world.

Eaton is a family of technologically related businesses with a balanced combination of manufacturing and engineering skills. We're always looking for new ways to use these skills in markets where needs are growing. This approach to the management of change has been achieving record sales and earnings. For the complete story, write to: Eaton Corporation, 100 Erieview Plaza, Cleveland, Ohio 44114.

EATON



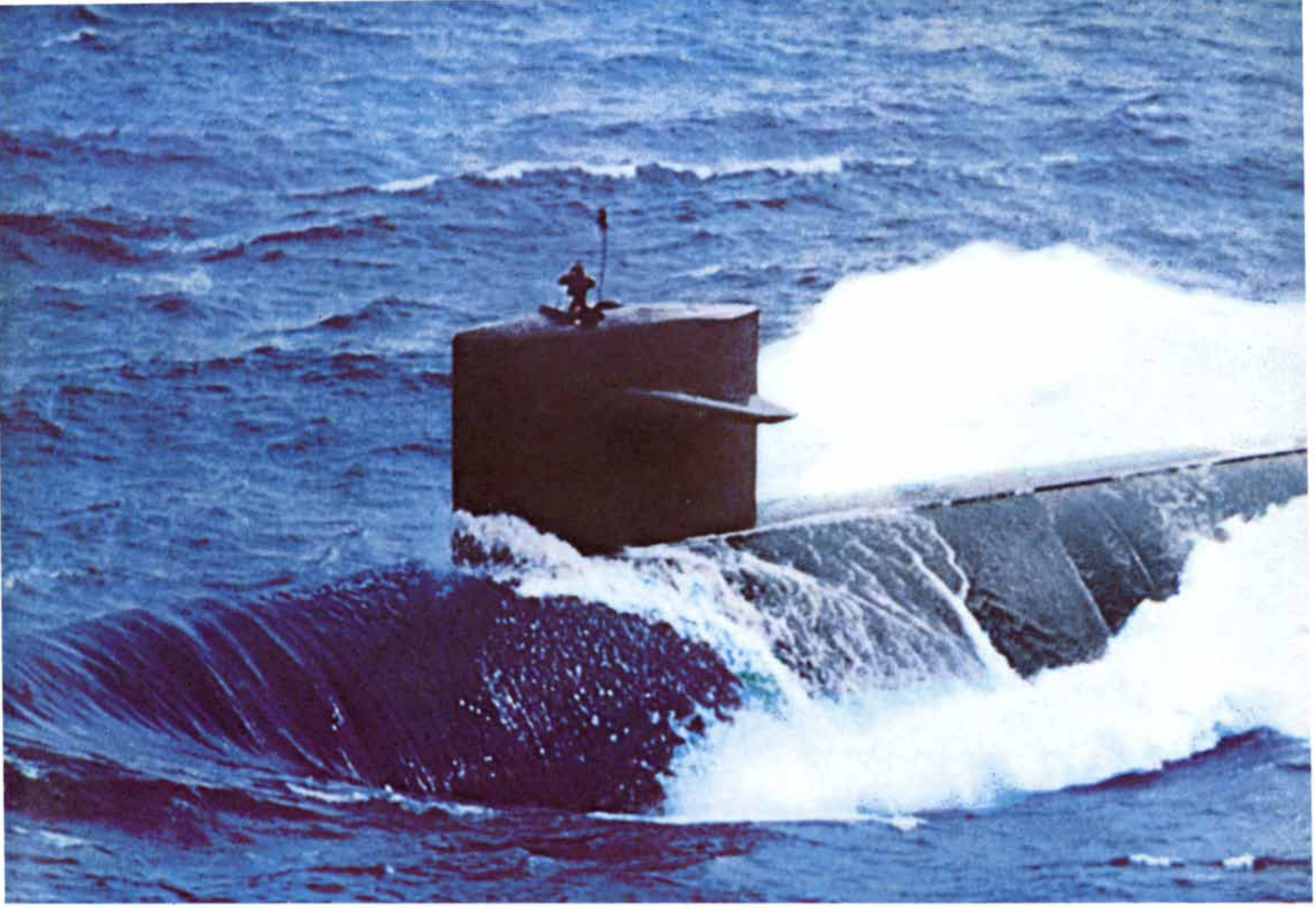
small step-down transformer, and the rectifier tubes convert the alternating current to direct current at suitable voltages to replace ‘B’ batteries. The number of receivers of the table and the console type is about evenly divided.”

“The Norwegians have perfected whaling ships capable of operating in the Antarctic, thousands of miles from their home port. These ships are fitted with a false bow that can be tilted downward into the water to serve as a runway on which one of these huge mammals can be drawn to be cut up. Machinery aboard extracts the oil from the blubber and converts the carcass into meal. These ships are independent of a land base, and having filled their storage tanks with the whale oil, which is in special demand by soap-makers, they steam to whatever world port holds forth the best promise of a profitable market for their cargo. In recent years the number of whaling companies has increased rapidly, and no ocean area is exempt from whaling operations. In excess of 10,000 whales are killed annually, the maximum yield of oil having been reached in 1923, amounting to 44,000,000 gallons. Millions of gallons of whale oil now find a ready market in this country. This freedom of operations without restraint on the high seas has aroused the fear of intelligent observers that whales may soon become commercially extinct. The only possible control of such operations must be found in international agreement.”

SCIENTIFIC AMERICAN

NOVEMBER, 1877: “Mr. Thomas A. Edison, the renowned electrician of New Jersey, has in the course of a series of extended experiments in the production of his speaking telephone conceived the highly bold and original idea of recording the human voice on a strip of paper, from which at any subsequent time it might be automatically delivered with all the vocal characteristics of the original speaker accurately reproduced. A speech delivered into the mouthpiece of this apparatus may 50 years hence—long after the original speaker is dead—be reproduced audibly for an audience with sufficient fidelity to make the voice easily recognizable by those who were familiar with the original. As yet the apparatus is crude, but it is characterized by the wonderful simplicity that seems to be a trait of all great inventions or discoveries.”

“Practiced mountaineers who have climbed to a height of 17,000 or 18,000 feet have been of the opinion that even at such altitudes there is a very important and perceptible diminution of the bodily powers, and they think the height



"The only gusher I'll ever see is at the movies."

Gulf Production Superintendent Bob Valentine perforates a legend. "I don't think I ever saw an oil movie where they didn't have a gusher. Everybody gets greasy, and they laugh a lot.

"But today the only gushers are in the movies, not in real life. And a good thing, too. All that oil spraying all over the landscape. All those tools and pipe flying around—a man could get killed that way.

"The fact is that wells just don't come in as gushers anymore.

The easy oil is gone

"One reason is that drilling and well-completion technology has improved. These days, we bring the oil to the surface under carefully controlled conditions, in order to avoid spillage.

"Another reason is that the easy oil is gone. We're drilling deeper—sometimes as deep as 20,000 feet. We're drilling in tough, inaccessible, out-of-the-way locations we wouldn't have attempted ten years ago.

Wet rock

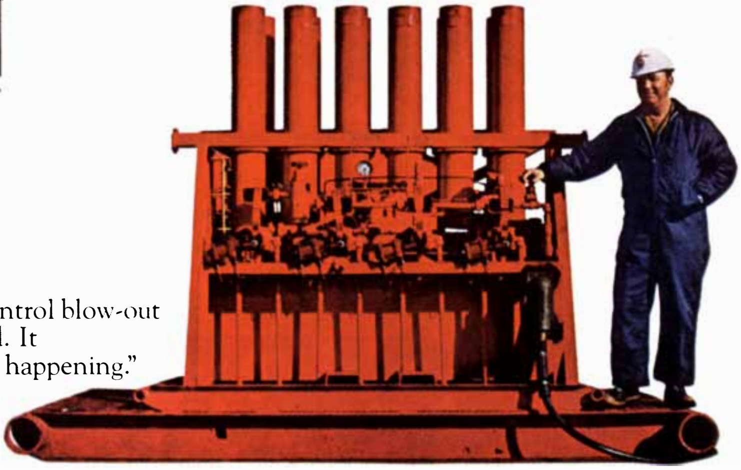
"These days, an oil strike is a lot less dramatic. At the end of a successful drilling operation, your best indication of oil may be a wet rock. The oil is in the pores of the rock, and you sometimes have to do some incredible things to get it out. Stimulation with chemical solutions; fracturing at eight or ten thousand pounds' pressure; or steam injection flooding.

"These days, getting the oil out is a real challenge. But we've got the tools and the knowledge, and we'll do it."

Gulf

Gulf people: meeting the challenge.

"A modern oil strike: rock with oily pores."



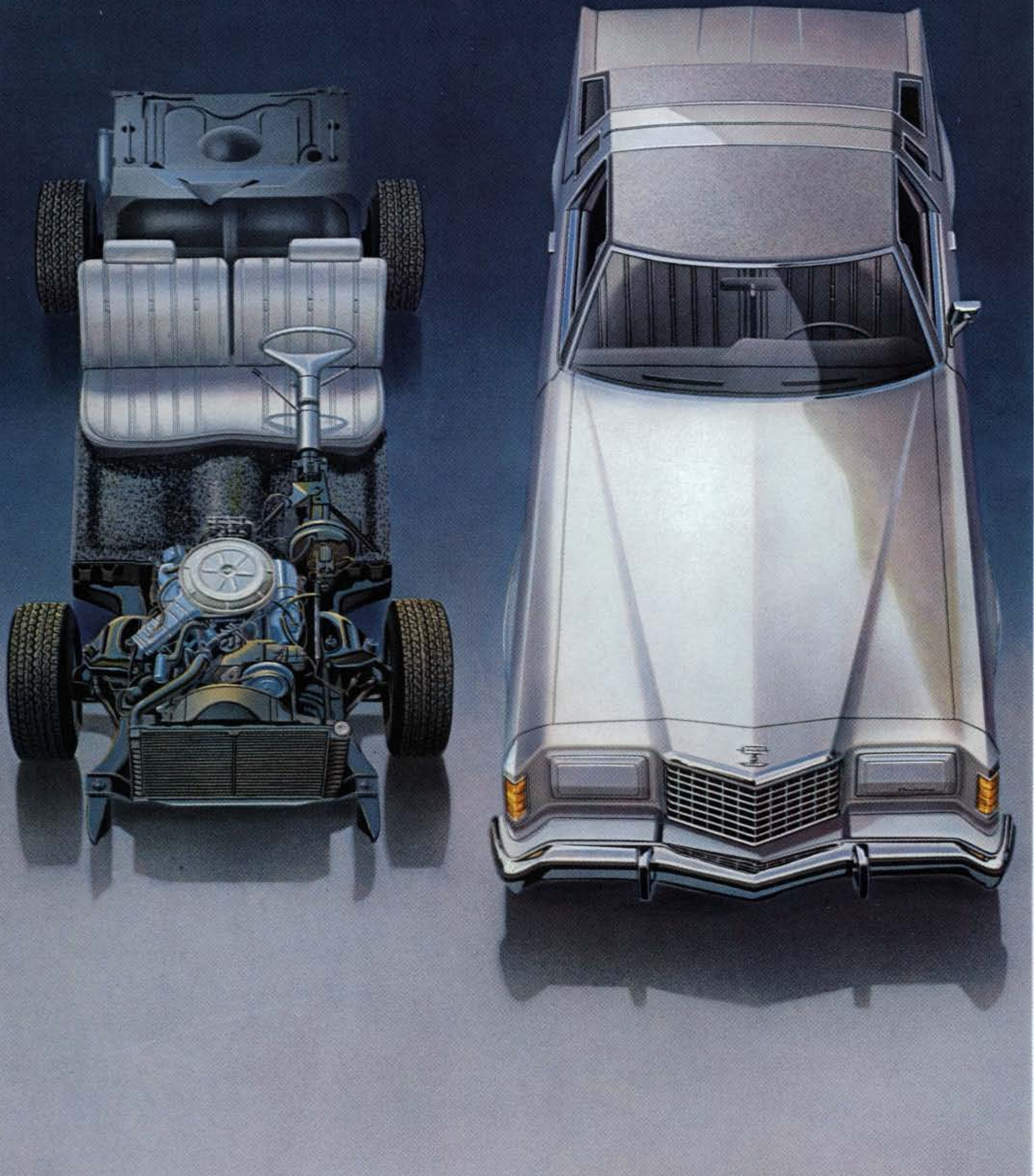
"This is a remote control blow-out preventer manifold. It keeps gushers from happening."

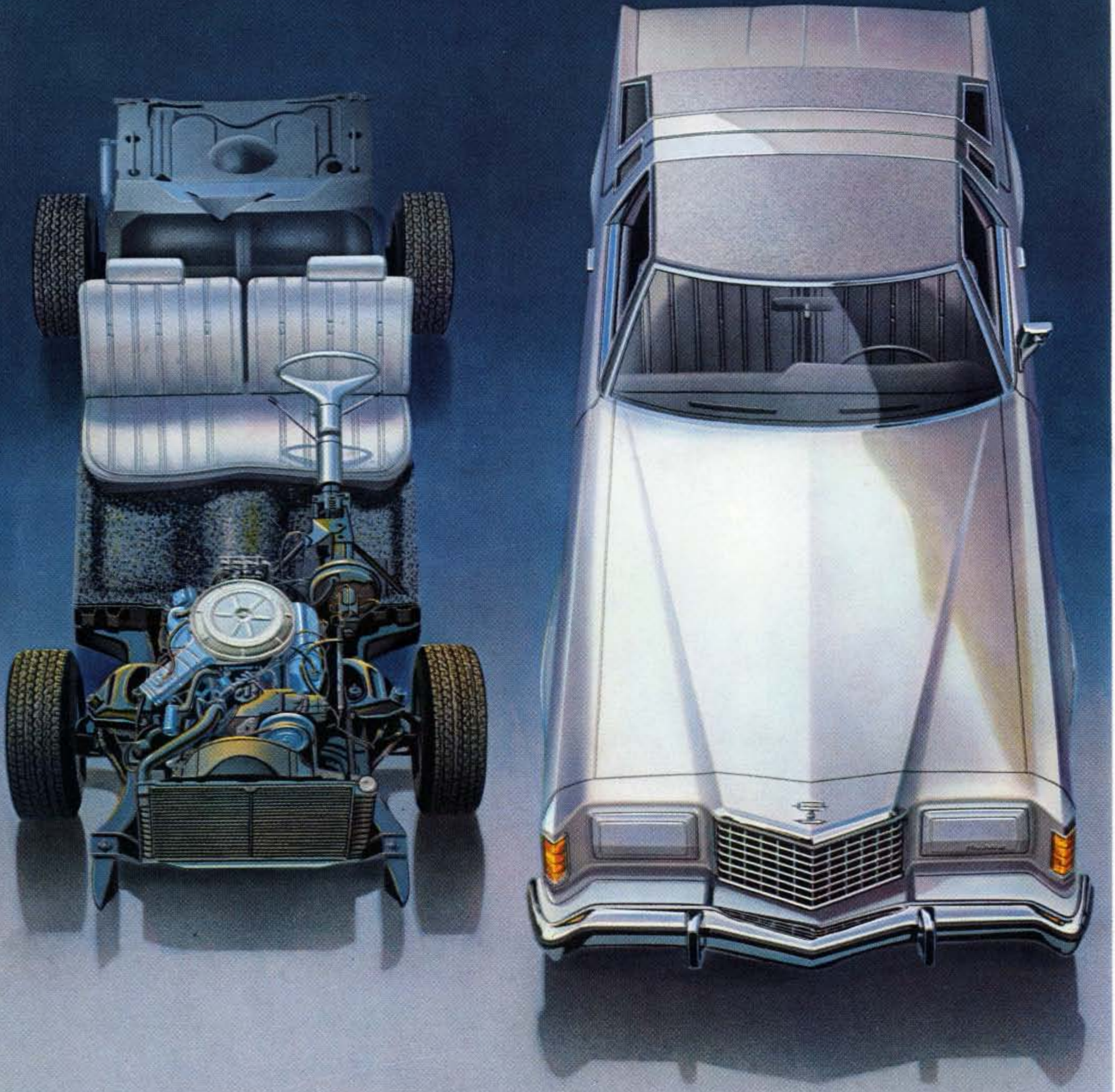
Gulf Oil Corporation

of 25,000 or 26,000 feet will be found to be about the limit that will ever be reached on foot. Aeronauts have proved that life can exist at 30,000 feet above the level of the sea, and that at 25,000 feet and upwards one can be positively comfortable if one is dressed warmly enough. Mr. Glaisher, in his memorable balloon ascent of September 5, 1862, left the ground at 1:00 P.M. and in less than an hour had shot up to a height of 30,000 feet. At the start the temperature of the air was 59 degrees Fahrenheit, and at the greatest altitude it was 61 degrees lower! Mountaineers experience no such extreme variations as these. They rarely ascend more rapidly than 1,000 feet per hour, never so much as 15,000 feet in a day, and become to some extent acclimatized as they progress upwards. On the whole we are inclined to think man will not rest until he has at least attempted to reach the loftiest summits on the earth, although we shall venture to assert that it will be long before anyone crushes down the snow on the summit of Mount Everest."

"It is now an established fact that there is oil in Ventura County, California, in paying quantities. One of the chief advantages is in the ease with which the refined oil can be placed on board vessels bound for foreign ports. A pipe line will convey every gallon to the barrels in the holds of the vessels, thus saving all the immense expense of hauling and storing in hazardous places the oil barrels awaiting shipment."

"Are the brain, and the moral and intellectual processes known to be associated with the brain, subject to the laws we find paramount in physical nature? Science has led us into the domain of metaphysics, and we have been prepared for the affirmative response. The phenomena of heredity, how much we owe to the transmitted influence of the past, how closely we are bound up in a chain of evolutionary events whence we cannot escape—all are adduced to prove that we are not masters of the circumstances in which our motives and wishes originate, and if finally our motives and wishes determine our actions, in what sense can these actions be said to be the result of free will? Professor Tyndall writes: 'There is on all hands a growing repugnance to invoke the supernatural in accounting for the phenomena of human life; and thoughtful minds, finding no trace of evidence in favor of any other origin, are driven to seek in the interaction of social forces the genesis and development of man's moral nature. If they succeed in the search, and I think they are sure to succeed, social duty would be raised to a higher level of significance, and the deepening sense of social duty would, it is to be hoped, lessen, if not obliterate, the strife and heart burnings that now beset our social life.'"





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KOBE SHOJI ("Drip Irrigation") is senior vice-president of the Alexander & Baldwin Agribusiness Corporation in Honolulu. He was educated at Pomona College and the University of California at Los Angeles, where he received his Ph.D. in plant physiology in 1950. He then joined the faculty of the University of Hawaii and did research on the mineral nutrition of coffee, banana and sugarcane plants. From 1960 to 1975 he worked for a series of agricultural companies in Hawaii, Iran and Puerto Rico, directing research devoted to optimizing the yield of sugarcane and other tropical crops. In his present position Shoji is involved in the evaluation and development of a wide variety of agricultural projects. During the past year he traveled a total of 30,000 miles to consult in such diverse places as the Australian outback, Central and South America, the Libyan desert, Khartoum, Teheran, Rome and London.

EDWARD J. GROTH, P. JAMES E. PEEBLES, MICHAEL SELDNER and RAYMOND M. SONEIRA ("The Clustering of Galaxies") are a group of cosmologists at Princeton University. Groth was educated at the California Institute of Technology and at Princeton, where he received his Ph.D. in physics in 1971. He stayed on and studied pulsars before taking up his present research. Peebles is professor of physics at Princeton and the leader of the group. A native of Canada, he attended the University of Manitoba, going on to obtain his Ph.D. in physics from Princeton in 1961. An initial interest in the physics of gravity led him to astrophysics and then cosmology. Seldner did his undergraduate work at Rutgers University and received his Ph.D. from Princeton this year. His thesis research dealt with the clustering of radio sources. He has also collaborated with Groth "on a number of double plays for the physics department softball team." Soneira, a Ph.D. candidate, received his bachelor's degree in physics from Columbia University in 1972.

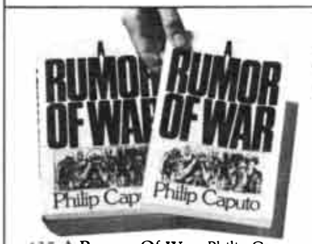
NEIL B. TODD ("Cats and Commerce") is director of the Carnivore Genetics Research Center in Newtonville, Mass. He was educated at the University of Maryland, the University of Massachusetts and Harvard University, where he received his Ph.D. in biology in 1963. From 1964 to 1968 he was employed as a geneticist at the Animal Research Center of the Harvard Medical School, where he was responsible for breeding programs for dogs and cats for research purposes. In 1968 he joined the Carnivore Genetics Research Center, and he worked concurrently for private animal-breeding laboratories and as adjunct professor of biology at Boston University until last year. Todd's research on the population genetics of domestic cats has involved field studies throughout the world. Apart from his scientific work his major interest is numismatics. He has just completed for publication "extensive research notes on the tavern tokens associated with the wine and spirit trade in late-19th-century Dublin."

LAWRENCE H. KEELEY ("The Functions of Paleolithic Flint Tools") is an anthropologist with a special interest in prehistoric stone implements. He did his undergraduate work at California State University at San Jose and his graduate work in anthropology at the University of Oregon and the University

of Oxford, where he received his D. Phil. this spring. He has participated in archaeological investigations in California and in England, and he has applied computer and microwear analysis to flint implements from sites in Britain, Germany and Syria. "As for future research," he writes, "I am of course interested in applying my methods of microwear research to stone implements from the European and African Paleolithic and from the North American Paleo-Indian period. I am also engaged in a study of preagricultural technologies, with particular reference to the use of chipped stone implements in the exploitation of plant resources." This past year Keeley has been a guest lecturer at the University of Edinburgh, the University of Chicago and the University of California at Berkeley.

DAVID EPEL ("The Program of Fertilization") is professor of biology at the Hopkins Marine Station of Stanford University. He first became interested in biology as a high school student, when he was given a vintage 1880 Leitz microscope with which he spent long hours observing protozoa. He continued his study of biology at Wayne State University and went on to obtain his Ph.D. in zoology from the University of California at Berkeley in 1963. After two years of postdoctoral research in Britton Chance's laboratory at the Johnson Research Foundation of the University of Pennsylvania School of Medicine, he joined the staff of the Hopkins Marine Station in 1965. In 1970 he moved to the Scripps Institution of Oceanography of the University of California at San Diego; he returned to Hopkins this fall. For the past three summers Epel has codirected the embryology program at the Marine Biological Laboratory in Woods Hole, Mass.

JOHN U. NEF ("An Early Energy Crisis and Its Consequences") is professor emeritus of economic history at the University of Chicago. Born in 1899, Nef attended Harvard College and the Robert Brookings Graduate School in Washington, where he received his Ph.D. in economics in 1927. After teaching for two years at Swarthmore College he joined the Chicago faculty. In 1942 he founded the Committee on Social Thought, a small interdisciplinary faculty devoted to the study of historical and cultural development. The committee attracted many eminent thinkers and artists to Chicago, among them Friedrich von Hayek and Saul Bellow (who became the committee's chairman after Nef's retirement). Nef is the author of 15 books, including a two-volume history of the British coal industry and, most recently, a memoir titled *Search for Meaning: The Autobiography of a Nonconformist.*



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228

MATHEMATICAL GAMES

In which joining sets of points by lines leads into diverse (and diverting) paths

by Martin Gardner

> "Prove that at a gathering of any six people, some three of them are either mutual acquaintances or complete strangers to [one an]other."
>
> —Problem E 1321,
> *The American Mathematical Monthly,*
> June–July, 1958

My column this month, on Ramsey graph theory, honors the appearance this year of *The Journal of Graph Theory,* a periodical exclusively concerned with one of the fastest growing branches of modern mathematics. The editor-in-chief is Frank Harary, an eminent graph theorist and author of the world's most widely used textbook on the subject. The publisher of the magazine is John Wiley & Sons.

Graph theory studies sets of points joined by lines. Two articles in the first issue of the new journal deal with Ramsey graph theory, a topic that has a large overlap with recreational mathematics. Although a few papers on Ramsey theory, by the Hungarian mathematician Paul Erdös and others, appeared in the 1930's, it was not until the late 1950's that work began in earnest on the search for what are now called Ramsey numbers. One of the great stimulants to this search was the innocent-seeming puzzle quoted above.

It is easy to transform this puzzle into a graph problem. Six points represent the six people. Join every pair of points with a line, using a red pencil, say, to indicate two people who know each other and a blue pencil for two strangers. The problem now is to prove that no matter how the lines are colored you cannot avoid producing either a red triangle (joining three mutual acquaintances) or a blue triangle (joining three strangers).

Ramsey theory, which deals with such problems, is named for an extraordinary University of Cambridge mathematician, Frank Plumpton Ramsey. Ramsey was only 26 when he died in 1930, a few days after an abdominal operation. His father was president of Magdalene College, Cambridge, and his brother was archbishop of Canterbury from 1961 to 1974. Economists know him for his remarkable contributions to economic theory. Logicians know him for his simplification of Bertrand Russell's ramified theory of types (it is said that Ramsey Ramseyfied the ramified theory) and for his division of logic paradoxes into logical and semantical classes. Philosophers of science know him for his interpretation of probability in terms of beliefs and for his invention of the "Ramsey sentence": a symbolic device that greatly clarifies the nature of the "theoretical language" of science.

In 1928 Ramsey read to the London Mathematical Society a now classic paper, "On a Problem in Formal Logic." (It is reprinted in *The Foundations of Mathematics,* a posthumous collection of Ramsey's essays edited by R. B. Braithwaite and currently available in paperback.) In this paper Ramsey proved a deep result about sets that is now known as Ramsey's theorem. He proved it first for infinite sets, observing this to be easier than his next proof, for finite sets. Like so many theorems about sets, it turned out to have a large variety of unexpected applications to combinatorial problems. The theorem in its full generality is too complicated to explain here, but for our purposes it will be sufficient to see how it applies to graph-coloring theory.

When all pairs of n points are joined by lines, the graph is called a complete graph on n points and is symbolized by K_n. Since we are concerned only with topological properties, it does not matter how the points are placed or the lines are drawn. The illustration on page 23 shows the usual ways of depicting complete graphs on two through six points. The lines identify every subset of n that has exactly two members.

Suppose we arbitrarily color the lines of a K_n graph red or blue. We might color the lines all red or all blue or any mixture in between. This is called a two-coloring of the graph. The coloring is of course a simple way to divide all the two-member subsets of n into two mutually exclusive classes. Similarly, a three-coloring of the lines divides them into three classes. In general an r-coloring divides the pairs of points into r mutually exclusive classes.

A "subgraph" of a complete graph is any kind of graph contained in the complete graph in the sense that all the points and lines of the subgraph are in the larger graph. It is easy to see that any complete graph is a subgraph of any complete graph on more points. Many simple graphs have names. The illustration on page 24 shows four families: paths, cycles, stars and wheels. Note that the wheel for four points is another way of drawing K_4. It is often called a tetrahedron because it is a planar projection of the tetrahedron's skeleton.

Consider now the following problem involving six pencils of different colors. To each color we assign any kind of graph we like. For example:

1. Red: a pentagon (five-point cycle).
2. Orange: a tetrahedron.
3. Yellow: a seven-point star.
4. Green: a 13-point path.
5. Blue: an eight-point wheel.
6. Purple: a bow tie (two triangles sharing just one point).

We now ask a curious question. Are there complete graphs that, if they are arbitrarily six-colored, are certain to contain as a subgraph at least one of the six graphs listed above? In other words, no matter how we color one of these complete graphs with the six pencils we are certain to get either a red pentagon or an orange tetrahedron or a yellow seven-point star, and so on. Ramsey's theorem proves that beyond a certain finite size all complete graphs have this property. The smallest graph of this infinite set is called the Ramsey graph for the specified set of subgraphs. Its number of points is called the Ramsey number for that set of subgraphs.

Every Ramsey graph provides both a game and a puzzle. For our example the game is as follows. Two players take turns picking up any one of the six pencils and coloring a line of the Ramsey graph. The first person to complete the coloring of one of the specified subgraphs is the loser. Since it is a Ramsey graph, the game cannot be a draw. Moreover, it is the smallest complete graph on which a draw is not possible.

The related puzzle involves a complete graph with one less point than the Ramsey graph. This obviously is the largest complete graph on which the game can be a draw. Such a graph is called the critical Ramsey graph for the specified set of subgraphs. The puzzle consists in finding a coloring for the critical graph in which none of the subgraphs appears. The coloring is called a critical coloring.

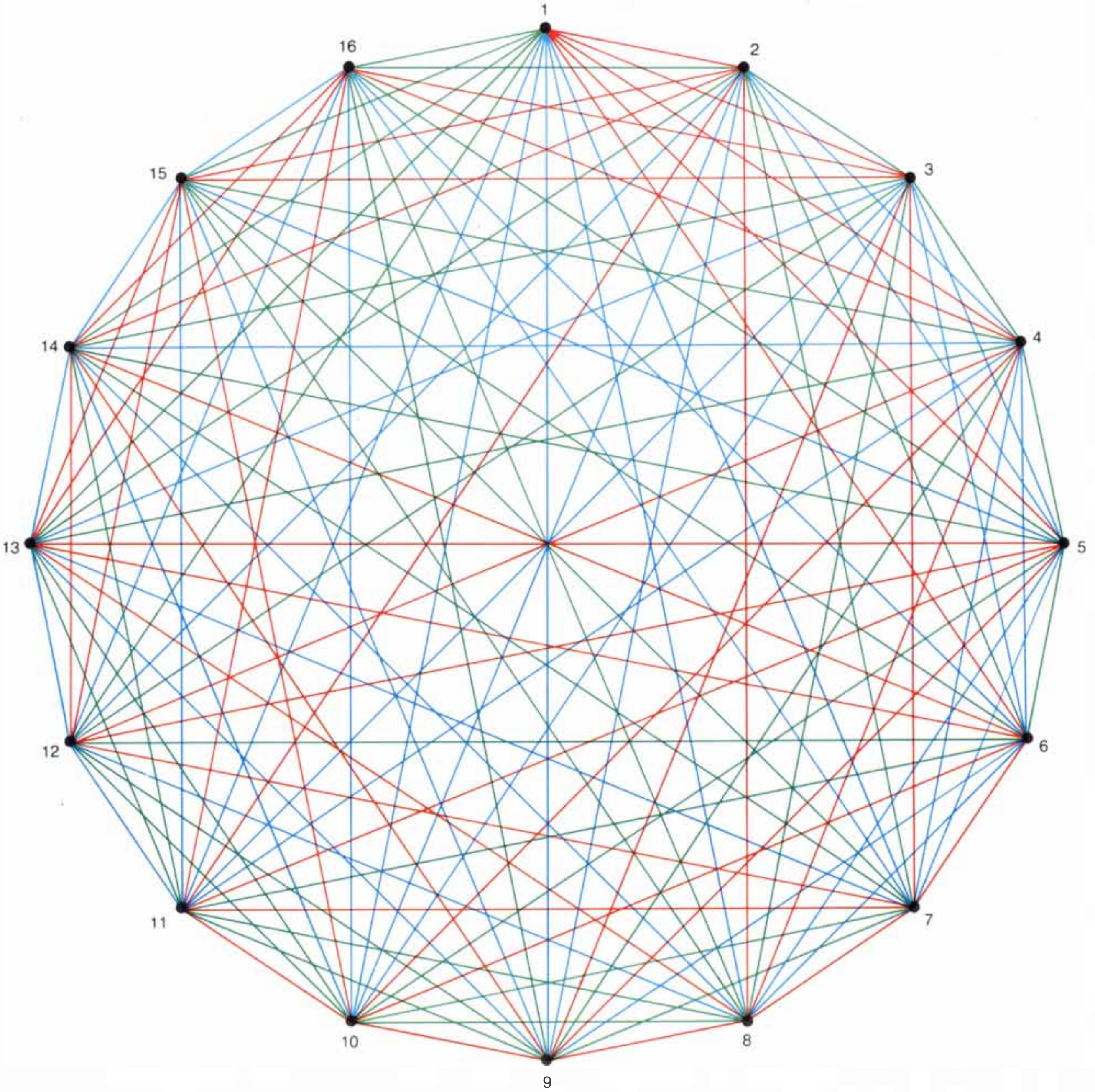
I have no idea what the Ramsey number is for the six subgraphs given. Its complete graph would be so large (containing hundreds of points) that playing a game on it would be out of the question, and the associated puzzle is far too difficult to be within the range of a feasible computer search. Nevertheless, Ramsey games and puzzles with smaller complete graphs and with pencils of just two colors can be quite entertaining.

The best-known Ramsey game, called Sim, was discussed in this column for January, 1973. It is played on the complete graph on six points (K_6), which models the problem about the party of six people. It is not hard to prove that 6 is the Ramsey number for the following two subgraphs:

1. Red: triangle (K_3).
2. Blue: triangle (K_3).

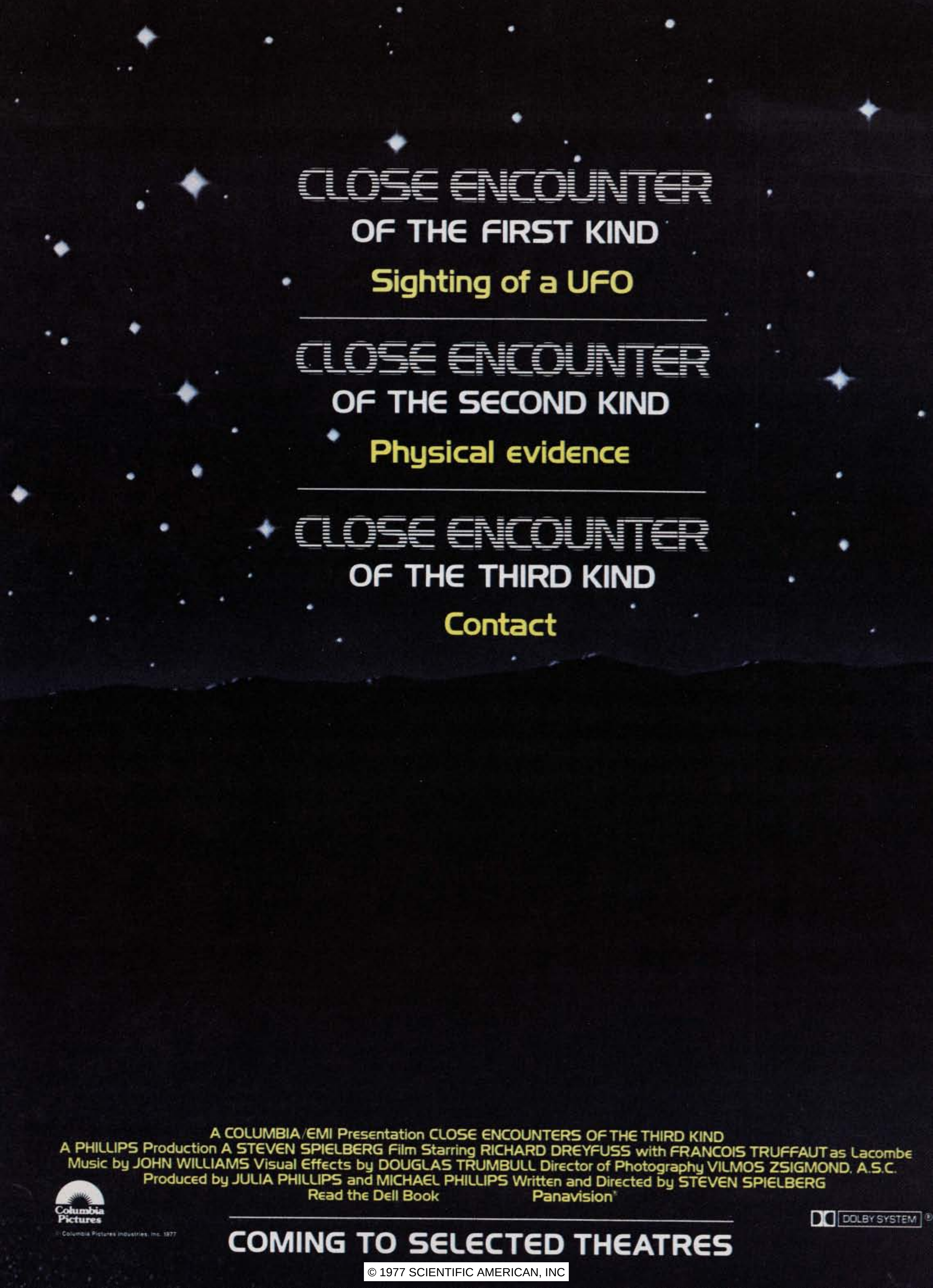
In "classical" Ramsey theory it is customary to use solitary numbers for complete graphs, and so we can express the above result with this compact notation: $R(3,3) = 6$. This means that R, the Ramsey number for the smallest complete graph that forces a "monochromatic" (all red or all blue) triangle when the graph is two-colored, is 6. Thus if two players alternately color the K_6 red and blue, one player is certain to lose by completing a triangle of his color. The corresponding and easy puzzle is to two-color the critical graph, K_5, so that no monochromatic triangle appears.

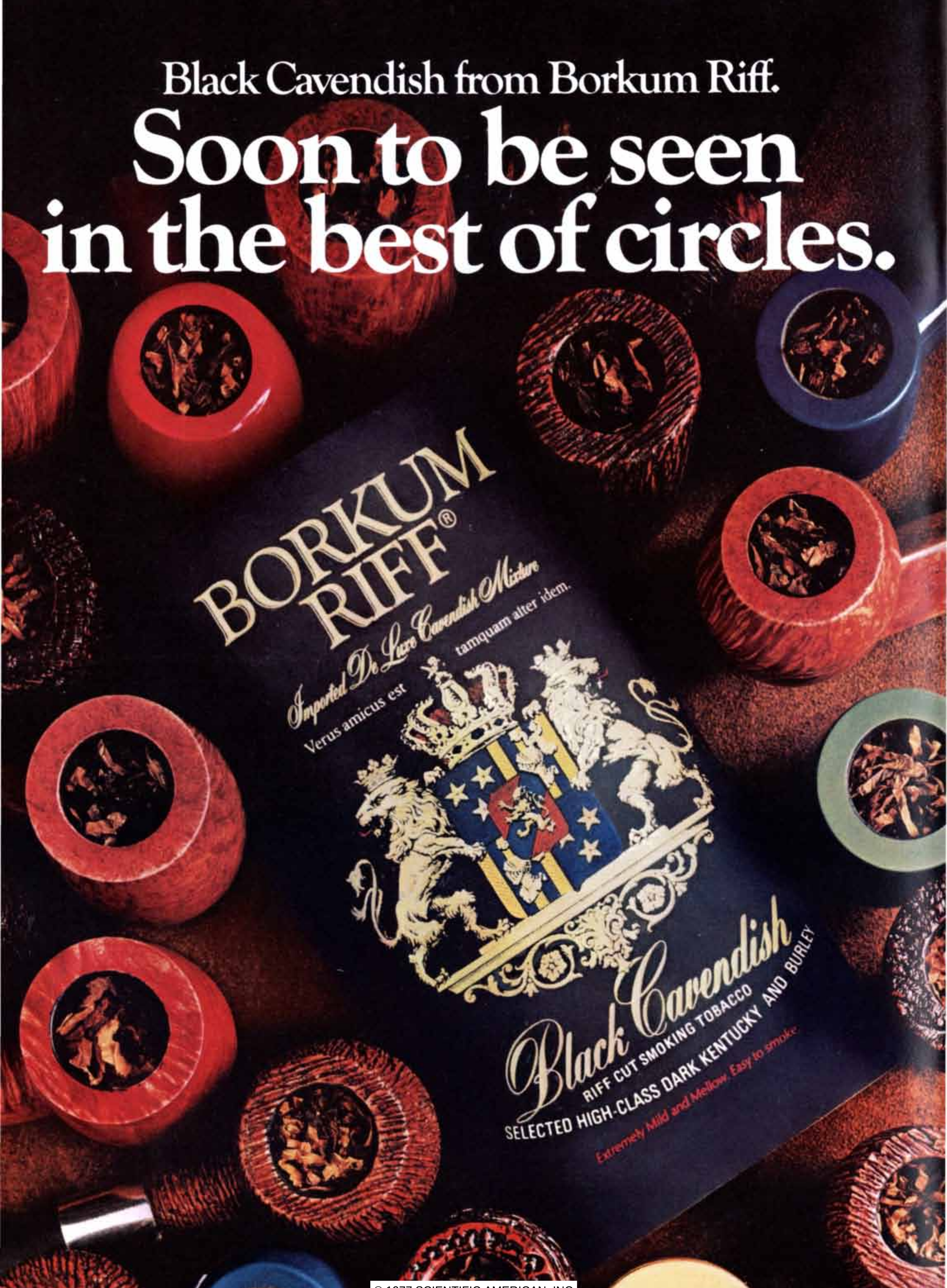
It turns out that when K_6 is two-colored, at least two monochromatic triangles are forced. (If there are exactly two and they are of opposite color, they form a bow tie.) This raises an interesting question. If a complete graph on n points is two-colored, how many monochromatic triangles are forced? A. W.



A critical three-coloring of K$_{16}$*, a complete graph on 16 points*

WE ARE NOT ALONE
CLOSE ENCOUNTERS
OF THE THIRD KIND




Black Cavendish from Borkum Riff.
Soon to be seen in the best of circles.
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Black Cavendish
RIFF CUT SMOKING TOBACCO
SELECTED HIGH-CLASS DARK KENTUCKY AND BURLEY
Extremely Mild and Mellow, Easy to smoke

Goodman was the first to answer this in a paper, "On Sets of Acquaintances and Strangers at Any Party," in *The American Mathematical Monthly* (Vol. 66, No. 9, November, 1959, pages 778–783). Goodman's formula is best broken into three parts:

If n has the form $2u$, the number of forced monochromatic triangles is $\frac{1}{3}u(u-1)(u-2)$. If n is $4u+1$, the number is $\frac{1}{3}2u(u-1)(4u+1)$. If n is $4u+3$, it is $\frac{1}{3}2u(u+1)(4u-1)$. Thus for complete graphs of six through 12 points the numbers of forced one-color triangles are two, four, eight, 12, 20, 28 and 40.

Random two-coloring will usually produce more monochromatic triangles than the number forced. When the coloring of a Ramsey graph contains exactly the forced number of triangles and no more, it is called extremal. Is there always an extremal coloring in which the forced triangles are all the same color? (Such colorings have been called blue-empty, meaning that the number of blue triangles is reduced to zero.) In 1961 Léopold Sauvé showed that the answer is yes. This suggests a new class of puzzles. For example, draw the complete graph on seven points. Can you two-color it so that there are no blue triangles and no more than four red triangles? It is not easy. (Next month I shall give a solution.)

Very little is known about "classical" Ramsey numbers. They are the number of points in the smallest complete graph that forces a given set of smaller complete graphs. There is no known practical procedure for finding classical Ramsey numbers. An algorithm is known: one simply explores all possible colorings of complete graphs, going up the ladder until the Ramsey graph is found. This task grows so exponentially in difficulty and at such a rapid rate, however, that it quickly becomes computationally infeasible. Even less is known about who wins—the first player or the second—if a Ramsey game is played rationally. Sim has been solved (it is a second-player win), but almost nothing is known about Ramsey games involving larger complete graphs.

So far we have considered only the kind of Ramsey game that Harary calls an avoidance game. As he has pointed out, at least three other kinds of game are possible. For example, in an "achievement" game (along the lines of Sim) the first player to complete a monochromatic triangle wins. In the other two games the play continues until all the lines are colored, and then either the player who has the most triangles of his color or the player who has the fewest wins. These last two games are the most difficult to analyze, and the achievement game is the easiest. In what follows "Ramsey game" denotes the avoidance game.

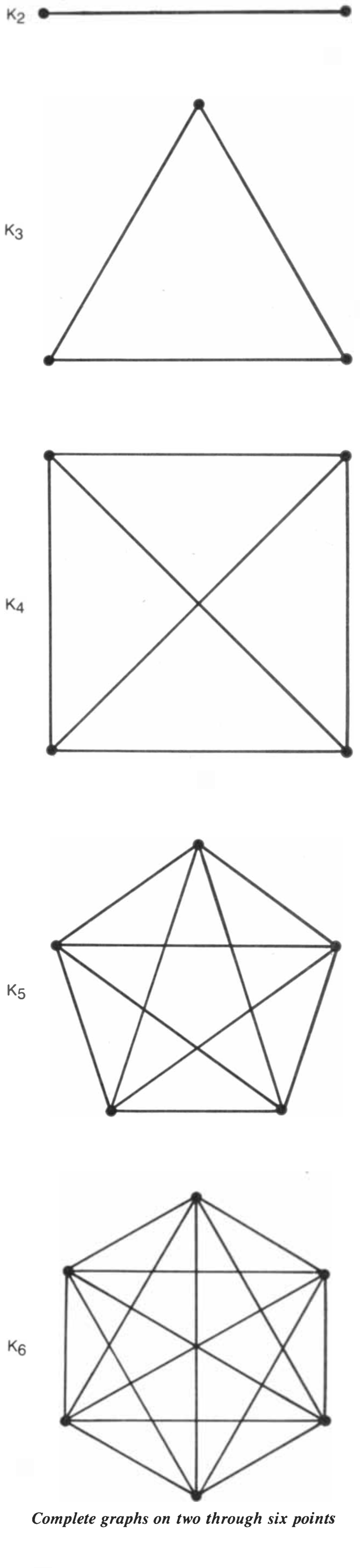
Apart from $R(3,3)$, the basis of Sim, only five other nontrivial classical Ramsey numbers are known for two-colorings:

1. $R(3,4)$ equals 9. If K_9 is two-colored, it forces a red triangle (K_3) or a blue tetrahedron (K_4). No one knows who wins if this is played as a Ramsey game.
2. $R(3,5)$ equals 14.
3. $R(4,4)$ equals 18. If K_{18} is two-colored, a monochromatic tetrahedron (K_4) is forced. This is not a bad Ramsey game, although the difficulty of identifying tetrahedrons makes it hard to play. The graph and its coloring correspond to the fact that at a party of 18 people there is either a set of four acquaintances or four total strangers.
4. $R(3,6)$ equals 18. At the same party there is either a set of three acquaintances or six total strangers. How these two sets are related to the two tetrahedral sets in the preceding example is an interesting question that no one seems to have investigated.
5. $R(3,7)$ equals 23.

Note that the above list does not include $R(5,5)$. That is because no one yet knows the Ramsey number for a complete graph that, if it is two-colored, forces a monochromatic K_5. Stefan A. Burr of the long-lines department of the American Telephone and Telegraph Company, a leading expert on Ramsey graph theory, thinks it is possible that $R(5,5)$ will never be known, so great is the jump in complexity. Even $R(4,5)$, he believes, is so difficult that it is conceivable it too may never be found. In both cases, however, there are known bounds. $R(5,5)$ is between 38 and 67 inclusive; $R(4,5)$ is between 25 and 29 inclusive.

Only one other classical Ramsey number is known, and it is for three colors. $R(3)=3$ is trivial because if you one-color a triangle, you are sure to get a one-color triangle. We have seen that $R(3,3)$ equals 6. $R(3,3,3)$ equals 17. This means that if K_{17} is three-colored, it forces a monochromatic triangle. Actually it forces more than one, but the exact number is not known.

$R(3,3,3)=17$ was first proved in 1955. The Ramsey game for this graph uses pencils of three different colors. Players alternately color a line, using any color they want to, until a player loses by completing a monochromatic triangle. Who wins if both players make their best possible moves? No one knows. The corresponding Ramsey puzzle is to three-color K_{16}, the critical graph, so that no monochromatic triangle appears. The illustration on page 19, reproduced from *Graphs and Hypergraphs*, by the French graph theorist Claude Berge, shows one of the two essentially different solutions. ("Differ-



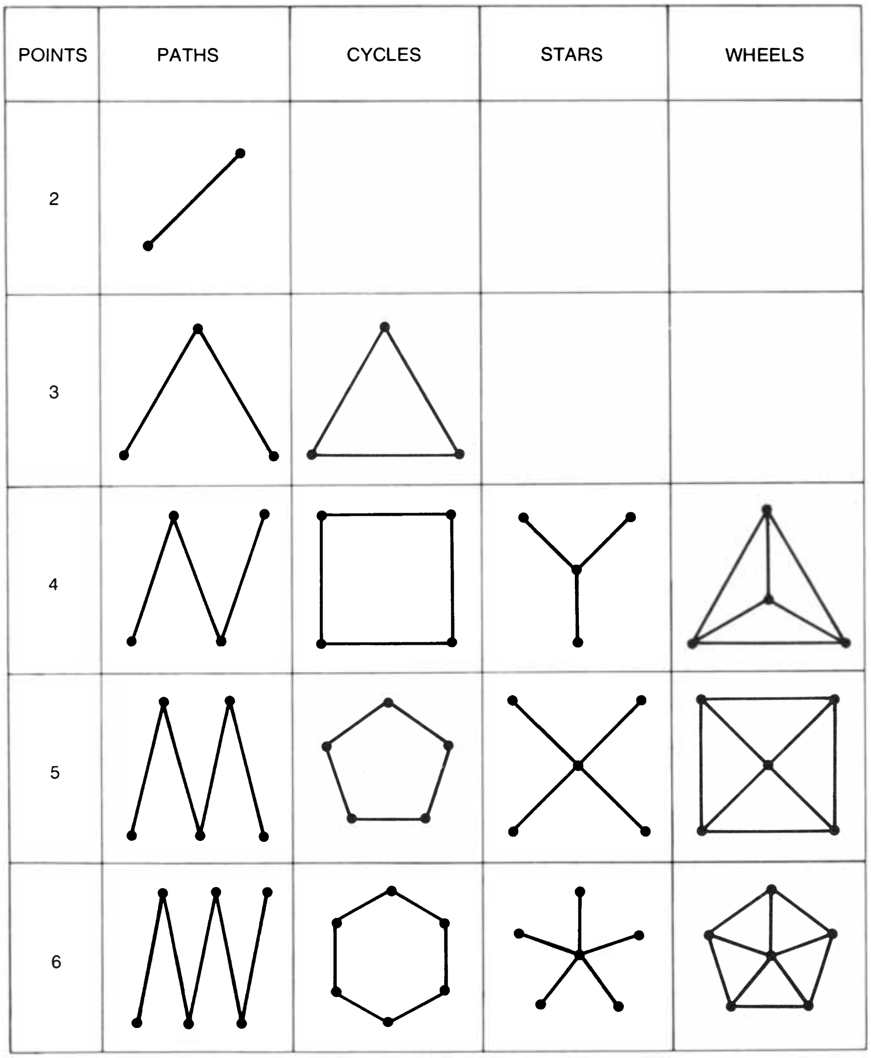
Complete graphs on two through six points ent" is used here in a combinatorial sense deeper than mere exclusion of rotations and reflections.)

What about $R(3,3,3,3)$, the minimum complete graph that forces a one-color triangle when it is four-colored? It is unsolved, although an upper bound of 64 was proved by Jon Folkman, a brilliant combinatorialist who committed suicide in 1964 at the age of 31, following an operation for a massive brain tumor. The best lower bound, 51, was established by Fan Chung, a young Chinese mathematician at Bell Laboratories who gave the proof in her Ph.D. thesis.

Classical Ramsey theory generalizes in many fascinating ways. We have already considered the most obvious way: the seeking of what are called generalized Ramsey numbers for r-colorings of complete graphs that force subgraphs other than complete ones. Václav Chvátal and Harary were the pioneers in this territory, and Burr has been mining it for the past five years. Consider the problem of finding Ramsey numbers for minimum complete graphs that force a monochromatic star of n points. Harary was the first to solve it for two-coloring. In 1973 Burr and J. A. Roberts solved it for any number of colors.

Another generalized Ramsey problem is to find Ramsey numbers for two-colorings of K_n that force a specified number of monochromatic "disjoint" triangles. (Triangles are disjoint if they have no common point.) In 1975 Burr, Erdös and J. H. Spencer showed the number to be $5d$, where d is the number of disjoint triangles and greater than two. The problem is unsolved for more than two colors.

The general case of wheels is not even solved for two colors. The Ramsey number for the wheel of four points, the tetrahedron, is, as we have seen, 18. The wheel of five points (a wheel with a hub and four spokes) was recently shown to have a Ramsey number of 15 by Tim Moon, a Nigerian mathematician. The six-point wheel is unsolved, although its Ramsey number is known to have bounds of 17 to 20 inclusive. The conjectured value is 20. If this is true, complete graphs of 17, 18 and 19 points can be two-colored without containing a monochromatic six-point (five-spoke) wheel. It would be of considerable interest to obtain such a coloring for K_{17}, and I would be pleased to hear from any reader who finds one. If it exists, it probably has a high degree of symmetry.



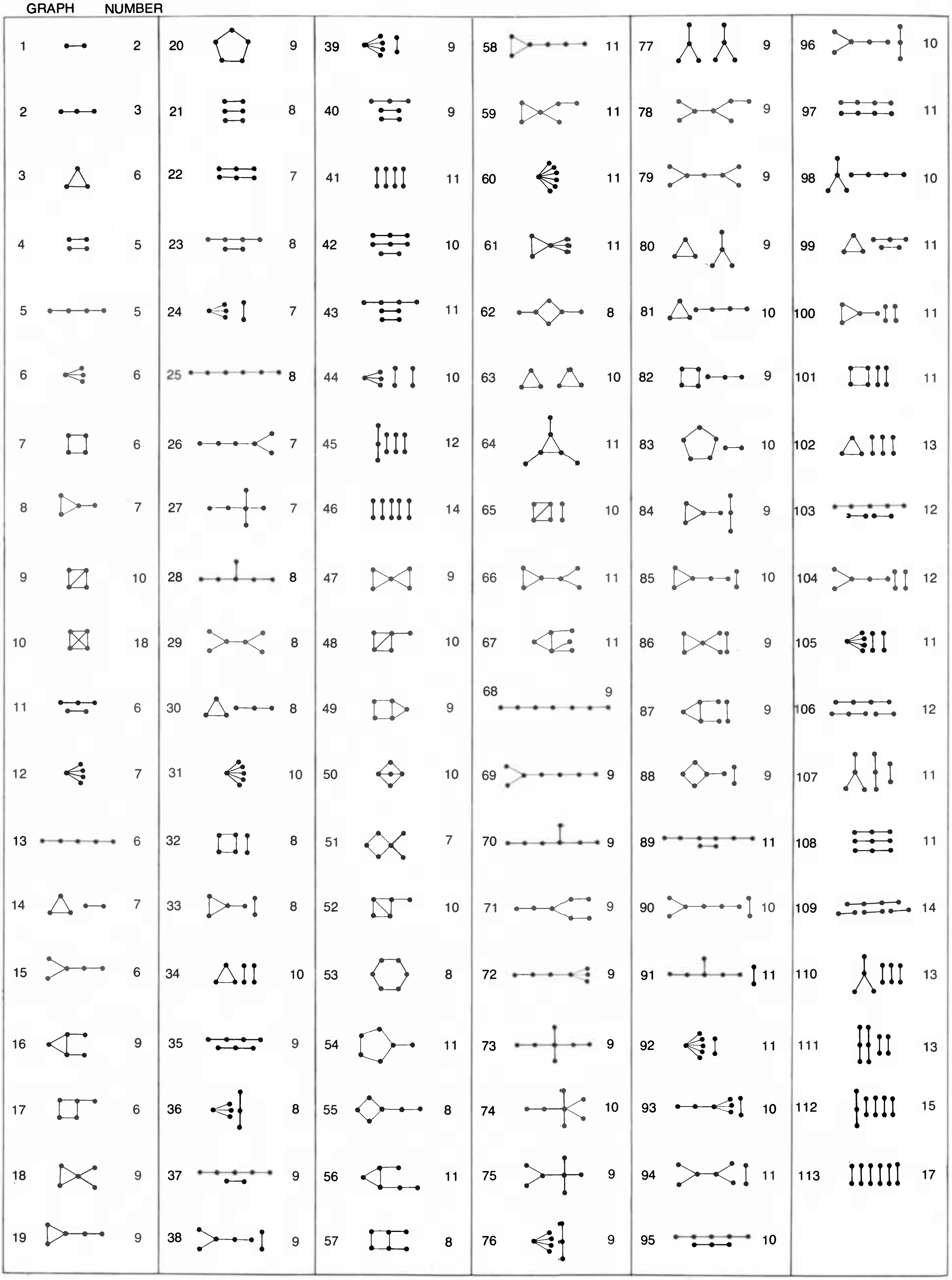
Four important families of simple graphs

The illustration on page 26, a valuable chart supplied by Burr and published here for the first time, lists the 113 simple graphs with no more than six lines and no isolated points for which the generalized Ramsey number is known. Note that some of these graphs are not connected. In such cases the entire pattern, either all red or all blue, is forced by the complete graph with the Ramsey number indicated.

Every item on Burr's chart is the basis of a Ramsey game and puzzle, although it turns out that the puzzles—finding critical colorings for the critical graphs—are much easier than finding critical colorings for classical Ramsey numbers. Note that the chart gives six variations of Sim. A two-coloring of K_6 not only forces a monochromatic triangle but also forces a square, a four-point star (sometimes called a "claw"), a five-point path, a pair of disjoint paths of two and three points (both the same color), a square with a tail, and the simple "tree" that is 15 on Burr's chart. The triangle with a tail (8), the five-point star (12), the Latin cross (27) and the fish (51) might be worth looking into as Ramsey games on K_7.

Ronald L. Graham, one of the nation's top combinatorialists (he heads the Discrete Mathematics Department at Bell Laboratories), has made many significant contributions to generalized Ramsey theory. It would be hard to find a creative mathematician who less resembles the motion-picture stereotype. In his early youth Graham and two friends were professional trampoline performers who worked for a circus under the name of the Bouncing Baers. He is also one of the country's best jugglers and former president of the International Juggler's Association. The ceiling of his office is covered with a large net that he can lower and attach to his waist, so that when he is practicing with six or seven balls, any missed ball obligingly rolls back to him.

In 1968 Graham found an ingenious solution for a problem of the Ramsey type posed by Erdös and András Hajnal. What is the smallest graph of any kind, not containing K_6, that forces a monochromatic triangle when it is two-colored? Graham's unique solution is the eight-point graph shown in the top illustration on page 28. The proof is a straightforward reductio ad absurdum. It begins with the assumption that a two-coloring avoiding monochromatic triangles is possible, then shows that this forces such a triangle. At least two lines from the top point must be, say, gray, and the graph's symmetry allows us to make the two outside lines gray with



GRAPH	RAMSEY NUMBER
1	2
2	3
3	6
4	5
5	5
6	6
7	6
8	7
9	10
10	18
11	6
12	7
13	6
14	7
15	6
16	9
17	6
18	9
19	9
20	9
21	8
22	7
23	8
24	7
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46	14
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94	11
95	10
96	10
97	11
98	10
99	11
100	11
101	11
102	13
103	12
104	12
105	11
106	12
107	11
108	11
109	14
110	13
111	13
112	15
113	17

Simple graphs for which the generalized Ramsey number is known no loss of generality. The endpoints of these two lines must then be joined by a colored line to prevent the formation of a gray triangle. Readers may enjoy trying to complete the argument.

What about similar problems when the excluded subgraph is a complete graph other than K_6? The question is meaningless for K_3 because K_3 is itself a triangle. K_5 is unsolved. The best-known solution is an 18-point graph described by Robert W. Irving in a 1973 paper. K_4 is even further from being solved. Folkman, in a paper published posthumously, proved that such a Ramsey graph exists, but his construction used more than $2\uparrow\uparrow\uparrow 2^{901}$ points. This is such a monstrous number that there is no way to express it without using a special arrow notation. The notation is introduced by Donald E. Knuth in his article "Mathematics and Computer Science: Coping with Finiteness" in *Science* (December 17, 1976).

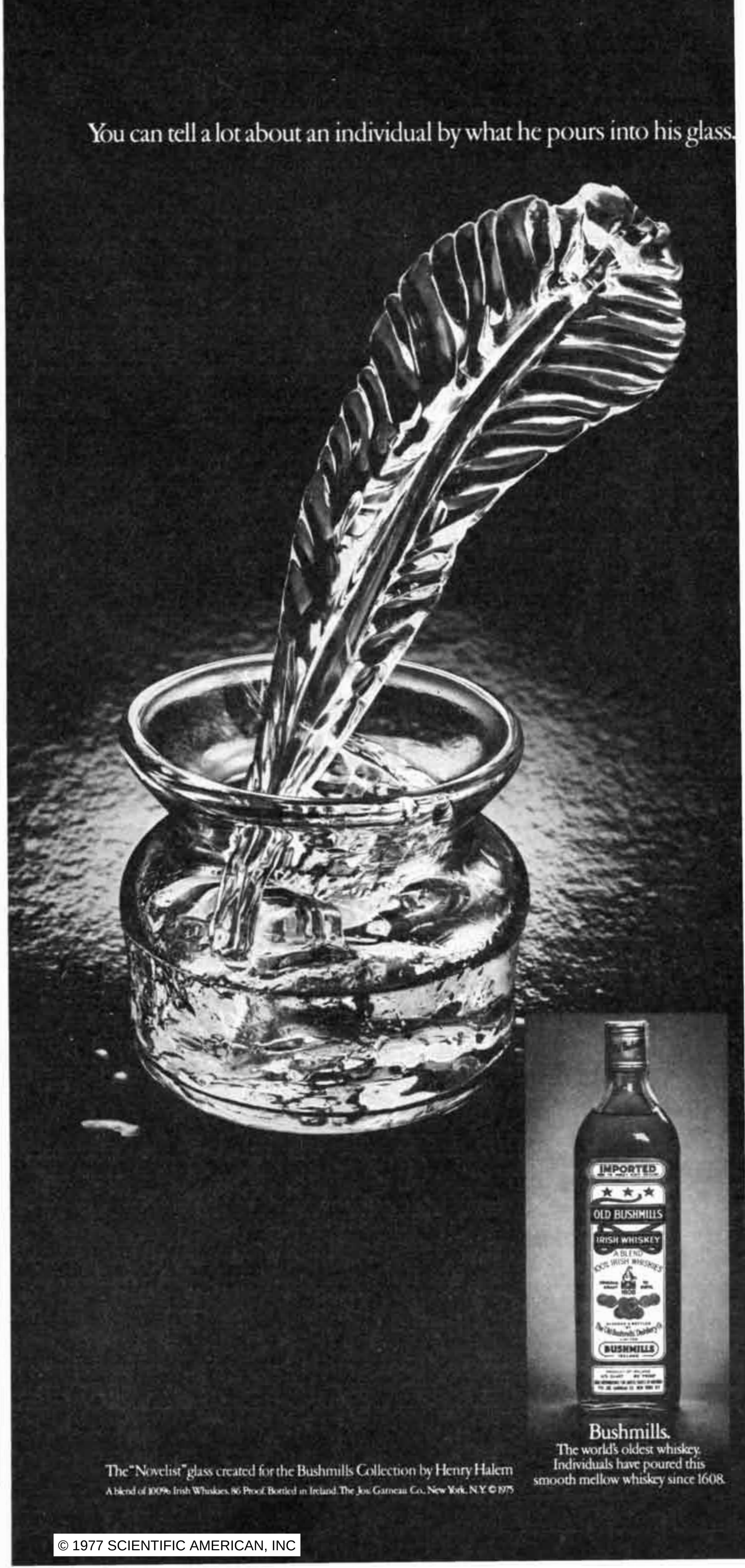
Imagine the universe tightly packed with spheres the size of electrons. The total number of such spheres is inconceivably smaller than the number occurring in Folkman's graph. Erdös has a standing offer of $100 to anyone finding a graph for this problem that has fewer than a million points.

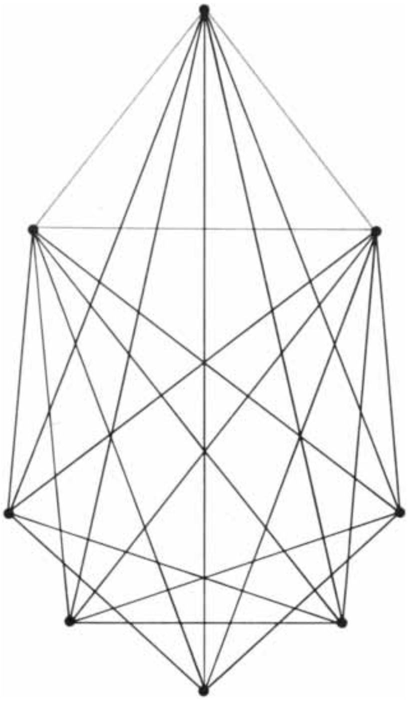
Folkman's graph dramatically illustrates how enormously difficult a Ramsey problem can be even when the problem's statement mentions no graph with more than four points. But as Al Jolson liked to say, you ain't heard nothin' yet. Graham has found an even more mind-boggling example.

Consider a cube with lines joining every pair of corners. The result is a complete graph on eight points, except now we have added a Euclidean geometric structure. Imagine the lines of this spatial K_8 arbitrarily colored red and blue. Can it be done in such a way that no monochromatic K_4 results that *lies on a plane?* The answer is yes, and it is not hard to do.

Let us generalize to n-dimensional cubes. A hypercube has 2^n corners. On the four-dimensional hypercube, it also is possible to two-color the lines of the complete graph of 2^4, or 16, points so that no one-color complete planar graph of four points results. The same can be done with the 2^5 hypercube of 32 points. This suggests the following Euclidean Ramsey problem: What is the smallest dimension of a hypercube such that if the lines joining all pairs of corners are two-colored, a planar K_4 of one color will be forced? Ramsey's theorem guarantees that the question has an answer only if the forced K_4 is not confined to a plane.

The existence of an answer when the forced monochromatic K_4 is planar was first proved by Graham and Bruce L. Rothschild in a far-reaching generaliza-





Graham's solution to a problem by Erdös

tion of Ramsey's theorem that they found in 1970. Finding the actual number, however, is something else. In an unpublished proof Graham has recently established an upper bound, but it is a bound so vast that it holds the record for the largest number ever used in a serious mathematical proof.

To convey at least a vague notion of the size of Graham's number we must first attempt to explain Knuth's arrow notation. The number written $3 \uparrow 3$ is $3 \times 3 \times 3 = 3^3 = 27$. The number $3 \uparrow\uparrow 3$ denotes the expression $3 \uparrow (3 \uparrow 3)$. Since $3 \uparrow 3$ equals 27, we can write $3 \uparrow\uparrow 3$ as $3 \uparrow 27$ or 3^{27}. As a slanting tower of exponents it is

$$3^{3^{3}}.$$

The tower is only three levels high, but written as an ordinary number it is 7,625,597,484,987. This is a big leap from 27, but it is still such a small number that we can actually print it.

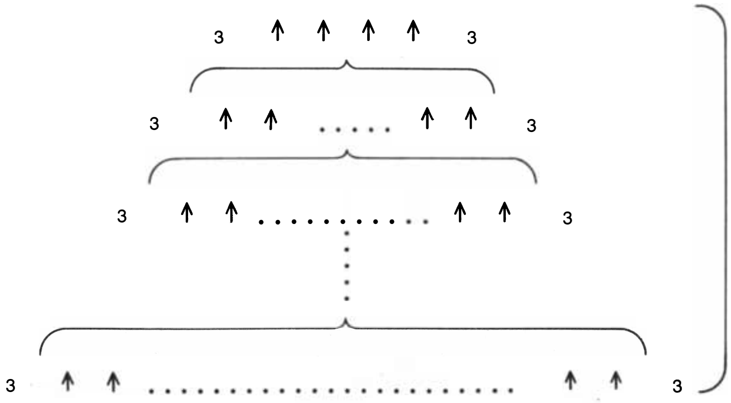
When the huge number $3 \uparrow\uparrow\uparrow 3 = 3 \uparrow\uparrow (3 \uparrow\uparrow 3) = 3 \uparrow\uparrow 3^{27}$ is written as a tower of 3's, it reaches a height of 7,625,597,484,987 levels. Both the tower and the number it represents are now too big to be printed without special notation.

Consider $3 \uparrow\uparrow\uparrow\uparrow 3 = 3 \uparrow\uparrow\uparrow (3 \uparrow\uparrow\uparrow 3)$. Inside the parentheses is the gigantic number obtained by the preceding calculation. It is no longer possible to indicate in any simple way the height of the tower of 3's that expresses $3 \uparrow\uparrow\uparrow\uparrow 3$. The height is another universe away from $3 \uparrow\uparrow\uparrow 3$. If we break $3 \uparrow\uparrow\uparrow\uparrow 3$ down to a series of the double-arrow operations, it is $3 \uparrow\uparrow (3 \uparrow\uparrow (3 \uparrow\uparrow \ldots \uparrow\uparrow (3 \uparrow\uparrow 3) \ldots))$, where the number of steps to be iterated is $3 \uparrow\uparrow\uparrow 3$. As Knuth says, the dots "suppress a lot of detail." $3 \uparrow\uparrow\uparrow\uparrow 3$ is unimaginably larger than $3 \uparrow\uparrow\uparrow 3$, but it is still small as finite numbers go, since most finite numbers are very much larger.

We are now in a position to indicate Graham's number. It is represented in the illustration below. At the top is $3 \uparrow\uparrow\uparrow\uparrow 3$. This gives the number of arrows in the number just below it. That number in turn gives the number of arrows below it. This continues for 2^6, or 64, layers. It is the bottom number that Graham has proved to be an upper bound for the hypercube problem.

Now hold on to your hat. Ramsey-theory experts believe the actual Ramsey number for this problem is probably 6. As Stanislaw M. Ulam has said many times in his lectures, "The infinite we shall do right away. The finite may take a little longer."

Last month's problem was to guess the secret rule that determined the final layout for a round in the card game Eleusis. The rule was: "If the last card is lower than the preceding legally played card, play a card higher than the last card, otherwise play a lower one. The first card played is correct unless it is equal to the starter card."



Graham's upper bound for the solution to a Euclidean Ramsey problem

BOOKS

Perpetual motion, shaman ritual and art and the responsiveness of blind infants

by Philip Morrison

PERPETUAL MOTION: THE HISTORY OF AN OBSESSION, by Arthur W. J. G. Ord-Hume. St. Martin's Press ($15). By the time of the cathedrals the idea was already firm: an "uneven number" of mallets hanging on a wheel might make it turn of itself. In about 1640 the Marquess of Worcester probably did demonstrate such a wheel "fourteen foot over" and bearing 40 50-pound weights on levers to Charles I at the Tower of London. (Inertia is impressive, and flywheels were almost unknown.) He gave a brief account of the wheel in his *Century of Inventions,* under the deadpan rubric *An Advantageous Change of Centres.* Water mills contrived to pump water up, subsequently to fall back down on the wheel, and a windmill-bellows cycle were drawn and sometimes constructed. There were skeptics. Bishop Wilkins wrote in 1648 that he "could scarce forebear, with Archimedes, to cry out 'Eureka!' " when he first had the waterwheel idea, but that experience and trial convinced him that the "stream, though multiplied, will not be of force enough to turn about the screw." Simon Stevinus used the unbalanced chain of balls running around an inclined plane to derive the equilibrium of nonparallel forces by invoking the impossibility of perpetual motion. "A wonder, and yet no wonder," he wrote. Nevertheless, in 1730 the best-known volumes of mechanisms still showed the perpetual cyclical machines, and frauds began to appear about then in various royal precincts. Hopeful patents continued to pour out. The first British patent for perpetual motion was granted in 1635, and there were 600 or more issued up to 1903. Most were Victorian in epoch, and the topic was discussed in the skeptical pages of *Scientific American* during the Yankee inventors' heyday.

Mere mechanisms came to lack mystery, and innovators, such as Jean Bernoulli, Robert Boyle and Sir William Congreve in their time, began to invoke capillarity (Congreve had weighted chains pressing unequally on wet sponges), asymmetries of buoyancy, magnetism, eventually motors and generators wired head to tail.

Enter the day of public frauds. Philadelphia housed two of them. The first, in about 1813, was displayed by one Charles Redheffer. "Incontestably a perpetual self-moving principle," it deployed a big gear driven by a small pinion. A clever young man noticed that these meshing gears had become worn on the wrong faces: power was coming in by way of the supposed output. Redheffer took his device to New York (but only after the ingenious Philadelphians had made up and showed him their own perpetual-motion machine. Driven by a hidden clock spring, it remains a masterpiece of indirection with little weights sliding on inclined planes, arranged so that the inner clockwork could not drive the wheels unless the pressure of the weights was present). In New York it was the redoubtable Robert Fulton who exclaimed as he entered the showroom, "Why, this is a crank motion!" He noticed the rhythm of an unseen hand, hardly to be expected from perpetual movers. Fulton knocked away some light wood braces that were there apparently to steady the machine. A catgut belt drive was revealed that led to "an old man with a long beard" turning the power crank in an attic room.

Some 50 years later John W. Keely, a Philadelphia enterpriser with a cool head but little education, sold shares in his "hydro-pneumatic-pulsating-vacu-engine" to thousands of Gilded Age speculators, who received a fine picture of it on their stock certificates. That engine drew "etheric force" from a thimbleful of water. The firm made millions from stock sales but sold not one joule of energy. After eight or 10 years of high living Keely was without support. The newspaper account of his struggles in poverty attracted a woman, newly widowed by the death of her wealthy husband, who became his benefactress. The Keely engine revived, now "vibratory" and calculated to take a ship across the Atlantic on a gallon of water. Until 1896 the issue was contested, in spite of the fact that skeptics had noticed hollow wires—represented as being solid—in nearly every piece of apparatus in Keely's laboratory. These were compressed-air supplies, people guessed, and so they turned out to be. After Keely's death, examination of his house revealed air ducts, moving magnets, shafts and hydraulic-pressure sources, all hidden in the walls and driven by a strong, silent spring motor in the basement.

There is active in southern California today a well-financed chemical-engineering project for releasing hydrogen fuel from water without cost in energy. Certainly the hydrogen is there; we all await the results.

Self-delusion is more disarmingly wholehearted than fraud. In 1918 an expert commission set up by act of Congress undertook official study of the project of an honest man, Garabed Giragossian. He had stirred the entire country, particularly the press, with his public offer: he asked only searching and expert scrutiny when the time should come for him to present the American people with his new scheme for free energy—perpetual motion at last. He had gone direct to Congress because he doubted the protection of the Patent Office. His invention was the flywheel! He saw that he could run his wheel, once it was started, with a 1/20-horsepower motor but that it delivered 10 measured horsepower every time it was braked rapidly to rest. Utterly honest, he had never grasped the difference between energy and power.

The book enters a few whimsical bypaths of interest. A clock made in the 1760's was powered by variations of atmospheric pressure, which induced small but reliable motions of the column of a barometer to wind up the weights. Mr. Cox's Perpetual Motion, a handsome cynosure in its time, did in fact run well on the bounty of the atmosphere for a lifetime; it stands mute today in the Victoria and Albert Museum, its heavy mercury load long since removed, a noble ruin. Ord-Hume can take some comfort from the fact that a well-known Swiss firm now makes a line of handsome and practical mantel clocks with the same never-wind virtue but with an aneroid chamber rather than a mercury column. In an Oxford laboratory today (we see its photograph) there is an electric chime run by two dry voltaic piles, potted in sulfur in 1840. The minute current still flows to strike the bells a few times a second, except when the humidity is too high. The striker ball is wearing visibly, and below it lies "a tiny but ominous pile of metallic dust." Was this not the forerunner of modern low-power integrated circuitry?

There is good humor, generally careful history and physical sense in this well-illustrated nontechnical book by a British aeronautical engineer. Not every analysis is quite to the point, but there are many good ones. It is hard to forget Ord-Hume's own encounter in 1958 with a touching elderly Londoner who had made in his little flat a wonderful new aircraft engine that ran reliably at

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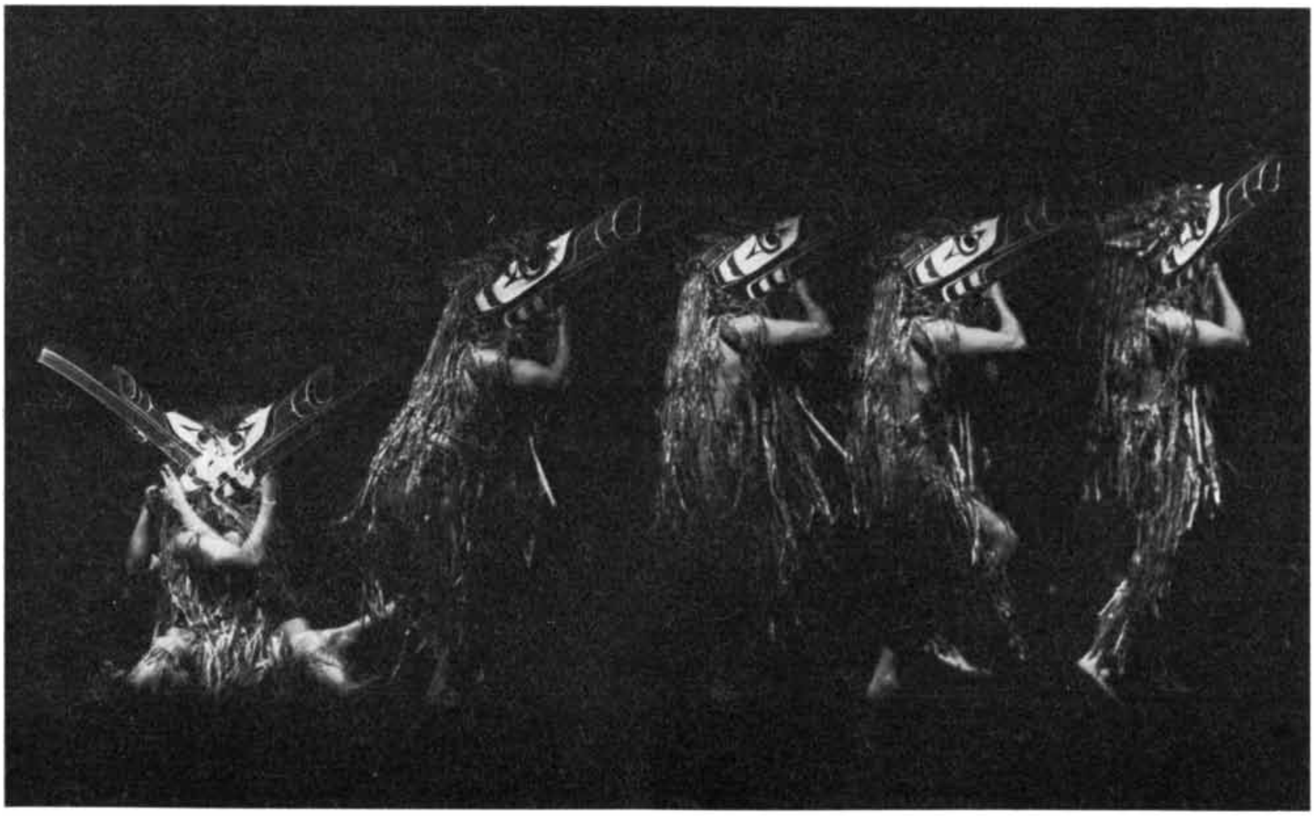
high power without any fuel. The author's natural question was might he see it? The polite reply was even more reasonable. Of course, it had been working just out there in the hall for weeks, but the inventor could not make it stop, and so the other tenants had insisted that he disassemble it completely to end the tiresome noise!

STONES, BONES AND SKIN: RITUAL AND SHAMANIC ART, edited by Anne Trueblood Brodzky, Rose Danesewich and Nick Johnson. The Society for Art Publications, Toronto ($27.50). A shaman, a woman of the Mapuche Indians of Chile, looks gravely out of the page at you, bearing a shallow drum. The drum she beats as she stands on the notched pole (at once the world tree and her own celestial ladder) is not new to us. It is the very form of the drum, celebrated in Enlightenment Europe, that the dashing and ambitious Carl von Linné—Linnaeus himself—held as he stood for his portrait in the full shaman's dress he brought back from a journey among the Lapps. In this real medicine bundle of a book, with crowded pages bearing many images and diverse text, and with gatefolds and color plates as well, the editors assemble for us almost 20 picture essays on the theme of the title.

Our cultural sensitivity to the shaman of the hunting peoples has reached unprecedented heights. We easily accede now to the proposition that the "shamanic system . . . can be said to be mankind's oldest religion," for the evidence is strong. Depicted in the painted cave of Les Trois Frères, a half-animal, half-human figure appears to charm the deer and the bison—themselves not far from human—who dance around him. His music comes from what appears to be a small bow held in the mouth. Just such a musical bow is shown here in the hands of the Huichol shaman Ramón Medina, and another mouth bow of bent white birch is shown from the instrument collection of the National Museum of Man in Ottawa. A shaman healer in Nepal is seen ritually sucking the evil out of a patient's body, exactly as his counterpart operates in the delta of the Orinoco. Mankind spread past the edge of the ice to all the Americas, and clearly the marginal Old World peoples who are closest to the hunting life still practice the ancient periglacial arts, which lie, below the surface and much enriched, more or less everywhere. That ancient art is a la mode today. Consider the abstract, evocative intensity of "stones, bones and skin," the numinous union of animal and human, the living flesh revealing the bone within, the hallucinogens, the vocation sickness, the use of ecstatic trance to heal, the spirit language, the priestly guardianship of the public weal and even the selfish exploitation of those dark powers.

In these pages we watch a long-evolved Kwakiutl dance with great creative masks, cannibal birds, wasps and the raven, in a fine multiple-flash photographic record. In one colorful gatefold we see a shaman's costume in loving detail. It is a Siberian costume (now in New York) collected by the sinologist Berthold Laufer from the Goldi along the Amur River in 1900. (Why we see no drum is not explained.) A special feature of the volume is a set of accounts and displays of contemporary art inspired by shamanism. Bill Reid, an artist whose mother was a Haida, has brilliantly transformed the motifs and vision of that culture into intricately worked gold, silver and wood, the forerunner of a renascence of Pacific Northwest art. The six little heads peering out between the clamshell valves at a sheltering Creator Raven illustrate the Haida Genesis: "'Whah! Come out!' whispered the Creator. . . . Then human faces appeared one by one, in a row." It is all carved into one vibrant clam-sized piece of boxwood.

The fictionalized account of the Yaqui shaman Don Juan became a popular prototype of mysteries in the past decade. Much more wonderful is the honest account, together with photographs, of the Huichol shaman given us here by the anthropologist Peter T. Furst of the State University of New York at Albany. We see Don Ramón in "spectacular,



Repetitive-flash photograph in **Stones, Bones and Skin** *shows part of the "cannibal bird" dance of a Kwakiutl shaman* and very dangerous, rapid-fire leaps—flights might be more appropriate"—from one slippery boulder to another at the lip of a high waterfall. He said, "I took you there to show you what it means 'to have balance.' So you could see and understand about the shaman." We see and in part do understand; he is a real shaman, acting as a human being is given to act at the farthest reaches. Here is no demeaning hyperbolic fiction.

At Baker Lake the story is told: "When the moon rocket went to the moon and some of the young kids were trying to tell the old people about this, they were getting really frustrated because the old people were saying, 'Oh, that's nothing, my uncle went to the moon lots of times.'" Uncle belongs to the *Apollo* story, all right; in a way, he first urged us to go, but we should not expect that he brought back samples.

INSIGHTS FROM THE BLIND: COMPARATIVE STUDIES OF BLIND AND SIGHTED INFANTS, by Selma Fraiberg, with the collaboration of Louis Fraiberg. Basic Books, Inc., Publishers ($11.95). "Now in 1961 it was written in all our books (including one of my own) that it is the *visual* stimulus of the human face that elicits smiling in the baby at three months." But Toni, a robust little girl five months old and blind from birth, had an experienced and tender mother. "When her mother went over to her and called her name, Toni's face broke into a gorgeous smile.... Toni's smile had just shattered a theory, which shows you what one baby can do."

This volume reports a decade-long study of 10 infants, totally blind from birth, who were each studied carefully as individuals for several years. They were chosen to be neurologically intact and free of all other sensory or motor handicaps. They lived at home with their families but were visited by senior staff members twice a month. The data consist of careful narrative records, including a list of hundreds of items of behavior held in the observer's memory as he or she watched and tested during the usual one-hour visit. A "generous and unprejudiced film sample" of behavior was made (about 500 feet every few weeks) and analyzed, often frame by frame. A readable and coherent summation of a series of journal articles (some written with coauthors), this affecting, engaging and hopeful book opens the discipline with easy intimacy and logical rigor to a general reader. The investigations have the meticulous and objective quality of ethology and yet retain the sensitivity to context and implication and the acute concern for individuality that are typical of psychoanalysis. Although its questions are hard ones, this field has the best of two clinical worlds.

The aim of the work is clear: to learn how healthy blind infants manage the social, linguistic and epistemological achievements of the first years. They must acquire a system of signs without sight and long before they have speech. Only with such feedback loops can they develop human attachments based on the recognition of one who cares as an enduring object. They need to reach and manipulate the world, as sighted infants reach for a toy or the moon. They must, for healthy development, come to some purposeful mobility. They must learn speech and then, most subtle of all, how to represent themselves as individuals in speech and in thought: "the self as 'I' in a universe of 'I's.'" All of this most of them can do, and do well (if generally a little later than sighted children) without the model of other people's faces, without the early ability to sense most objects at some distance, without the powerful self-image of a mirror, without.... Much indeed is lost when the entire visual cortex of the brain stands useless, but the task can be completed pretty well, if heroically, by the human mind and spirit given half a chance. These investigators did not fail to share what they were learning. "The research... found solutions, and the gift from science was returned, as it should be, to the clinic."

Take infant smiles. At eight or 10 weeks sighted infants smile regularly at the visual stimulus of a human face. The blind do not smile automatically, even at the sound of the mother's voice. "In our records and film we often see the mother coaxing a smile.... Something was needed that was not automatically given." It turned out (one could say "of course" if behavior were not so subtle a structure) that it was bouncing, tickling and nuzzling games that were almost certain stimuli. Parents had learned the way to close their own behavioral loops, which needed a smile!

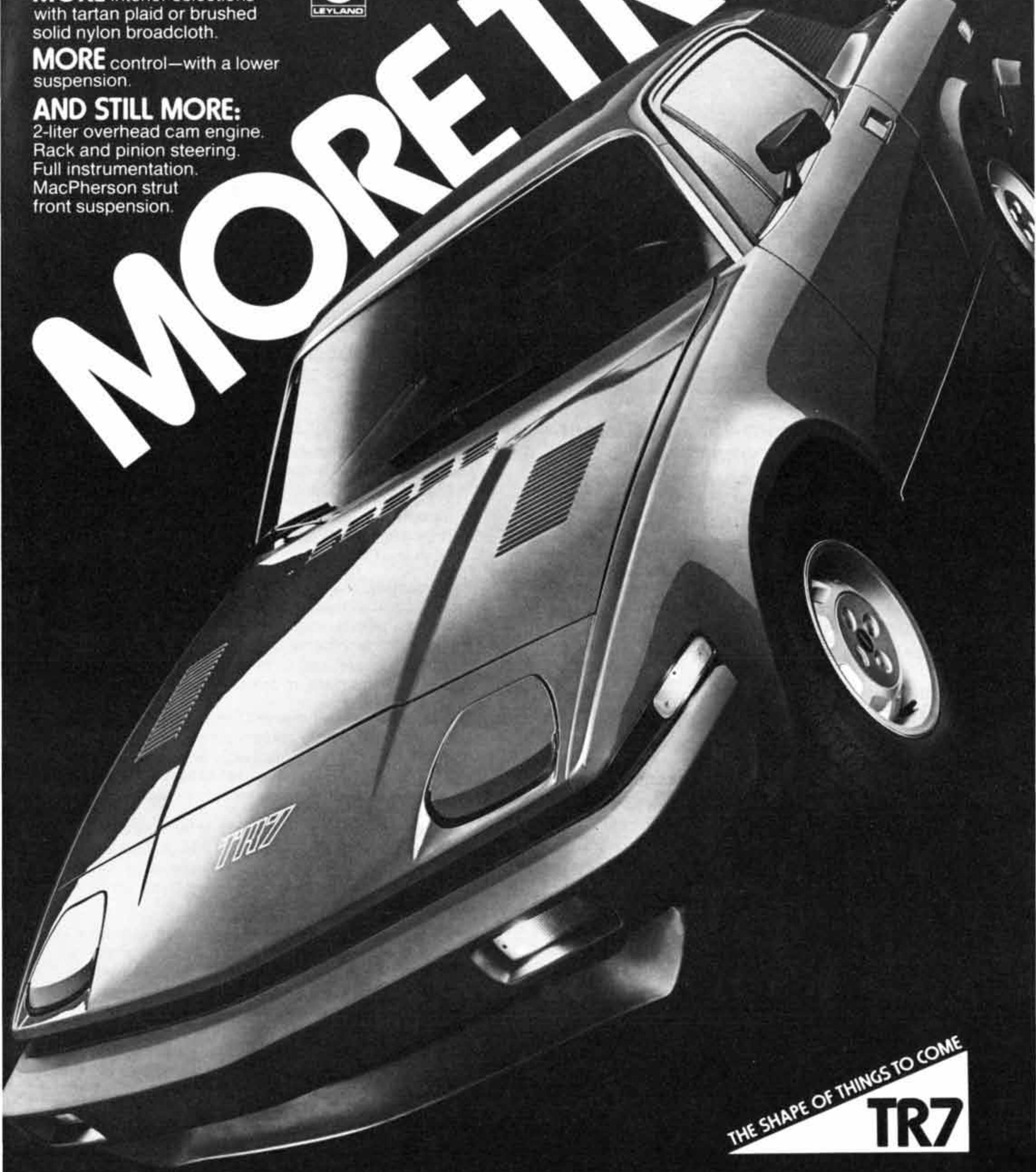
We read much in the face. A smiling baby and a crying baby are legible to all. In between we recognize modulations, partly imitative, that seem to express boredom, coyness, longing, uncertainty—a wide range of affect and attitude. Not so in the blind. The visitor can read little in the blind face and comments, "She looks depressed" or "The face is so bland. No expression." The stranger misses what we normally read in the face visually examined. Yet those states are present, and they are expressed; they must be in order to record attachment and preference, to encourage and repeat the experiences that change affect. The expression of such states in healthy, adequately stimulated and developing blind babies, however, lies elsewhere. "We have to turn our eyes away from the face to discover them. To do this is so alien to normal human discourse" that it might easily have been missed.

It was in watching the baby's hands to study prehension and coordination that the observers found all that, and more. The hands give meaning to emotional experience; the hands state preference, intention, reciprocity. Eight-month-old Robbie was too young to reach out for a musical toy dog. His face remained blank, giving no sign of yearning or wanting—but he held his hands in the posture that anticipated grasping the dog. No doubt this hand language is present in sighted infants early, but it is soon covered by the swifter eloquence of eye, face and smile. Thus do we learn, the comparisons bringing insight as the title promises, although many questions are still unanswered, with sight or without it. Plainly a serious and intelligent effort to make up for the lack of stimulus and the impaired channels of learning can and does work. It is no simple training scheme but a rich program of sensitivity to a need and provision of new incentives for growth. A baby must "reach on sound" before it is apt to creep toward it.

It is all a subject filled with awe, and these clinical researchers do not conceal their delights and frustrations, although their language remains somewhat technical throughout. The author had as consultants during her work the best-known of her colleagues worldwide. Would you know the human quality of this project? Dr. Fraiberg tells us how it was when she showed the film clips in which little blind Robbie first made it clear that he had understood what the theory of Jean Piaget calls the "object permanence" of a sound-making toy, adaptively pursuing it into the place where it was lost. The old philosopher from Geneva watched the film. "Piaget tossed his beret into the air and cheered."

CORRESPONDENCE PRINCIPLE AND GROWTH OF SCIENCE, by Wladyslaw Krajewski. D. Reidel Publishing Company. 160 Old Derby Street, Hingham, Mass. ($19.50). Studies of the sociology and the philosophy of science have prospered in the past 15 years or so; as the sciences have acquired a measure of public suspicion a scholarly critique of science has grown in energy and appeal. It is a contentious discipline given to trends and schools, to elderly sages and young Turks. It is a hard subject too. One recent well-accredited volume impressed a physicist reader with its nice distinctions, ingenious verbal examples and painstaking sophistication of approach, and then its last pages produced as a culmination an argument that can be seen only as a thorough misunderstanding of the theory. And such an anticlimax is not unique.

This pungent little book by a senior scholar at the University of Warsaw makes a quite different and very congenial impression. A physicist can only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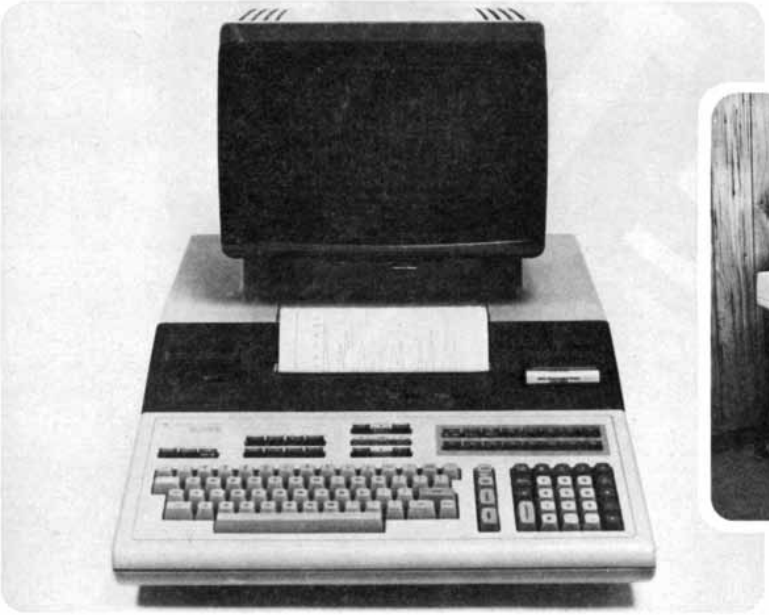

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welcome the central theme, which has been recognized as a major principle for the development of novel physics since Niels Bohr first made it explicit when quantum theory grew. Not until 1948 did there appear "a small but important book—the first book in world literature devoted especially" to the correspondence principle. It was the Russian philosopher I. V. Kuznietsov who took this step, not without courage in the context.

Professor Krajewski writes of it all with unusual directness and candor, almost in aphorisms. He tells in three pages what he sees in the history of the philosophy of science since the years between the wars. It is clear that since about 1960 the central interest has shifted away from an essentially ahistorical study of the boundary between science and metaphysics, from the role of the a priori and the empirical (as from the "search for examples supporting some ideas of the classics of Marxism") to a serious look at how modern science has actually grown—at the nature of revolutions in science. (That phrase was not out of the red East but out of the crimson Ivy League.)

The correspondence principle itself, a major instrument for the quantum triumph, is the requirement that every new theory contain, in as formal a way as its methods allow, a limiting transition to the old theory it replaces. Insofar as the old theory has fitted some sound experiments, the new theory must concur. If Planck's constant h tends toward zero, the quantum equations become just the classical ones; if the speed of light approaches infinity, Einstein's kinematic and dynamical equations go over to Newton's, and so on over a large number of examples from contemporary physics. The principle is a "magic stick" for searching out new laws, because it sets formal constraints on the new mathematics. It also secures science against loss of the achievements of the past; for innovators it is a warning like the Hippocratic maxim for physicians: above all do no harm! Classical mechanics is not a mere blunder that was repudiated in 1905, as the headlines imply.

The principle, like all other deep ideas, has logical problems. What can it mean to have a world with infinite light speed? What is an approximate theory about, anyhow? Are we to accept as argument admitted contradictions? Now the philosophers go to work. To be sure, the problem is a delicate one, not easy for the matter-of-fact and ingenuous scientist to grasp. The solution proposed is also rather slippery, in spite of a table and a diagram. The law—say Newtonian velocity addition—is transformed into relativistic form, and the limit c equals infinity is taken to restore the classical result. An intermediate step is needed: the true relativistic form, with the actual c value, is replaced, or "abstracticized." (The author's frequent resort to ad hoc neologisms has not been taken very pleasantly into English.) This step appears to be the same in form, but now c is taken to be a free parameter, eliminating the c-equals-constant assumption without changing the theory. A fuller discussion argues that the meaning of the symbols remains the same.

Much is made of the correspondence between Kepler's laws and the full classical mechanics. The discussion is physically reasonable, but so far no philosopher has grappled with the real growth of celestial mechanics, via perturbation theory, from Lagrange through Hamilton to the present day. It would seem that here was the great testing ground and theater of classical mechanics. Could the laws of Newton give us not only the rough Kepler orbits for the solar system, for the moon systems of the major planets and for double stars but also the precise motions? It is exactly here that Einstein found Mercury's missing 44 seconds of arc per century.

Vigorous schools of thought in Poznań and Warsaw have touched on these matters for a dozen years and have tried to engage topics in the development of science that have been debated in the West as well: What is the role of models and idealization, of continuity and revolution? Are not all facts laden with theory? Do experiments falsify or prove hypotheses? The positions are described, assessed, placed in appealing if slightly bewildering logical schemes by Krajewski, whose own subtle reconciling positions are put forward disarmingly. There are hints, perhaps inadvertent, that in the end the entire philosophical topic will be seized by the statisticians, the logicians and the historians, to disappear by partition as did certain kingdoms of the past! Until that happens this book offers a stimulating introduction and review for any reader of philosophical bent with a background in science. It is too brief and personal to be more than a beginning; its bibliography is the best guide to the next steps.

The book brings American readers something more: an internal account of living scholarship in Eastern Europe, about which we know remarkably little. It is good to read for that reason alone. Writes Krajewski: "Many Marxist philosophers now pay more attention to logical analysis, many Western analytical philosophers turn to the study of the methods used in advanced sciences and of the growth of knowledge.... My prognosis about the future of the philosophy of science (I do not speak about philosophy in general) is optimistic."

HANDBOOK OF ADHESIVES, edited by Irving Skeist. Van Nostrand Reinhold Company ($39.95). "In a world of ominous disruption, the adhesives go about their business of combining and uniting." They perform their subtle two-dimensional task more or less visibly throughout American technology, from the plywood or gypsum wallboard of your room to the shoes on your feet, the match heads in your pocket, the paperbound books on your shelves, the envelope and stamp you lick, the grocery bags and boxes you carry and the wall-to-wall pile carpet you cross in the lobby. Four million tons are produced per year. They are mainly synthetic polymers, including a wide variety of rubbers, but sticky stuff for many applications is still provided by beef bones, hog blood, fish skins, casein from acid-treated skim milk, corn- and milo starch and cotton linters—natural polymers all.

This hefty volume, a second edition, is an interesting representative of a well-known genre. Here some 75 specialists join the present 56 chapters around the glue line, that thin frontier of adhesion. The first few chapters, bound to attract the general reader, review the theory, the economic importance and the specification and testing of adhesives; the bulk of the book treats them chemical type by chemical type, from good old water glass to library paste, schoolroom "white glue," a wide variety of synthetics, the newish silicones and even newer organic polymers, which are serviceable glues at red heat. The volume closes with chapters (more mechanical engineering than chemical) reviewing the applications and techniques, including pressure-sensitive tapes, bonded abrasives, glues and cements in dental and medical practice. (The natural proteinaceous adhesive of the holdfast disk of the common mussel sticks, wet and dry, through pounding surf to "all known surfaces," including Teflons.) The reference value of the volume is plain, although it stays at a high technical level. What gives it value is the richness with which it conveys by example, better than any assertive single survey article, the ingenuity and vigor of a growing and diverse technology.

The theory of adhesives goes back to Thomas Young and Willard Gibbs, who gave simple but fundamental treatments, respectively mechanical and thermodynamic, of spreading and capillarity. The adhesive bond is first of all a problem of liquid-solid interaction. There are at least five components in every join: the two adherent slices, the adhesive filling of the sandwich and the two "butter" interfaces. The first act is the wetting of the solid surfaces by the adhesive, complicated like all surface physics by the reality of surface roughness, adsorbed vapors, internal surface stresses and chemical interaction between the liquid and the solid surface. A generation of careful study by a group around W. A. Zisman of the U.S. Naval Research Laboratory has begun to put

the chemistry of adhesive choice on a quantitative basis. The old thermodynamic concepts work only if the nature of the surfaces is controlled. The surface wets and the liquid spreads freely whenever the surface energy of the liquid is less than that of the solid under the actual conditions. Most liquids at ordinary temperatures have surface energies in the same order of magnitude as the energy of water, and hard, high-melting crystalline solids exceed such energies by up to a hundredfold. The organic polymers (paper, wood, rubber) we like to glue are low-surface-energy solids, however, with values rather like those of the liquids, and so nonspreading is frequent.

The main progress has been a set of careful measurements establishing for many types of such solids what the critical surface energy is for wetting. Given extreme cleanliness, pure materials, glass-smooth surfaces and chemical savvy about the effect of contaminating vapors, the contact angles of fluid drops are reproducible, independent of whether the drop is advancing or receding over the surface, and are chemically reasonable. Even one monolayer of adsorbed molecules—water, say—will largely hide most solid surfaces from the fluids; for nonpolar substances the forces are the dispersion forces of Fritz London, which fall off rapidly with distance; for polar substances the dipolar forces of hydrogen bonds are an even stronger molecular mechanism.

Recent controversy obscured the very foundations of the subject for more than five years. Does pure water freely wet pure polished gold surfaces, with the zero contact angle required by thermodynamic concepts? By the 1970's the answer was a clear yes. This chemistry of samples of bulk materials that are effectively in layers only a few molecules thick is the triumph of rational virtuosity in technique, redeeming our faith in simple concepts.

Finally the glued joint sets (except for the peelable tacky tapes we all use). Now solid-state physics commands. Shrinking and flexure give rise to strains. A glued joint commonly pulls apart at a tenth of the stress calculated from surface energies. We are in the domain of crack propagation. Surface roughnesses tend to allow gas bubbles to form at the "butter" interface, and the concentrated stresses propagate a crack failure along a plane of bubbles like a zipper. It is conventional to roughen the glued surface, which does increase the contact area, but coplanar bubbles are a distinct counterindication. Roughness is too crude a concept; it is the form of the surface that counts. Undesired adhesion is governed by the same theory, and technologically it too is of high importance. In all molding, casting and rolling, sticking is a problem; then consider ice on wings and windshields. Perhaps the right kind of roughness could weaken the icy grip, but it is not easy. Repeated thawing and freezing can get ice to adhere even to Teflon, the ice creeping into the pores and acquiring a large surface area of contact.

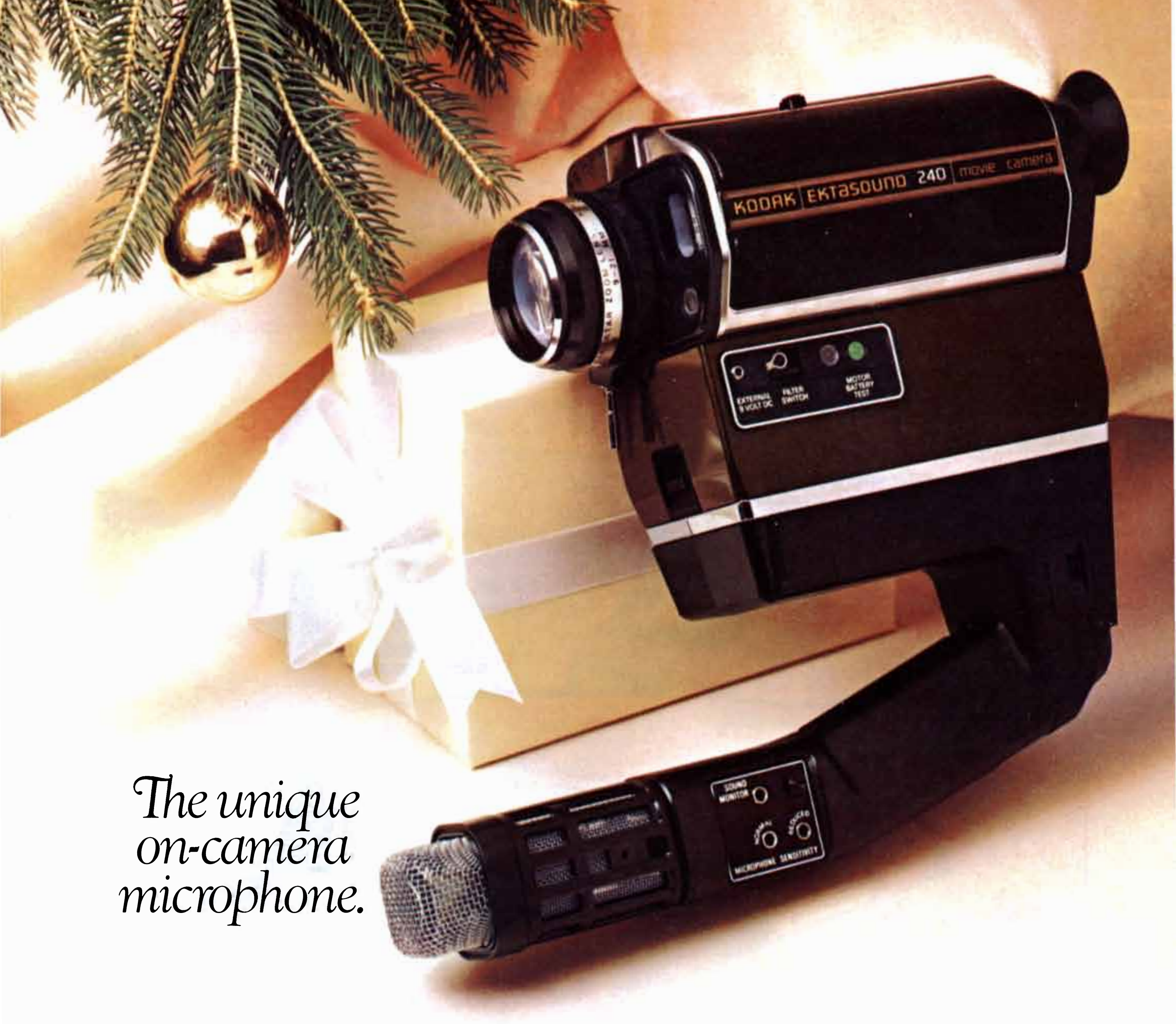
A few ingenuities are worth retelling. Gummed paper curls on drying, as the amateur wallpaper-hanger quickly learns. It is traditionally flattened for the printer by "breaking" it over the sharp edge of a steel strip. The tiny segments of broken gum film can expand or contract without much stress on the paper. Nowadays printers are made still happier by stay-flat adhesives that require no mechanical gum-breaking and yet remain flat over a wider humidity range. Discrete glue particles are micropulverized, suspended in a slurry in a volatile nonaqueous solvent and rolled onto a tape or a label; the solvent is removed to serve again. The paper fibers are water-wetted for the first time when they are stuck in place.

There are anaerobic glues that replace lock washers and other fittings in many mechanical assemblies. Oxygen inhibits the polymerization of the monomer; even the air that diffuses into a polyethylene bottle keeps the stuff liquid on the shelf for a year or more. Spread the single substance on a bolt, however, thread the bolt into its fitting and the exclusion of oxygen allows hard setting as soon as the residual dissolved oxygen is used up. Indeed, it turns out that iron ions catalyze the process so that curing is fast, without the release of water or solvent or even heat, deep inside a loudspeaker or an electric motor. Some adhesives are being cured by ultraviolet in seconds.

The alkyl cyanoacrylates form strong bonds rapidly with nearly all materials. Their polymerization is initiated by alkaline substances; even water vapor is sufficiently baselike to do the job. A drop (the glue sells for more than $100 a pound) will bind a square inch of clean, sanded steel surfaces together with a shear strength of more than a ton. Alkyl cyanoacrylates have wide applications in surgery, mainly as supplements to sutures.

A clever device has been developed for mixing two fluid components intimately without any moving solid parts. A series of identical, cunningly perforated aluminum stoppers occupies a length of pipe. Two streams that enter the first element pass through four tricky tubular passageways to emerge as eight streams, rearranged in position. A set of 10 such elements, called interfacial surface generators, cuts and shuffles a couple of million layers of fluid.

This book has a glossary and a very full index; the first edition was issued in 1962.



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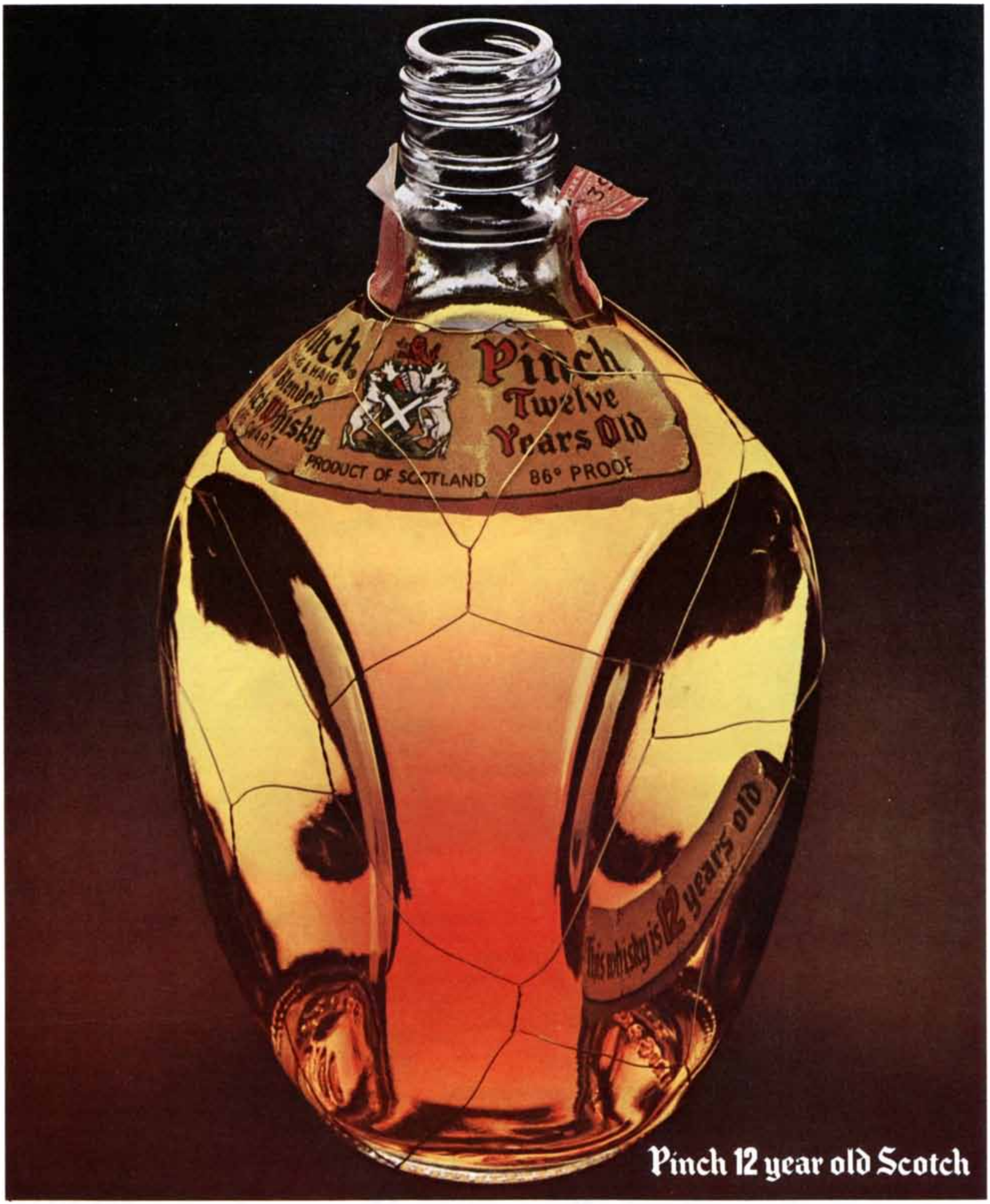
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The Job Problem

The composition of the U.S. labor force has been sharply changed by the influx of women. The failure of the economy to create enough jobs is aggravated by the poor quality of most of the jobs added since 1950

by Eli Ginzberg

The economic-stimulus program proposed by President Carter and passed by Congress early this year represented a major revision of Keynesian economics. Instead of continuing to rely exclusively on fiscal, monetary and tax measures as the major economic stimuli, the President decided to add the direct creation of jobs. About $10 billion of his stimulus program of more than $20 billion represents funds for public-service employment (PSE) and related manpower measures. The $10 billion job program includes $4 billion for public works, which is in addition to $2 billion appropriated for such purposes in the fall of 1976.

The fact that job creation represents a significant departure in economic policy can be judged by the fact that in the mid-1960's, in the heyday of President Johnson's "Great Society," Senator Joseph S. Clark of Pennsylvania and Senator Winston L. Prouty of Vermont could not generate any enthusiasm among their Congressional colleagues for a program to create jobs for the hard-to-employ. Only a few years later President Nixon vetoed the Comprehensive Manpower Act of 1970 because it provided for the creation of public-service jobs. He said he would not be a party to resurrecting the "leaf raking" philosophy of New Deal days. And only with the greatest reluctance did he sign the Public Employment Program (PEP) of 1971 and the Comprehensive Employment and Training Act (CETA) of 1973, each of which contains a modest provision for job creation.

When the Democrat-controlled Congress finally acted in December, 1974, to take stronger steps against unemployment, it provided for the creation of 260,000 new public-service jobs, which at the high point of the recession in the spring of 1975 provided a job for no more than one out of every 25 unemployed workers.

This summary of lack of enthusiasm, outright opposition, reluctant acceptance and restricted scale with regard to Federal job-creation efforts by both Democratic and Republican administrations since the mid-1960's should be sufficient to support the contention that President Carter's adoption of an aggressive manpower policy represents a major new departure in U.S. domestic policy. In fact, Secretary of Labor Ray Marshall has reported that he could have had more money for manpower programs but decided that an expansion from 310,000 public-service-employment jobs to 725,000 by September, 1978, was probably the maximum that could be effectively managed, particularly in the light of the additional job opportunities planned for in-school and out-of-school youth.

In order to understand the manpower aspirations of the Carter Administration and to assess their potential for energizing the U.S. economy and for providing jobs for a significant number of the nation's unemployed, the following issues must be assessed: How well did the U.S. economy perform during the past quarter century in creating new jobs? To what extent does the unemployment problem in 1977 reflect a shortage of total jobs and to what extent does it represent a shortage of good jobs? How much reliance can be placed on public-service employment and related efforts, such as public works, to overcome limitations to the expansion of employment in the private sector?

My brief answers to these three questions, for which I shall offer supporting data, follow. First, between 1950 and 1976 the percentage of civilian jobs increased at least as fast as the working-age population, yet the unemployment rate more than doubled. Second, there is today a shortage of both available jobs and good jobs. Since 1950 only three out of 10 jobs added in the private sector of the economy can be regarded as good jobs. In contrast, two-thirds of the jobs created by Federal, state and local governments can be considered good. Third, public-service employment and related efforts can absorb only a small fraction of the adults who are not now working but who are employable. Moreover, in addition to the seven million "officially" counted as unemployed (since they are "actively" seeking work) the total number of potentially employable Americans may be more than three times that number, or about 24 million.

When the unemployment rates of the major industrial nations of Western Europe were fluctuating between 1 and 2 percent in the 1960's and early 1970's, those countries were highly critical of the high unemployment rate of the U.S. and Canada, which for most of the period hovered between 5 and 6 percent. European statesmen and economists believed they had found the answer to operating their economies at full employment, and they saw no reason why the U.S. and Canada could not follow suit if they freed themselves from preoccupation with balanced budgets, price increases and balance-of-payment problems.

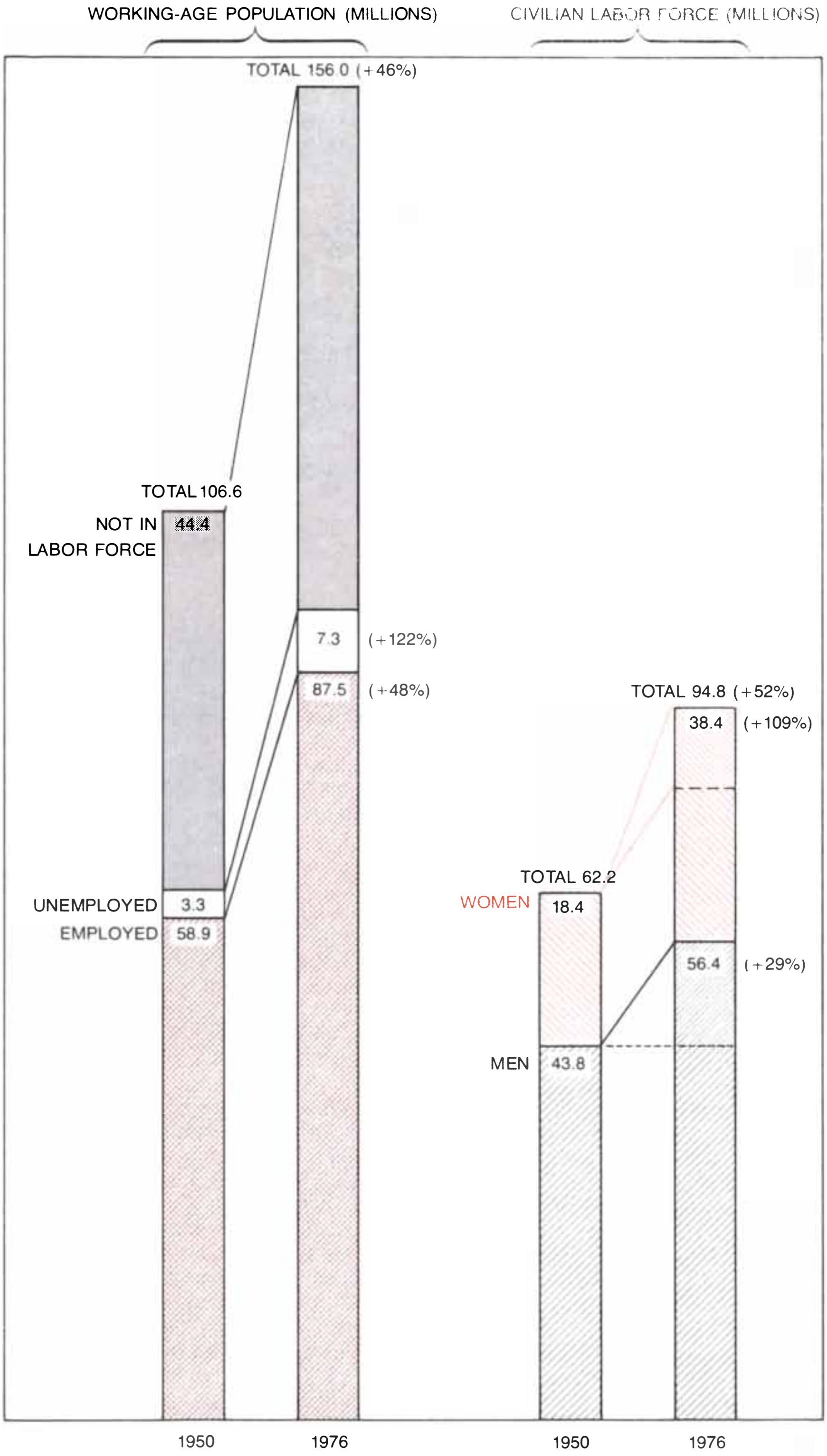
The worldwide recession that began late in 1974 has chastened those critics, who are now learning that maintaining full employment looks easier in retrospect than in prospect. The large countries such as the United Kingdom, Germany and France, and the smaller ones such as Sweden, Denmark and the Netherlands, now understand that "special circumstances," such as their long reconstruction cycle after World War II, their demographic profiles (relatively slow growth of new entrants into the labor force) and the sustained growth in international trade, all of which changed for the worse in the mid-1970's, may have had more to do with their maintaining full employment than did their skill in managing their economies.

Some of us have countered the European criticism of the high unemployment rate in the U.S. by emphasizing that the American economy had a good record, not a poor one, in job creation. Our high unemployment rate, we have pointed out, reflected excessively rapid increases in the number of job seekers, particularly young people and mature women.

Between 1950 and 1976 the U.S. population of working age (16 and over) increased by 47 percent. In the same period the economy expanded civilian employment from under 59 million to 87.5 million, a gain of 48 percent. This comparison points up the fact that in a period of unprecedented increases in the population of working age the U.S. economy expanded its employment opportunities at a comparable rate. Although the comparison of rates is impressive, a juxtaposition of the number of jobs and the number of job seekers is less favorable, since a rising proportion of the adult population actively sought work or would have looked for work if more jobs had been available.

If we divide the 26-year span into three periods—the 1950's, the 1960's and the first six years of the 1970's—we find substantial fluctuations in the numbers of potential job seekers and new jobs [*see illustration on opposite page*]. In the 1950's, when President Eisenhower was in office, the U.S. provided approximately one additional job for every two potential job seekers. In the 1960's, under the Kennedy and Johnson administrations, the ratio improved to nearly two jobs for every three new potential workers. And between 1970 and 1977, under the Nixon and Ford administrations, the ratio slipped back to approximately one job for every two new potential aspirants.

Although there are some advantages to dividing these 26 years into decades that roughly coincide with different national administrations, most economists rely on cyclical analyses to identify short and intermediate developments. Such analyses reveal the following additional aspects of the employment record. During the eight years of the Eisenhower Administration the job market fluctuated erratically. After a decline of 1.1 million in the total number of employed in 1954, following the end of the Korean war, civilian employment expanded briskly by 2.1 million in 1955 and 1.6 million in 1956 before slowing sharply in 1957 and contracting by one million jobs in 1958. In the last two Eisenhower years employment again ad-

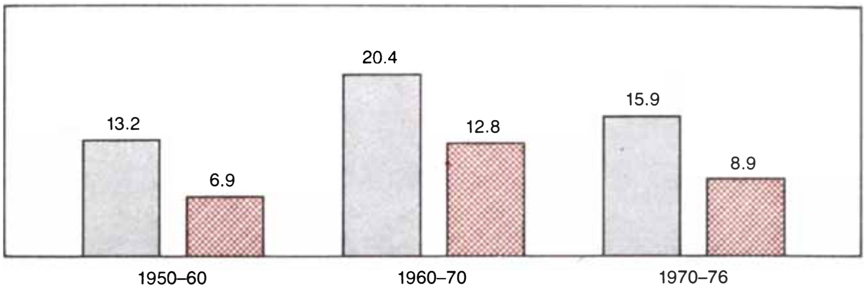


CHANGING STRUCTURE OF THE U.S. LABOR FORCE between 1950 and 1976 can be inferred from the disproportionate rise in unemployment that has taken place even as the number of jobs more than kept pace with the growth in the noninstitutionalized working-age population (*bars at left*) and from the dramatic influx of women into the civilian labor force (*bars at right*). Whereas the number of unemployed (defined as people actively looking for work) stood at 5.3 percent of the civilian labor force in 1950 and fell below 5 percent in six of the next nine years of the decade, the average number unemployed last year was 7.7 percent, and it was even higher the year before that. In mid-1977 the figure was 7 percent. In 1950 women made up slightly less than 30 percent of the civilian labor force. In the next 26 years more than 20 million women entered the labor force compared with only 12.6 million men, so that in 1976, 41 percent of the labor force consisted of women. For past 17 years unemployment among women has averaged about 1.5 percent higher than that among men. The number employed includes full-time, part-time and dual jobholders and unpaid family workers and the self-employed.

vanced strongly, averaging 1.4 million additional jobs per year. For the entire eight years the average gain was slightly under 700,000 new jobs per year.

In the next five years, from President Kennedy's taking office until the acceleration of the Vietnam war in 1965, the rate of job increases was slightly above a million per year; during the remainder of the decade, 1966–70, the rate of increase accelerated to about 1.5 million per year. The 1970's also show a good rate of increase: about 1.8 million per year between 1971, when President Nixon decided (at the prompting of Arthur F. Burns and over the objections of George P. Shultz) to become a Keynesian, and the worldwide economic collapse of 1974. Since the first half of 1975, which marked the low point in the recession, employment has again expanded strongly.

There is an additional observation that can be made on the basis of a close examination of the employment record. During four periods in the past eight years—the second half of 1968 through the first half of 1969, the second half of 1971 through the first half of 1973 and the second half of 1975 through the first half of 1976—new civilian employment increased by at least two million per year and in the last two periods by at least 2.6 million. This helps to explain why the National Commission for Manpower Policy in its *Second Annual Report to the President and the Congress* (December, 1976) suggested, among other recommendations, an annual goal of 2.5 million new civilian jobs in the period immediately ahead, which would represent a respectable level of job expansion if it could be achieved for a period of years.



INCREASES IN ADULT POPULATION AND EMPLOYMENT in the U.S. proceeded at uneven rates over the 27-year period 1950–76, as is shown in this breakdown by decades. The numbers above the bars represent millions of people. The gray bars in the chart show the increase in the working-age population, the hatched bars the increase in civilian employment. The strongest period of creation of new jobs was the decade of the 1960's, when three new jobs were created for every five people who were added to population 16 years of age and over.

The number of net new jobs created is one critical element in how well or poorly the economy is meeting its employment objectives. The other critical element is the number of potential workers, that is, the size of the civilian labor force, defined as the total of those who have jobs and those who are unemployed but are actively seeking work. The civilian labor force thus excludes those in the armed forces and other people of working age who are not actively seeking work for whatever reason: because they are in school, keeping house, retired or unable to work, or because they believe no jobs are available.

As with every accounting system, calculating the number of people in the labor force is not easy because it depends on many arbitrary definitions and conventions. Congress concluded in its 1976 session that the time was right for a new look at the problem and provided for a Presidential Commission to Study Employment and Unemployment Statistics. Sar Levitan, a distinguished manpower economist, has recently been chosen by President Carter to head the commission, which is scheduled to report by the end of 1978.

A fuller understanding of employment statistics in the U.S. over the past quarter century calls for a close look at the changing composition of the civilian labor force. Between 1950 and 1976 the labor force increased from 62 million to about 95 million, an increase of 33 million. Of the total increase men accounted for 12.6 million and women for more than 20 million, a simple demonstration of the greatly increased role of women in the labor force. In terms of participation rates (the proportion of each sex in the labor force) the male rate declined from 86.8 percent to 78.1 as the female rate increased from 33.9 percent to 47.4. In every age bracket from teenagers to people of 65 and older the male rate declined as the female rate increased, with the single exception of women of 65 and over, whose participation rate showed a slight decline.

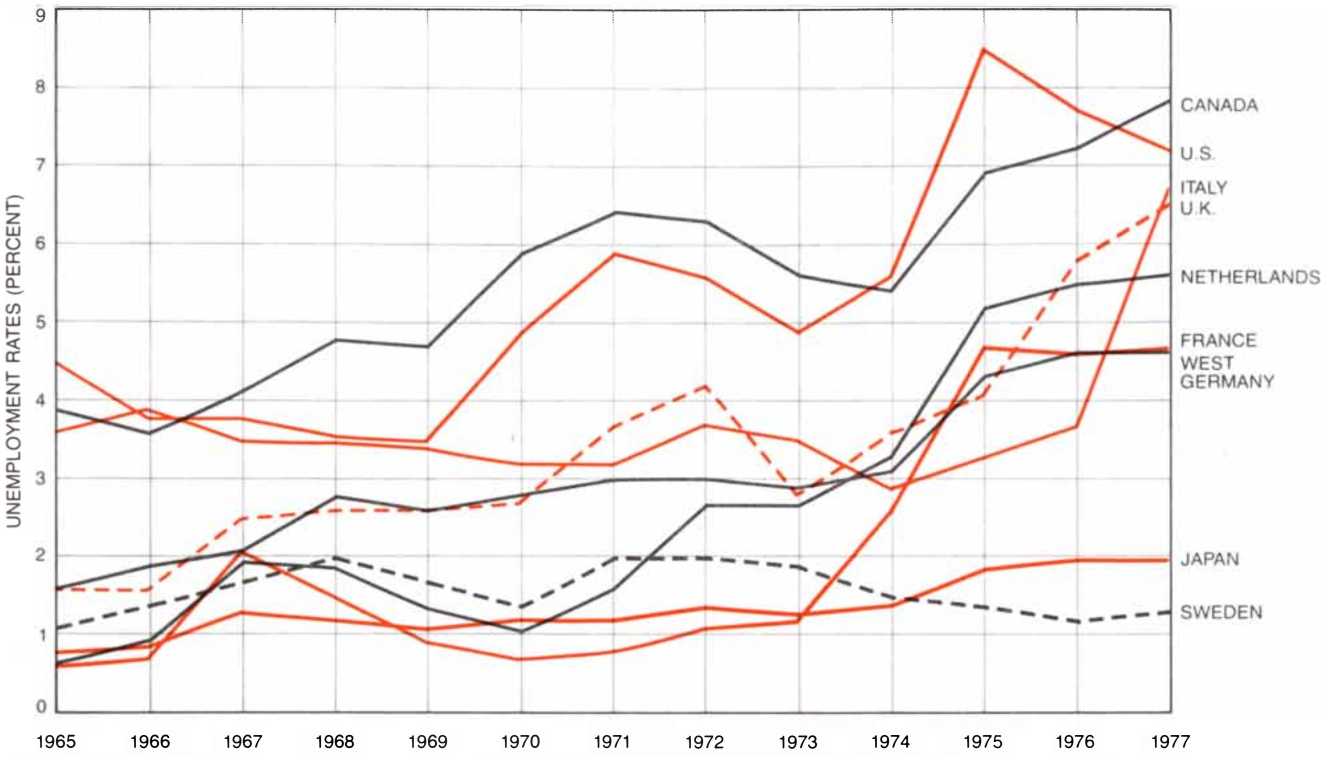
The first striking finding is that women accounted for 60 percent of the total increase in the size of the labor force between 1950 and 1976, even though in 1950 they were outnumbered by men by nearly 2.5 to one. By 1976 the male-female ratio had fallen below 1.5 to one. A closer look at the changes by age brackets reveals that in the period 1960–76 the number of young people (16 to 24) in the labor force increased from 11.5 million to 23 million, or by 100 percent. Another way to assess the importance of the substantially increased inflow of young people (in spite of the fact that many of them were remaining in school longer) is to recognize that they accounted for about one out of every three additions to the labor force in the entire period 1950–76.

When we add the 20 million women who entered the labor force to the 5.6 million new young male workers under the age of 24, we have accounted for just under eight out of 10 of the total increase. The remaining two out of 10 represent men between 25 and 64.

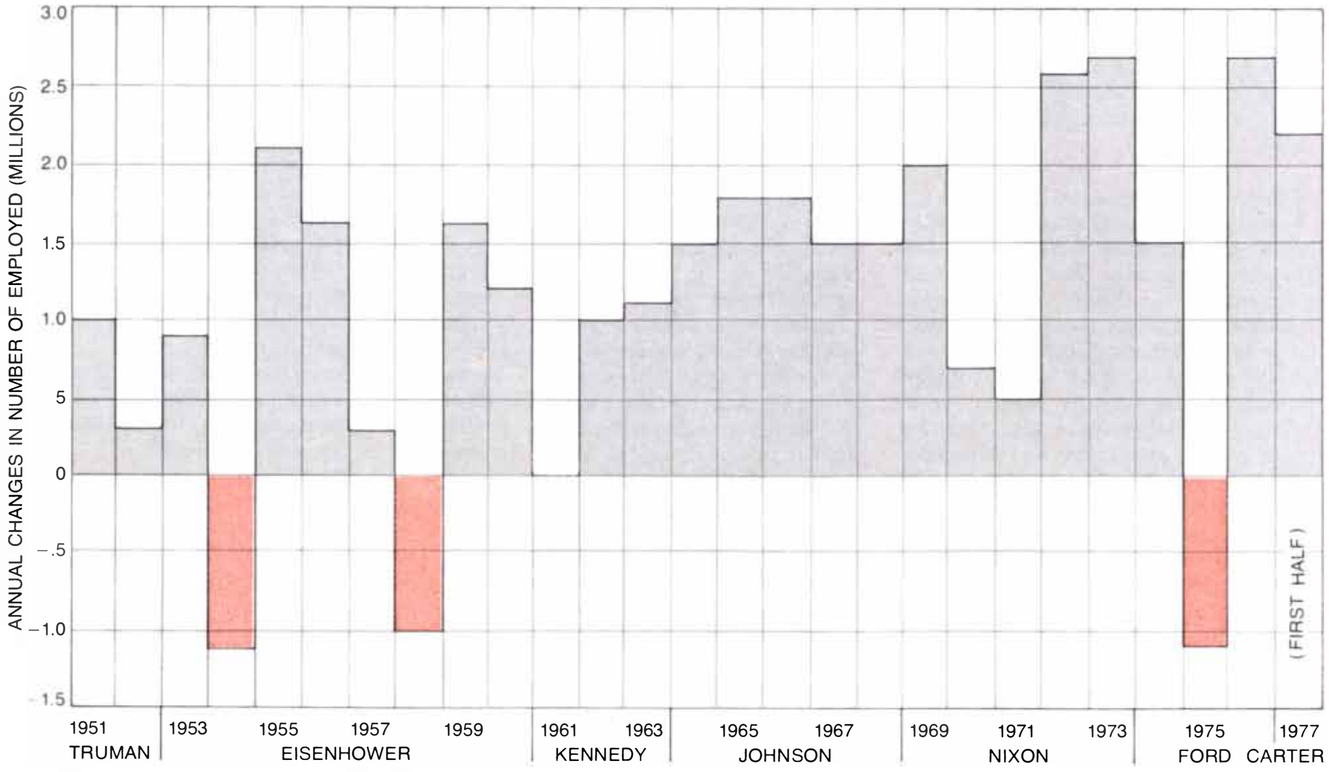
Several misconceptions about the American labor force can be eliminated by a closer inspection of the past quarter century. We commonly think of a worker as someone who is employed full-time all year. The reality, however, is different. Once a year the Bureau of Labor Statistics conducts a special survey that seeks to determine, among other things, the "work experience" in the preceding 12 months of everyone over the age of 16. The 1975 survey showed that although the civilian labor force averaged only 94.8 million, a total of 101 million individuals worked at some period during the year. The difference of 6.2 million between the two figures represents individuals who held jobs at some time during the year, who retired or who died while they were employed. Of the 101 million nearly 91 million were wage and salaried workers not employed in agriculture, 4.1 million were employed in agriculture, 5.6 million were self-employed and 600,000 were unpaid family workers. The proportion of people who worked all year at full-time jobs was only slightly more than half (54.4 percent). The remainder, out of preference or necessity (primarily the first), worked less than a full-time schedule throughout the year. In the 10 years between 1965 and 1975 nonagricultural workers on a full-time schedule increased by 14 percent and those in voluntary part-time employment increased by 40 percent. One of the consequences of the rapid rise of female and young male job seekers was the increasing demand for part-time work.

Another common assumption is that all men, particularly those between the ages of 25 and 65, are attached to the work force, either as jobholders or job seekers. The figures prove otherwise. In 1976, 19 out of every 20 males in the age bracket 25 to 45 were in the labor force; in the age bracket 46 to 54 the figure was 10 out of 11, and in the age bracket 55 to 64 it was only three out of four. Starting in their late forties and accelerating as they enter their fifties, men are increasingly being ejected from the labor force, are being encouraged to leave it or are retiring through choice.

Another assumption is that young women work for a few years, leave the



COMPARISON OF THE UNEMPLOYMENT RATES of the U.S. and Canada with those of Japan and the six largest economies among the countries of Western Europe show that with the single exception of Sweden all these countries have experienced rising unemployment rates since the recession of 1973–74. Unemployment in five of the Western European countries has now exceeded the 4 percent rate, which some economists believe is the maximum rate that can be tolerated in a healthy economy. The rate of unemployment in the U.S. exceeded that rate seven years ago. Because countries count their unemployed in different ways the data here are not strictly comparable.



EXPANSION OF CIVILIAN EMPLOYMENT in the U.S. was erratic over the period 1950–76, with one year of no growth and three years in which the total number of jobholders declined by a million or more. For the entire 27-year period the civilian economy added an average of 1.1 million jobs per year, slightly more under Democratic administrations and fewer under Republican ones. The civilian labor force was growing by 1.25 million per year, so that the number of unemployed increased from 3.3 million in 1950 to 7.3 million in 1976.

labor force to raise a family and return to work, if at all, only after their children are adolescents. The data belie the impression. The highest participation rate is no longer, as it was in 1950, among teenagers but rather among the 20-to-24 age group, in which two out of every three women are in the labor force. And although the rate drops off for the next three age brackets, which cover ages 25 to 54, the decline is modest and at no point drops below 55 percent. In short, an ever increasing proportion of women remain in the labor force throughout their adult lives, at least until they reach age 55.

The employment trends of the past quarter century can be summed up as follows:

The U.S. economy did well in creating jobs: the total number of civilian jobs was increased by over 28 million, or by just under 50 percent of its 1950 base.

The rapid rate of job expansion unquestionably facilitated the increased participation of women in the labor force; one out of approximately three worked in 1950 and nearly one out of two worked in 1975.

The rapid increase in jobs also helped to create opportunities for many, if not all, of the people in the larger pool of young entrants into the labor force, a pool that approximately doubled in the period after 1965.

The number of job seekers who wanted (or settled for) less than full-time work increased three times as much as the number of those on a full-time schedule.

Although adult women significantly increased their participation rates, mature men, beginning in their late forties, show striking declines.

For many years American economists have assumed that if the unemployment rate is 4 percent or lower, there is a rough balance between jobs and job seekers. Recently conservatively inclined economists have argued that the "natural rate of unemployment" has risen to 5 percent or even higher, to allow for the growing numbers of women and young people in the labor force. Using the higher figure, we find four poor years in the 1950's (1950, 1954, 1958 and 1959), five bad years at the beginning of the 1960's and five bad years in the 1970's. This makes a total of 14 out of 27 years in which unemployment was excessive. If we accept the more conventional figure of 4 percent as the norm for unemployment, we find that only seven of the 27 years meet the test of adequacy: three years near the beginning of the 1950's (during the Korean war) and the last four years of the 1960's (during the Vietnam war).

The "adequacy of job creation" should not, however, be assessed solely by the unemployment rate, since the number of jobs that are created has a significant effect on the number of job seekers. It is inconceivable that 20 million additional women would have joined the labor force between 1950 and 1976 if most of them had not been able to find—some quickly, others more slowly—jobs at which they were willing to work.

The success of the U.S. economy in providing jobs over the past quarter century might thus be evaluated as follows: By increasing employment opportunities by about half in the 26 years between 1950 and 1976, the economy provided the base for a major structural transformation whose most striking feature was an increase in the participation of women in the labor force from about one out of three to one out of two. This structural transformation was aided by two parallel developments: more young people decided to remain in school longer and pursue postsecondary education, and a growing proportion of males, particularly those in their fifties and early sixties, left the labor market voluntarily or otherwise.

It is now clear what happened. Although the U.S. economy provided a rapid and substantial increase in jobs, the number of job seekers, particularly married women and young people reaching working age, increased even more rapidly, and the unemployment rate therefore remained at an unsatisfactorily high level throughout most of the period.

Most adults work because they must support themselves and their dependents. If the jobs available pay little or are otherwise unattractive, however, many potential job seekers may choose to keep house, go to school, engage in illicit or illegal activities, or live off Social Security or some other form of income transfer. Hence a broad view of the employment situation requires that we look beyond the number of jobs to the quality of the job opportunities available.

There are different ways to assess the quality of a job, but most specialists would agree that the following characteristics are significant: wages, fringe benefits, regularity (or intermittency) of employment, working conditions, job security and opportunities for promotion. Although certain jobs must be performed under poor working conditions, such as those on an automobile assembly line or in a foundry, they may pay above-average wages. More often than not, however, favorable elements go together. Accordingly we can differentiate between good jobs and poor jobs, with earnings as the most reliable indicator.

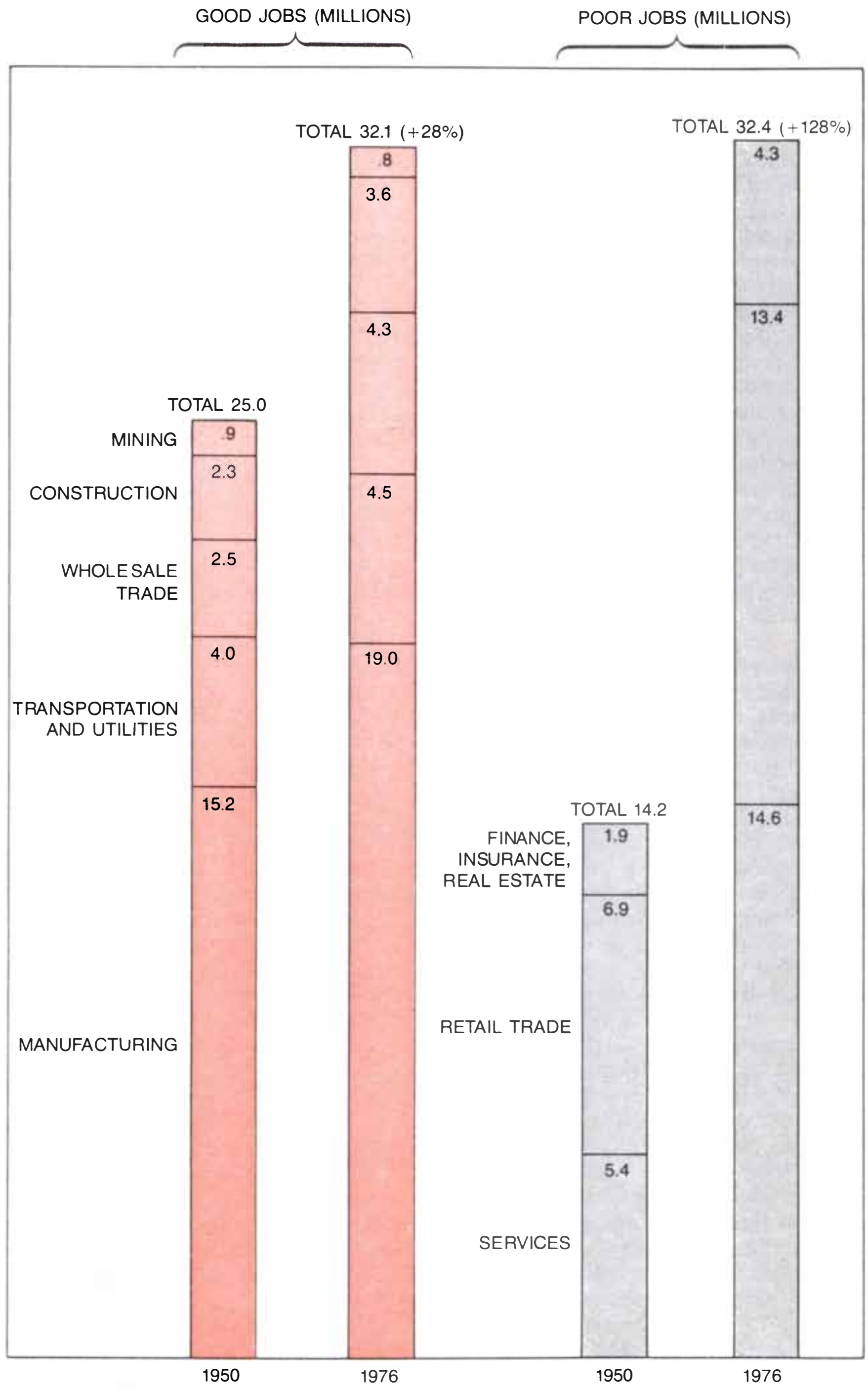
In the period between 1950 and 1976 total payroll employment in nonagricultural establishments showed important changes in numbers and division among industries. The number of workers on industrial payrolls increased by 25 million. If we analyze the relative growth of employment in different industrial groups, however, we find that the number of jobs that paid above-average weekly wages increased more slowly than the number that paid below-average wages. The five industrial groups that consistently pay above-average wages employed 25 million workers in 1950 and 32.1 million in 1976, an increase of about 28 percent. The five better-paying groups and the percentage changes between 1950 and 1976 in the number of jobs they provided are mining, minus 13 percent; construction, plus 54 percent; manufacturing, plus 24 percent; transportation and utilities, plus 12 percent, and wholesale trade, plus 70 percent. In actual numbers of new jobs manufacturing supplied by far the most: 3.7 million, or more than half of the total increase attributable to the five better-paying groups. Wholesale trade and construction respectively provided 1.7 million and 1.3 million additional jobs.

Total employment in the three industry divisions with below-average weekly earnings more than doubled between 1950 and 1976: from 14.2 million to 32.4 million. The division that includes finance, insurance and real estate added 2.4 million jobs, an expansion of 125 percent. Retail trade added 6.6 million jobs, expanding 96 percent. The service industries, which grew the fastest of all, added 9.3 million jobs, expanding 172 percent. In these industries weekly earnings are below average either because the industries pay low hourly rates or because they provide less than full-time work, and often both reasons apply. To summarize, between 1950 and 1976 about two and a half times as many new jobs (18.2 million v. 7.1 million) were added in industries that provide below-average weekly earnings as were added in industries that provide above-average earnings. More than three out of every five new jobs created in the past 26 years have been in retail trade or services, where many jobs are part-time and wages are traditionally low.

The difference in weekly earnings between the better-paying and the poorer-paying industrial groups was substantial. Compared with a national average of $176 in weekly earnings in 1976, earnings in services averaged $146 and in retail trade only $114. In construction, mining and transportation weekly earnings ranged between $258 and $284.

Not only are workers in retail trade and services poorly paid but also under the law and under collective-bargaining agreements they are generally precluded from participating in various government- and employer-sponsored benefit plans. Overall the statistics lend substantial support to the view that the U.S. economy has developed a dual labor market in which white men have preferred access to the good jobs while women and members of minority groups are the ones who generally get trapped in the poor jobs.

In a discussion of good and poor jobs special note should be taken of the transformation that has occurred in the character of government employment over the past quarter century. In 1950 there were just under two million civilian employees on the Federal payroll and just over four million on state and local payrolls, for a total of six million. In 1976 the number of Federal civilian employees had risen to 2.7 million (a smaller percentage increase, it should be noted, than there was in the private economy), but the number of state and local employees had approximately tripled to 12.2 million, for a total government civilian payroll of just under 15 million. Thus government at all levels accounted for more new net jobs (nearly nine million) than any industrial group in the private sector, services alone excepted. Over the 26-year period the employment growth rate of government was 150 percent, second again, but by only a slight margin, to the service industries.



NUMBER OF POOR JOBS increased much more rapidly than the number of good jobs between 1950 and 1976. Using earnings as the criterion of job quality, the best jobs have traditionally been provided by the five industry groups represented by the two bars at left. Between 1950 and 1976 they supplied only 7.1 million additional jobs, an increase of 28 percent. The number of jobs provided by lower-paying groups at right more than doubled in same period.

In 1949 average annual earnings of all civilian government employees were within $100 of the average for all private industries, $2,920 compared with $2,840. In 1975 the earnings in government were nearly $1,000 higher than they were in industry: $11,710 compared with $10,740, testifying to the greater gains for government employees. A closer inspection reveals that the greatest gains were made by Federal employees, whose average earnings in 1975 were $12,630 compared with $10,900 for state and local employees, a much wider spread than had been the case a quarter century earlier. For the most part government employees have reasonably good working conditions, enjoy various fringe benefits, belong to an internal promotion system and enjoy considerable job security. In terms of job quality most government jobs are good ones, but perhaps as many as one out of three can be considered poor, either because they are poorly paid or because they provide less than full-time work. Furthermore, not all government employees have the security of civil-service status. To sum up, between 1950 and 1976 government added some nine million new jobs, two-thirds of which can be classified as good in terms of wages, working conditions, fringe benefits, job security and opportunities for advancement. In the same period the private sector provided about 25 million new jobs, of which fewer than three out of 10 can be rated good by the same criteria.

Here four broad observations can be made. First, the number of jobs grew much faster in government than they did in the private sector of the economy. In fact, the figures I have cited are a considerable understatement of government's role in creating jobs; they do not include the large number of workers in private industry whose jobs depend on government purchases. According to studies I have made in collaboration with Dale L. Hiestand, government purchases in 1973 provided jobs for more than seven million industrial workers, or roughly half the number that government employed directly [see "The Pluralistic Economy of the U.S.," by Eli Ginzberg; Scientific American, December, 1976].

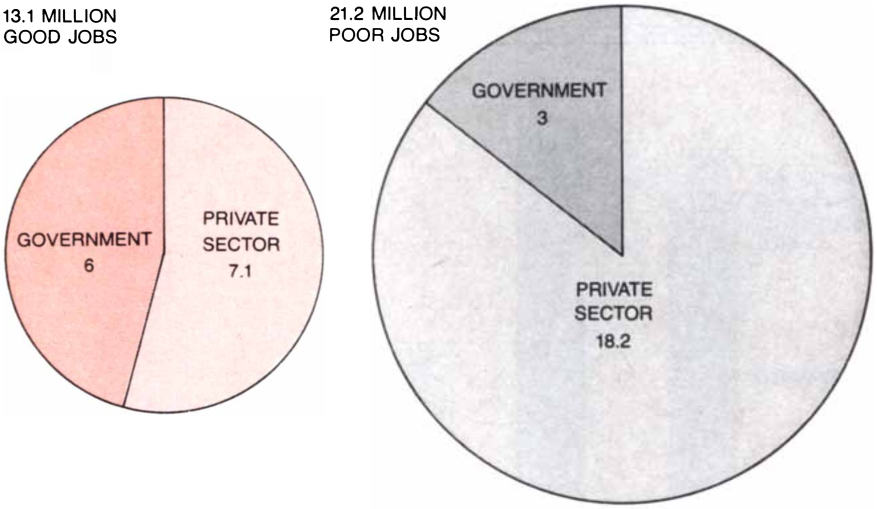
Second, again on a relative basis, government outperformed private industry in providing good jobs. Between 1950 and 1976 government accounted for only slightly less than half of all the good jobs that were added. Third, the private sector provided two and a half times as many poor jobs as it did good ones. Fourth, over the entire period three out of five of all the new jobs created must be classified as poor.

If most of the jobs that were added in the past quarter century were poor, how does one explain the near-absence of criticism and discontent among Americans who obtained those jobs? The most plausible answer is that most of the new jobholders were "secondary" workers whose earnings supplemented the income of the family's principal breadwinner.

Of the 28 million individuals added to the employed work force between 1950 and 1976 by far the largest category—about 12 million—were married women whose husbands were employed and living at home. A second large increase, amounting to 5.9 million, took place among single people, for the most part young, many of whom were still in school and therefore content with less than full-time work. About 10 million of the 28 million new jobholders were heads of households: six million men with nonworking wives and four million men or women who shouldered family responsibilities without spouses.

A comparison in the distribution of jobs held by women in 1950 and in 1976 emphasizes the extent to which they remained concentrated at the low end of the occupational hierarchy. In 1950, 76 percent of working women were employed as sales and clerical workers, as operatives in factories or as service workers, either in private households or in industry. In 1976, 73 percent of working women were still so employed. The proportion engaged as sales and clerical workers increased from about 35 to 42 percent, and the proportion working as operatives in factories decreased from 22 to 21 percent. There was also a small decline in the number of service workers, from 20 to 18 percent. There was, however, a sizable increase in the proportion of women in professional and technical occupations (from 10.3 to 16 percent) and a steep decline in the proportion working on farms (from 6.9 to 1.3 percent). The fact remains that at the end of the period, as at the beginning, three out of four women were employed as sales, clerical or service workers or as operatives in factories.

In looking ahead to 1990 we must take account of three likely developments. First, the number of young people reaching working age will decline sharply: the pool in 1990 will be three million lower than the 24 million in 1980. Second, the number of women in the labor force will continue to grow substantially: according to current estimates, this group will increase from 37 million in 1975 to 49 million in 1990, or by about a third. Third, an increasing number of women, because of their heightened attachment to the labor force, will be seeking good jobs and a career, not just any job. If this forecast proves to be correct, the availability of good jobs will become a central issue of public policy.



TWO-THIRDS OF THE NEW GOVERNMENT JOBS provided in the U.S. between 1950 and 1976, about six million out of a total of nine million, can be characterized as good jobs, whereas fewer than one out of three private-sector jobs so qualify. As two circle charts indicate, government supplied nearly half of the 13.1 million good jobs added between 1950 and 1976 (*left*). Private sector supplied six out of seven of 21.2 million poor jobs added in same period. Of nine million civilians added to public payrolls between 1950 and 1976, only 700,000 were employed by the Federal Government. The rest were added to state and local payrolls.

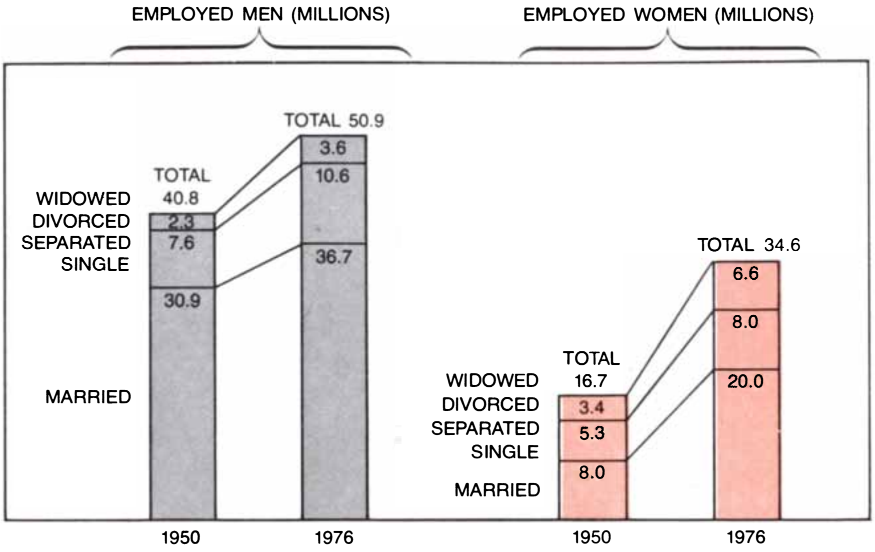
It is paradoxical that the U.S. became seriously interested in full employment as a national goal in the mid-1970's, just at the time the advanced countries of Western Europe were forced to lessen their commitment to full employment. We should not, however, overstate the change in the U.S. The President and his advisers now look to 1981 as the year when an interim target of about 4 percent unemployment will be reached. If the goal is realized, it will mean that the U.S. will have taken 11 years to return to a condition of a tight labor market such as the one that prevailed in 1969. It is always difficult to guess what Congress will do; we cannot forecast the legislation that may follow the bill submitted last year by Senator Hubert H. Humphrey of Minnesota and Congressman Augustus F. Hawkins of California, which would have established the Federal Government as the employer of last resort. The odds are, however, that in the short run Congress will do nothing.

If there is socially useful work to be done and people are able and willing to do it, what stops the Federal Government from taking the necessary action to put all unemployed job seekers to work? Up to a point nothing, or at least very little. Beyond that point dollars, management abilities and secondary consequences are likely to be the major barriers.

As I have noted, the Carter Administration has put some $10 billion into direct job creation that will provide useful employment for approximately 1.25 million people for a year. It is a matter of concern to Congress whether those placed in public-service-employment jobs will at the end of a year be able to make the transition into regular employment or whether they will become a continuing responsibility of the Federal Government.

If the sole or primary objective of manpower policy were to reduce the unemployment rate from about 7 percent to 4 percent, which would require jobs for about three million unemployed workers, the cost would be not $10 billion but nearly $25 billion, a large but not impossible sum. One reason to hesitate, however, is that such a program, dollars aside, would be three times larger than the one Secretary Marshall believed to be within the ability of the Federal Government to launch and carry out successfully by September, 1978.

In making such computations it is easy to overlook the fact that the numbers of people "overhanging" the labor market who would be interested in a government job far exceed the seven million now counted as unemployed. The number of people not in the labor force who nonetheless categorize themselves as "Want a job now" totaled more than five million in the Department of Labor's 1976 special survey. These people were not counted in the labor force for various reasons: 1.4 million were in school, 650,000 were in poor health or disabled, 1.2 million had home responsibilities and 900,000 had concluded they could not get a job. To this group we should add the estimated million employables who receive payments



FAMILY STATUS OF WORKING AMERICANS changed substantially between 1950 and 1976. In 1950 just under one out of four working men was single or living without a wife. By 1976 the number in these categories (14.2 million) had increased by more than 40 percent whereas the number of married men had increased less than 20 percent (*bars at left*). Among working women the changes were still more striking. The largest single addition to the labor force was among married women, whose numbers increased 150 percent, from eight million to 20 million. Number of single women or women living without husbands who were employed in 1976 (14.6 million) slightly exceeded number of men of equivalent single status (14.2 million).

from the Aid for Dependent Children (AFDC) program, possibly another million employables who receive Federal food stamps, a million in Federal training programs who are not counted as being unemployed although they want jobs and 3.5 million working part time because they cannot find full-time jobs.

In addition to the five million people not counted as part of the labor force who nonetheless reported they "want a job now" there were 54 million in 1976 who reported they "do not want a job now," leaving open whether or not they might consider working at a future time or under certain conditions. Included in the 54 million were more than 30 million with home responsibilities, 8.5 million retired, about five million in poor health, 6.4 million in school and 3.5 million categorized under "All other reasons." A Federal job-entitlement program even at modest (minimum) wages would surely induce some people to shift their classification from "Do not want a job now" to "Want a job now." Even a 10 percent shift would add 5.4 million job seekers to the labor force.

It would not be difficult to identify 5.4 million additional job seekers from the following categories: the considerable number of young people who remain in school because they cannot find jobs, the 30 million housewives who might be tempted to enter the labor market if jobs were available, the group of disabled and older workers who feel they could still be useful and people in still other groups who are not working but who are not currently counted among the unemployed because they are not actively seeking work.

In order to estimate the total number of people overhanging the labor market, one would have to add this group of 5.4 million potential job seekers to the five million who want jobs now, the two million employables receiving aid for dependent children or food stamps, the million currently in Federal training programs, together with another 3.5 million with part-time jobs who want full-time work. We can thus arrive at a total of some 17 million potential job seekers, allowing for a small amount of double counting, to add to the seven million currently counted as unemployed. The addition of 17 million would swell the labor force by about 18 percent, or more than three times the number of counted unemployed.

The Carter Administration is considering recommending, or has already passed, legislation in which Federal job creation has several roles to play. In the first instance the Administration decided to rely on public-service employment, together with the related program of public works, as one of two principal vehicles for stimulating the economy by increasing direct job creation; the other vehicle is fiscal and tax policy. The assumption is that job creation is a good way to put money into the hands of low-income people who will spend it quickly. Therefore a tentative first finding is that public-service employment can complement fiscal policy.

A second goal of Federal job creation is to provide employment opportunities for hard-to-place people in the expectation that after a year or so in a public-service-employment job they will be in a better position to move into the regular economy in the private or public sector. This was the intent of the Public Employment Program of 1971, the original intent of Title II of the Comprehensive Employment and Training Act (CETA) of 1973 and the intent of the CETA amendments of 1976.

A third goal, only haltingly implemented so far, is to use public-service employment as an instrument to remove employable people from extended unemployment insurance or from the welfare rolls. A fourth is directed to assisting young people in or out of school to gain work experience in the expectation that such experience will facilitate their long-term employability.

Two additional objectives should be noted. Federal job creation is used to provide basic or supplemental income opportunities for older people who would otherwise be forced onto welfare rolls. It also plays a central role in a limited number of experimental and demonstration projects that go under the rubric of "supported work," a program aimed at helping deviant groups such as former prison inmates and former drug addicts to reenter the working community.

The identification of these multiple objectives for public-service employment (and the listing could be extended by including certain rural manpower programs) emphasizes how fast and how far we have come since President Nixon vetoed the reinstitution of "leaf raking" jobs paid for by the Federal Government. There remains, however, a wide gap between the scale of the present and the proposed expanded public-service-employment program and the number of claimants for such employment. There are surely three million and possibly up to five million priority claimants for the approximately one million public-service-employment openings.

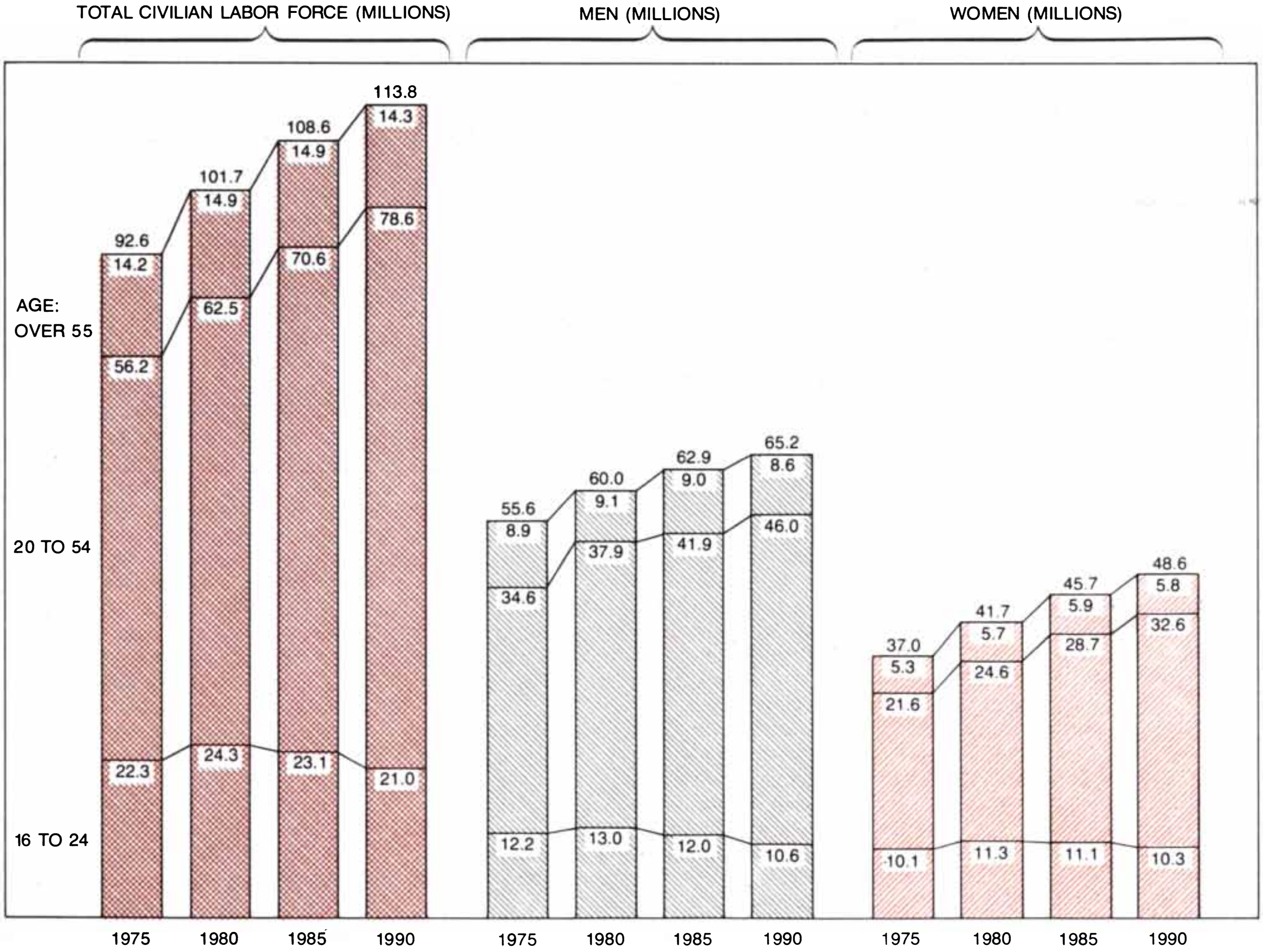
As readers of newspapers and viewers of television have repeatedly had impressed on them, unemployment weighs heavily on minority groups, particularly black and Spanish-speaking teenagers. As the Government recently reported, three out of every four minority-group teenagers in New York City have been unable to find full-time jobs. Because of the combined weight of past and present discrimination, low family income, poor schooling and other powerful negative factors, the young members of minority groups are concentrated at the end of the job queue. There is no prospect of this country's meeting its commitments with regard to racial equality and arresting the decline of its urban centers until the scourge of unemployment is eliminated. At a minimum, manpower and training measures should be focused on the groups that are currently the least equipped to find and hold jobs.

Many professors and politicians, in addition to businessmen, question whether the increasing involvement of the Federal Government in direct job creation is a sensible policy. They suggest as an alternative the stimulation of the private sector, which they feel is the backbone of a healthy economy. Apart from the fact that they continually underestimate how much of the current employment in the U.S. is supported directly or indirectly by government dollars—surely one out of every three jobs—they have yet to acknowledge the large number of potential job seekers who remain invisible and uncounted.

The Administration has put off until 1981 the goal of a labor market in reasonable equilibrium, but that goal looks only to the reabsorption of three million or so people currently on the unemployment rolls. It surely does not include absorbing a significant number of the estimated 17 million additional people not currently counted in the labor force who need work or want to work.

One should not be regarded as antibusiness if one concludes that there is no prospect of the private sector's expanding sufficiently to make a significant impression on the overhanging mass of potential job seekers. If the private economy can find jobs over the next four years for the new entrants into the job market and for three million of the currently unemployed, it will be doing well. On the other hand, one should not be regarded as antigovernment if one concludes that there is no realistic prospect of the Federal Government's succeeding in the years immediately ahead in significantly reducing the pool of potential employables. The Government could do so, if it could do it at all, only at the price of extreme inflation.

In economic policy, as in political and social policy, a country that avoids the pursuit of unrealizable goals is a country that protects its treasure. It is therefore in a better position to experiment, to innovate and to modify its programs as it gains greater knowledge of how to translate goals into accomplishments. That is the stance the U.S. should adopt with respect to employment policy, now and in the future. We cannot assume that the private sector will be able to create adequate numbers of new jobs, and we cannot assume that the Federal Government will be able to provide a job for everyone who is able and willing to work. That is a commitment that, at least for the present, is too ambitious. The Federal Government has begun to and should continue to identify groups in the community that are most in need of assistance in improving their employability and employment. Government should not be so hesitant to help those citizens most in need of help, and it should not be so foolhardy as to make promises on which it will be forced to renege. A responsible democracy with a $2,000 billion annual output cannot afford to ignore its responsibility to experiment vigorously, intelligently and continuously to improve employment opportunities for all its citizens and particularly for those most in need of assistance.



PROJECTIONS OF LABOR-FORCE COMPOSITION in the U.S. show several probable developments. The pool of young people reaching working age will begin to decline after 1980, and the rate of participation of young women in the labor force will increase, so that by 1990 the age group 16 to 24 will contain nearly equal numbers of the two sexes. With increasing participation of older women, by 1990 nearly as many women between the ages of 24 and 55 will have been added to labor force as men of same age (11 million v. 11.4 million).

The Search for Life on Mars

The Viking landers have completed their biological experiments. The experiments did not detect life processes, but they did reveal much of interest about the chemistry of the surface of the planet

by Norman H. Horowitz

Is there life on Mars? The question is an interesting and legitimate scientific one, quite unrelated to the fact that generations of science-fiction writers have populated Mars with creatures of their imagination. Of all the extraterrestrial bodies in the solar system Mars is the one most like the earth, and it is by far the most plausible habitat for extraterrestrial life in the solar system. For that reason a major objective of the Viking mission to Mars was to search for evidences of life.

The two Viking spacecraft were launched from Cape Canaveral in the summer of 1975. Each spacecraft consisted of an orbiter and an attached lander. When the spacecraft arrived at Mars in July and August of 1976, each was put in a predetermined orbit around the planet, and the search for a landing place began. Cameras aboard the orbiters were the principal source of information on which the choice of the landing sites was based; important data also came from infrared sensors on the orbiters and from radar observatories on the earth. The sole consideration in the final selection of the sites was the safety of the spacecraft. It would be a mistake to suppose, however, that the sites were therefore without biological interest. Biological criteria dominated the initial decisions as to the latitude at which each spacecraft would land. Once the latitudes had been chosen there was relatively little difference between sites at different longitudes.

On command from the earth each lander separated from its orbiter. With the help of its retroengines and parachute it dropped to the surface of Mars. Both orbiters continued to circle the planet, operating their own scientific instruments and relaying to the earth data transmitted from the landers. Both landings were in the northern hemisphere of Mars, and the Martian season was summer. (Mars has seasons like those on the earth, but each season lasts approximately twice as long. The Martian year is 687 Martian days; each Martian day, named a sol by the Viking team to distinguish it from a terrestrial day, is 24 hours 39 minutes long.) On July 20, 1976, the *Viking 1* lander came to rest in the Chryse Planitia region of Mars, some 23 degrees north of the equator. Six weeks later the *Viking 2* lander settled down in the Utopia Planitia region, some 48 degrees north of the equator. In longitude the two landers are separated by almost exactly 180 degrees, thus placing them on opposite sides of the planet. Since the instrumentation of the two landers is identical, the difference in their landing sites is the only distinction between them.

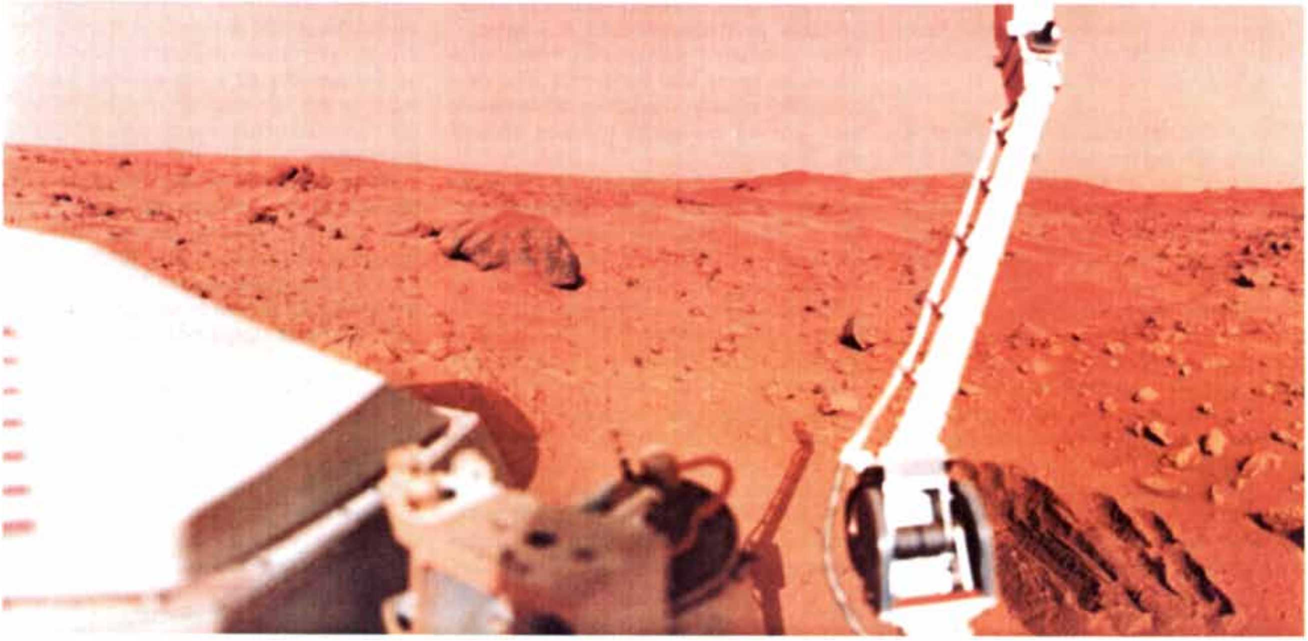
The first biologically significant task carried out by each lander was the analysis of the Martian atmosphere. Life is based on the chemistry of light elements, notably carbon, hydrogen, oxygen and nitrogen. To be suitable as an abode of life a planet must have those elements in its atmosphere. Spectroscopic observations from the earth and from spacecraft that had flown past Mars in previous years had already shown that carbon dioxide was the principal component of the Martian atmosphere. Small quantities of carbon monoxide, oxygen and water vapor had also been detected. Nitrogen had not been detected in any form, however, and atmospheric theory suggested that Mars had lost most of its nitrogen in the past.

Each Viking lander analyzed the atmosphere by means of two mass spectrometers. One spectrometer, operating during the descent to the surface, sampled and analyzed the atmospheric gases every five seconds. The second spectrometer operated on the ground. The results showed that the atmosphere near the ground was approximately 95 percent carbon dioxide, 2.5 percent nitrogen and 1.5 percent argon, and that it also held traces of oxygen, carbon monoxide, neon, krypton and xenon. At both landing sites the atmospheric pressure was 7.5 millibars. (The atmospheric pressure at sea level on the earth is 1,013 millibars.)

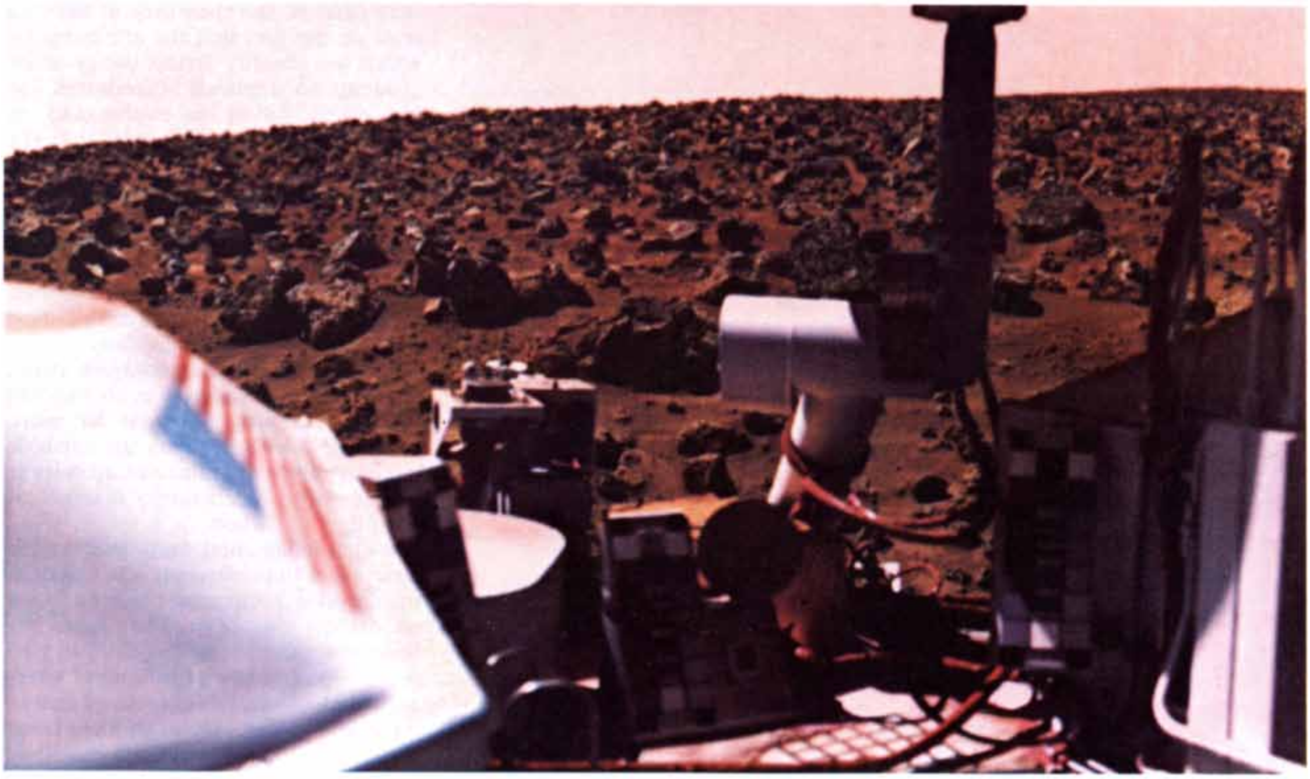
Since the Viking spacecraft revealed that nitrogen is indeed present in the Martian atmosphere, we can say that the elements necessary for life are available on Mars. Missing from the list of gases, however, is one critically important compound: water vapor. Although earlier measurements had shown that traces of water vapor are present in the Martian atmosphere, the quantity varies with season and place. The Viking orbiters carried out a survey of water vapor over the entire planet with infrared spectrometers. The results showed that the highest concentration of atmospheric water vapor was at the edge of the north polar cap (the summertime hemisphere), and that the concentration fell off toward the south (the opposite of what is found on the earth). In the polar region the amount of water vapor in the atmosphere would form a film only a tenth of a millimeter thick if all of it were to be condensed on the planet's surface. At the landing sites the concentration of water vapor ranged between 10 and 30 percent of the concentration at the pole.

These numbers put into quantitative terms a long-known fact about Mars: It is a very dry place. Mars has ice at its poles, but nowhere on its surface are there oceans or lakes or any other bodies of liquid water. The absence of liquid water is related to the dryness of the atmosphere through a fundamental law of physical chemistry: the phase rule. The phase rule states that for liquid water to exist on the surface of a planet the pressure of the water vapor in the atmosphere must at some times and in some places be at least 6.1 millibars. The Viking measurements imply that the vapor pressure of water at the surface of Mars in the northern hemisphere is at most .05 millibar, even if all the water vapor is concentrated in the lower atmosphere. At that low pressure liquid water cannot remain in the liquid phase; depending on the temperature, it must either freeze or evaporate. By the same token raindrops cannot form in the Martian atmosphere and ice cannot melt on the Martian surface.

The extreme dryness presents a difficult problem for any Martian biology. Liquid water is essential for life on the earth. All terrestrial species have high and apparently irreducible requirements for water; none could live on Mars. If there is life on Mars, it must operate on a different principle as far as water is concerned. If Mars had a more favorable environment in the past, however, and if the planet did not dry up too fast, species may have had time to evolve and adapt to present conditions. Pictures made by the *Mariner 9* spacecraft, which went into orbit around Mars in 1971, suggested that Mars may indeed have had running water on its surface in the past. The pictures from the Viking orbiters have confirmed that impression. The evidence consists of channels in the Martian desert that resemble dry riverbeds. There seems to be little doubt that the channels were carved by rapidly flowing liquid, and



LANDING SITE OF VIKING 1 LANDER on Mars was photographed from the spacecraft in February to document the digging of the series of trenches seen at the lower right. Soil samples from the trenches were delivered to instruments in the spacecraft to be tested for their chemical composition and for signs of life. The orange tinge of sky shows that a great amount of dust is suspended in atmosphere.



LANDING SITE OF VIKING 2 LANDER is a field of boulders superficially similar to the landing site of the *Viking 1* lander. The camera aboard the lander made this picture early in the afternoon of September 24, 1976, three weeks after spacecraft had landed and before samples of soil were taken. Horizon is tilted because lander is not quite level. Objects in foreground are instruments on spacecraft.

there is widespread agreement that the most probable liquid is water.

If liquid water once existed on Mars, could life have arisen on the planet? If the life evolved to meet changing conditions, could it exist there still? There is no way to settle these questions by deductive reasoning or even by experimentation in laboratories on the earth. They can be answered only by the direct exploration of Mars, and that is what the Viking spacecraft did.

Five different types of instrument on each Viking lander were involved in the search for evidences of life: two cameras for photographing the landscape, a combined gas chromatograph and mass spectrometer for analyzing the surface for organic material and three instruments designed to detect the metabolic activities of any microorganisms that might be present in the soil. In this brief account I shall not be able to mention the names of the many scientists, engineers and managers whose joint efforts made all the Viking projects possible. They work in universities, industrial laboratories and the National Aeronautics and Space Administration and its field centers. Their names are recorded in the growing technical literature dealing with this historic mission.

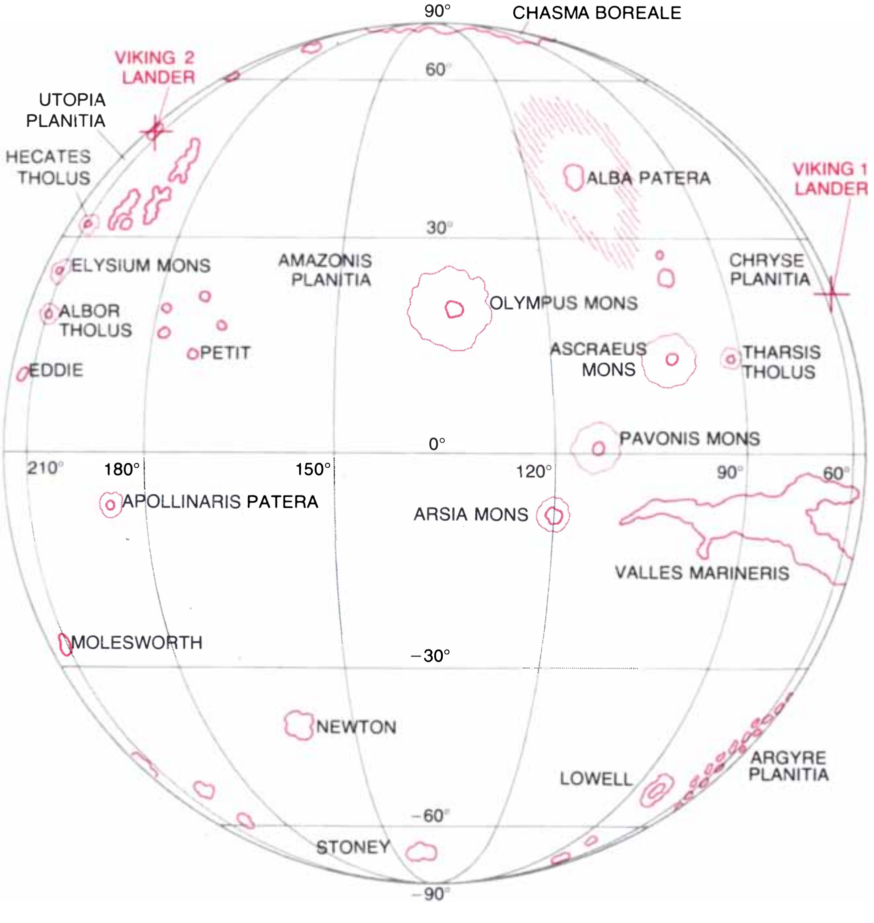
Each of the Viking landers carried two cameras of the facsimile type, which built up a picture of the scene by scanning it in a series of narrow strips. Such cameras make pictures slowly, but they are rugged and versatile. Their resolution was moderately high: a few millimeters at a distance of 1.5 meters. They produced pictures in black and white, in color and in stereo. The two cameras on each lander could between them survey the entire horizon around the spacecraft.

As life-seeking tools cameras have inherent advantages and disadvantages. Their chief advantage lies in the fact that a picture contains a large amount of information. In principle it would be possible to prove unequivocally the existence of life on Mars with a single photograph. For example, if a line of trees were visible on the horizon or if footprints appeared on the ground in front of the spacecraft one morning, there would be no room for doubt that there is life on Mars. Another advantage lies in the fact that pictorial evidence is independent of all assumptions about the chemistry and physiology of Martian organisms. The organisms need not respond in certain ways to certain substances or treatments in order to be recognized. The cameras could identify, say, a mushroom made of titanium as a form of life if one were to sprout up from under a rock in the course of the mission. Of course, reliance on pictorial evidence rests on its own set of assumptions about the morphology of living things. The most obvious disadvantage of the camera as a life-seeking instrument is the fact that an entire world of life can exist below the camera's limit of resolution.

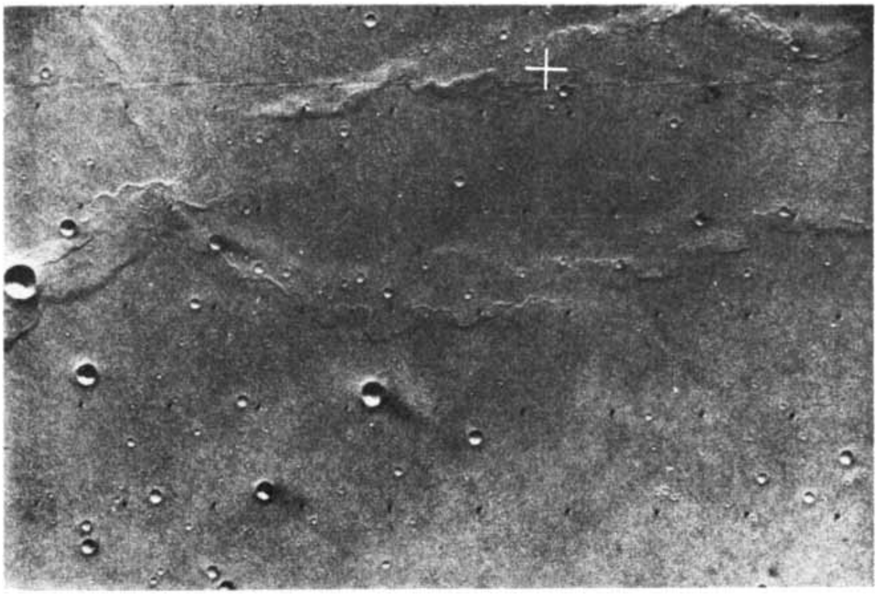
Of all the results of the Viking mission the wonderful photographs of the Martian desert at the two landing sites are the most impressive. The photographs have been eagerly scanned by alert and hopeful eyes, but no investigator has yet seen anything suggesting a living form.

The next step was to analyze the soil for any organic constituents. Among the elements carbon is unique in the number, variety and complexity of the compounds it can form. The special properties of carbon that enable it to form large and complex molecules arise from the basic structure of the carbon atom. That structure enables the carbon atom to form four strong bonds with other atoms, including other carbon atoms. The molecules thus formed are very stable at ordinary temperatures, so stable, in fact, that there seems to be no limit to the size they can attain. The connection between life and organic chemistry (that is, the chemistry of carbon) rests on the fact that the attributes by which we identify living things—their capacity to replicate themselves, to repair themselves, to evolve and to adapt—originate in properties that are unique to large organic molecules. It is the highly complex information-rich proteins and nucleic acids that endow all the living things we know, even "simple" ones such as bacteria and viruses, with their essential nature. No other element, including that favorite of science-fiction writers, silicon, has the capacity carbon has to form large and complex structures that are so stable. It is no accident that even though silicon is far more abundant than carbon on the earth, it has only minor and nonessential roles in biochemistry. Biochemistry is largely a chemistry of carbon.

Such fundamental facts lead to the conclusion that wherever life arises in the universe it will most likely be based on carbon chemistry. That view has been strengthened by the discovery of organic compounds of biological interest in meteorites and in clouds of dust in interstellar space. Although these compounds are nonbiological in origin, they are closely related to the amino acids and the nucleotides that are the respective building blocks of proteins and of nucleic acids. The fact that they are



LOCATIONS OF THE TWO VIKING LANDERS are indicated on this map of Mars, which shows some of the major geological features of the planet. The two spacecraft are on opposite sides of the planet, some 4,600 miles apart. Both are in the northern hemisphere at sites selected partly for their possible biological interest. *Viking 1* lander is in Chryse Planitia region at a latitude of 23 degrees; *Viking 2* lander is in Utopia Planitia region at a latitude of 48 degrees.



CHRYSE REGION was photographed from 1,555 kilometers above the Martian surface by the *Viking 1* orbiter on July 17, 1976, showing a recently determined accurate landing site of the *Viking 1* lander (*cross*). The landing area, in the western part of Chryse Planitia, is a smooth plain with many small impact craters dotting the surface. The wrinkle ridges to the west (*top*) seem to be similar to volcanic ridges found on smooth lava floors of maria on the moon.

formed in settings remote from the earth implies that carbon chemistry gives rise to familiar organic compounds throughout the universe. This fact in turn suggests that life elsewhere in the universe will be based on an organic chemistry similar to our own, although not necessarily identical with it.

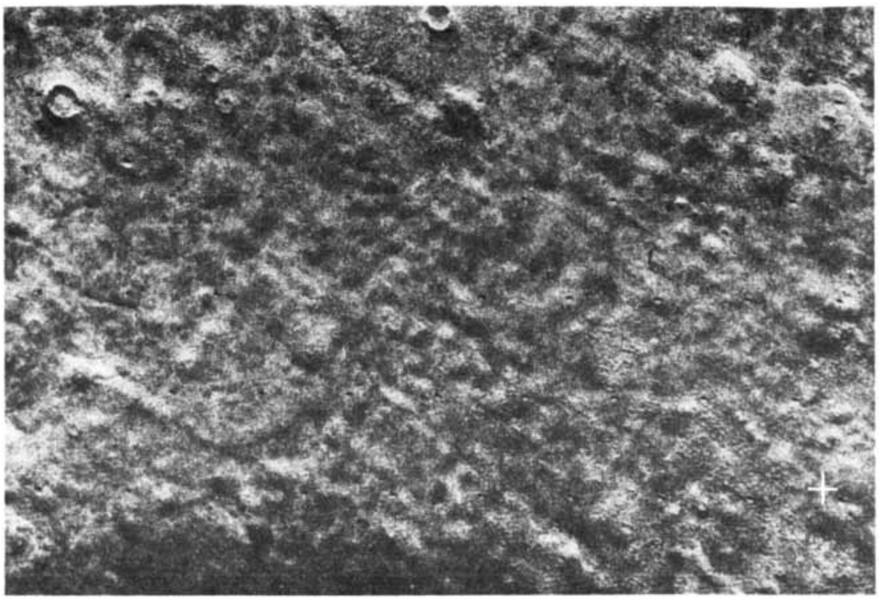
Such considerations led to the decision to include an organic-analysis experiment aboard the Viking landers. The instrument used in the experiment was the mass spectrometer that had analyzed the atmosphere combined with a gas chromatograph and a pyrolysis furnace. A sample of the Martian soil was first heated in the furnace through a series of steps up to a temperature of 500 degrees Celsius. Any volatile materials released were passed through the gas chromatograph. Since each of the different compounds has a different molecular weight, composition and polarity, among other properties, it passed through the columns of the gas chromatograph at a unique rate, and so the compounds were separated from one another. As each compound emerged from the chromatographic column it was directed into the mass spectrometer for identification. Since essentially all organic matter is cracked, or decomposed, into smaller fragments at 500 degrees C., the method is capable of detecting organic compounds that have a wide range of molecular weights.

Two soil samples were analyzed at each landing site. The only organic compounds detected were traces of cleaning solvents known to have been present in the apparatus. The fact that the solvents were detected shows the instruments were functioning properly. The heated samples gave off carbon dioxide and a small amount of water vapor; nothing else was found.

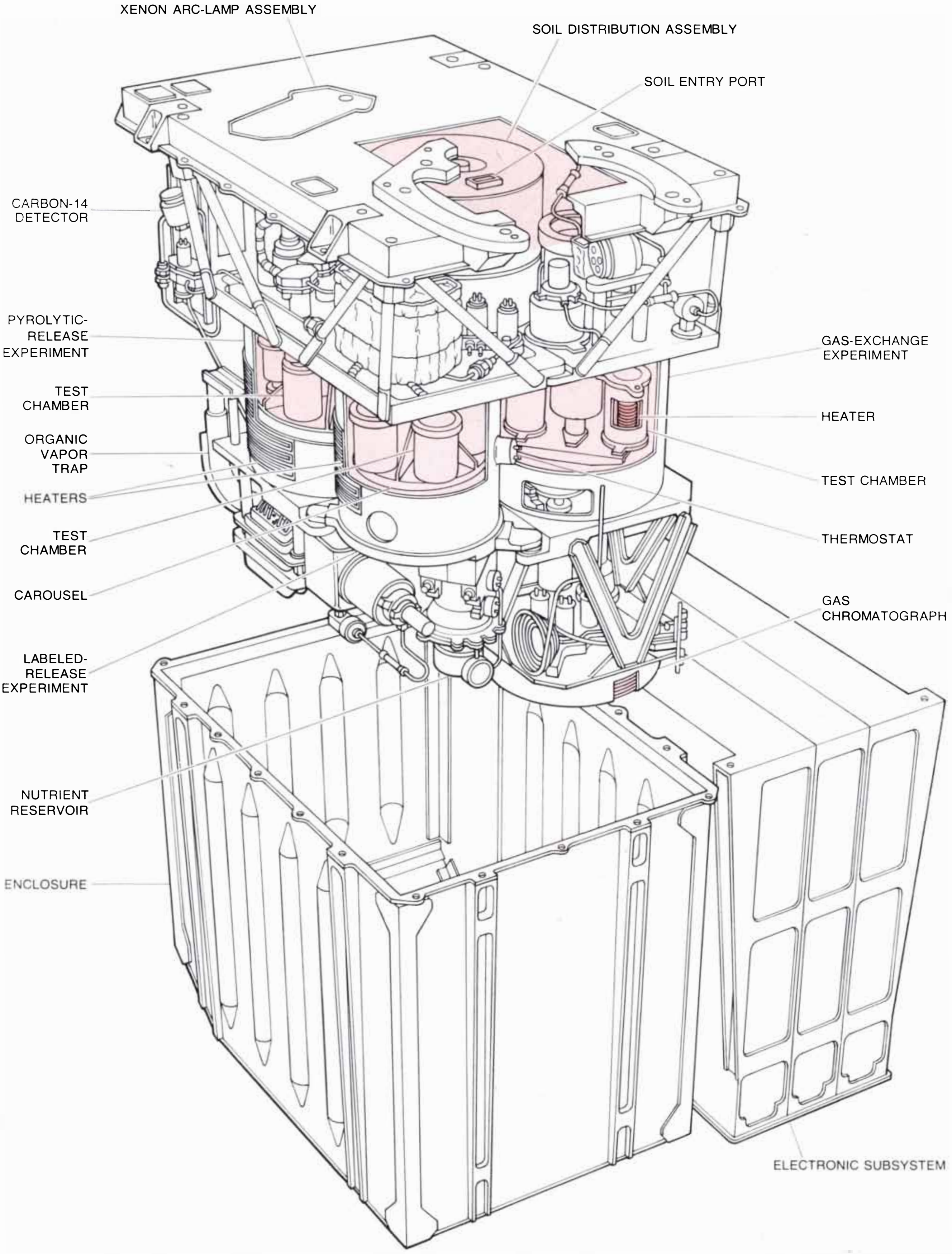
This result is surprising and weighs heavily against the existence of biological processes on Mars. The combined gas chromatograph and mass spectrometer aboard each Viking lander is a sensitive instrument, capable of detecting organic compounds at a concentration of a few parts per billion, a level that is between 100 and 1,000 times below their concentration in desert soils on the earth. Even if there is no life on Mars, it has been supposed the fall of meteorites onto the Martian surface would have brought enough organic matter to the planet to have been detected. Because Mars is near the asteroid belt, from which meteorites originate, it is believed to receive a much larger number of meteorite impacts than either the earth or the moon. Indeed, a question that was frequently discussed before the Viking spacecraft were launched was whether or not it would be possible to distinguish biological organic matter on Mars from the meteoritic organic matter that was expected to be present. The absence of organic matter at the parts-per-billion level, however, suggests that on Mars organic compounds are actively destroyed, probably by the strong ultraviolet radiation from the sun.

The other experiments aboard the Viking landers searched not just for organic matter in the soil but for living organisms. On the earth microorganisms such as bacteria, yeasts and molds are the hardiest of all species. There are few places on the earth where microbial forms do not live; they are the last survivors in environments of extreme temperature and aridity. The reasons for their hardiness are interesting but need not detain us here. Suffice it to say that if there is life on Mars, the chance of detecting it would be maximized by searching for microorganisms in the Martian soil.

Each Viking lander carried three instruments designed to detect the metabolic activities of soil microorganisms. First, the gas-exchange experiment was designed to detect changes in the composition of the atmosphere caused by



UTOPIA REGION was photographed from 3,360 kilometers above the surface of Mars by the *Viking 2* orbiter on August 16, 1976, as the spacecraft was surveying the planet for a landing site for the *Viking 2* lander. The area is rough, apparently blanketed by dunes. Site at which the *Viking 2* lander touched down is indicated by cross at far right (north) edge of photograph.



BIOLOGICAL LABORATORY aboard both Viking spacecraft occupies a volume of only one cubic foot. The three biological experiments were the gas-exchange experiment (*right*), the labeled-release experiment (*bottom left*) and the pyrolytic-release experiment (*top left*). Each experiment, shown cut away, had several test chambers on a carousel so that the experiment could test several samples of Martian soil. The soil was dumped into an entry port at the top of the laboratory, where it fell into a hopper. For each sample of soil one test chamber of each experiment was rotated under the hopper in order to receive a portion of the sample. All together approximately half a dozen samples of soil were tested at each landing site. The experiments were completed in April. Results are given on following pages.

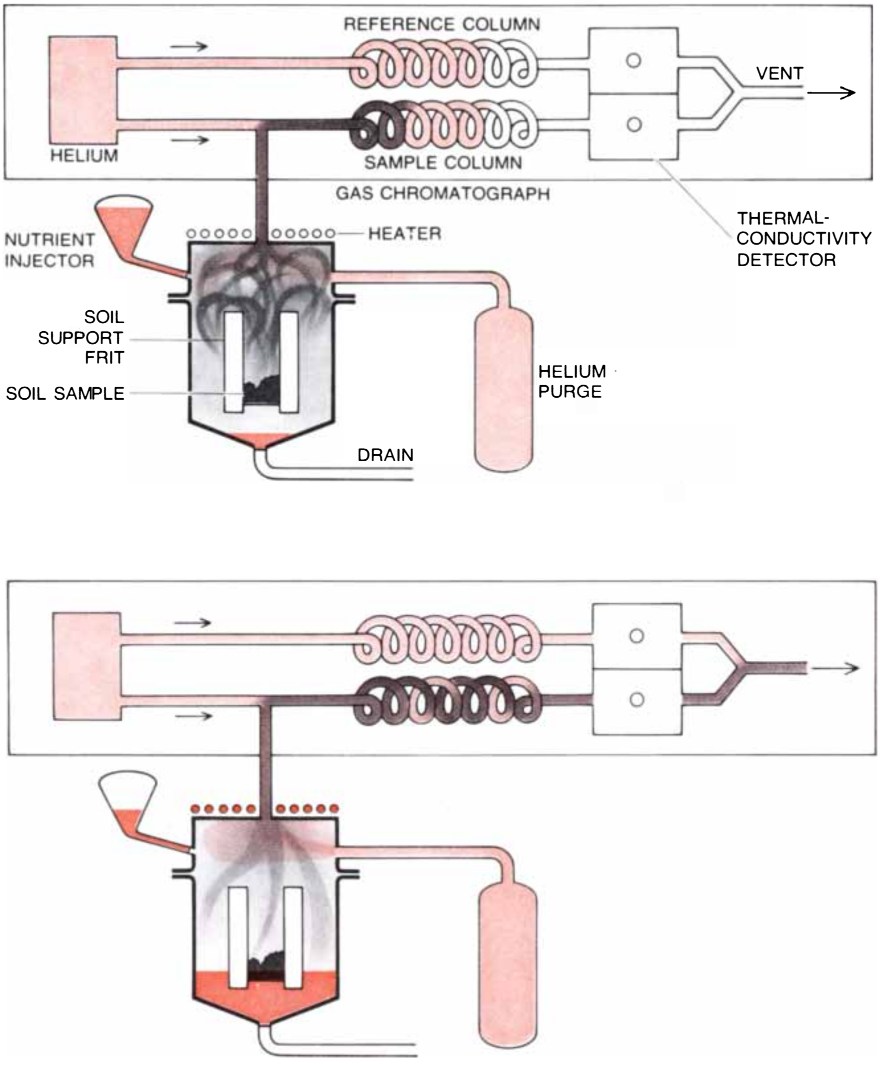
microbial metabolism. Second, the labeled-release experiment was designed to detect decomposition of organic compounds by soil microbes when they were fed with a nutrient. Third, the pyrolytic-release experiment was designed to detect the synthesis of organic matter in Martian soil from gases in the atmosphere by either photosynthetic or nonphotosynthetic processes. All three experiments analyzed portions of each sample of Martian soil.

All the experiments detected chemical changes of one kind or another in the soil. All the experiments are now completed, and some of the changes they observed suggest biological processes. There has been much discussion both within the team of Viking investigators and outside it as to the best way to interpret the findings. Are the changes due to biological responses or are they just chemical reactions we would like to believe are biological? Indeed, since life is a form of chemistry, how can the two be told apart?

One way to decide whether or not a process is biological is to test its sensitivity to heat. Living structures are highly organized and fragile, and they are destroyed by temperatures that leave many chemical reactions unaffected. A process that is insensitive to heat is thus likely to be a nonliving chemical reaction, but a process that is sensitive to it could be either living or nonliving.

The decision as to whether a heat-sensitive process is biological or not must be based on additional evidence. In the end, however, the judgment is based on Occam's razor: the traditional principle that the hypothesis most likely to be correct is the one that accounts for the maximum number of observations with the minimum number of assumptions.

The gas-exchange experiment and the labeled-release experiment were frankly terrestrial in orientation. In both experiments a nutrient medium composed of an aqueous solution of organic compounds was mixed with a sample of Martian soil. Since liquid water cannot exist on Mars, the experiments could not be conducted under Martian conditions; the test chambers had to be heated to prevent the water from freezing and pressurized to prevent it from boiling. Both experiments were based on the universal property of terrestrial organisms to evolve gas as they metabolize food. If a sample of soil from the earth is moistened with a nutrient solution, the microorganisms in the soil take up the nutrients and convert them partly into more microorganisms (that is, the population of microorganisms grows) and partly into various by-products, including gases. Among the gases given off in microbial metabolism are carbon dioxide, methane, nitrogen, hydrogen and hydrogen sulfide. On the earth gases evolved by one species of organisms are eventually consumed by other species of organisms. In that way the light elements at the earth's surface are continually cycled through the biosphere and the atmosphere.



GAS-EXCHANGE EXPERIMENT tested the Martian soil to see if there were any microorganisms in it that took in atmospheric gases and nutrients and gave off gaseous by-products. The experiment proceeded in two stages. In the first stage a small volume of a complex nutrient solution (*dark color*) was injected into the test chamber in such a way that it humidified the chamber without wetting the soil (*top*). The gases evolved (*light gray*) were flushed into a gas chromatograph with a stream of helium (*light color*), where they were analyzed for organic compounds and compared with results of reference analysis run as a standard. In second stage of experiment a large volume of nutrient was poured into chamber to wet the soil (*bottom*).

In the gas-exchange experiment a complex nutrient solution was added to a sample of Martian soil in a closed chamber, and the gases were analyzed periodically by means of a gas chromatograph. The experiment proceeded in two stages. In the first stage a small volume of the nutrient solution was introduced into the soil chamber in such a way that it humidified the chamber without actually wetting the soil, and the resulting gases were analyzed several times. In the second stage a large volume of the nutrient was poured into the chamber, saturating the soil. With the soil now in direct contact with the medium the main part of the experiment began. The soil was incubated for nearly seven months, so that whatever microorganisms might be in the sample had enough time to signal their presence by producing or consuming gases. During the period of incubation the atmosphere in the chamber was periodically analyzed.

The findings of the first stage of the experiment were both surprising and simple. Immediately after the soil sample was humidified carbon dioxide and oxygen were rapidly released. The release of the gases ceased soon after it had begun but not before the pressure in the chamber had risen measurably. At the Chryse site in a period of little more than one sol the quantity of carbon dioxide in the incubation chamber of the *Viking 1* lander increased by a factor of five and the quantity of oxygen increased by a factor of 200. At the Utopia site the increases were less, but they were still considerable.

The rapidity and the brevity of the response recorded by both landers clearly suggested that the process observed was a chemical reaction, not a biological one. The appearance of the carbon dioxide is readily explained. Carbon dioxide gas would be expected to be adsorbed on the surface of the dry Martian soil; if the soil was exposed to a very humid atmosphere, the gas would be displaced by water vapor. The appearance of the oxygen is more complex. The production of so much oxygen seems to require an oxygen-generating chemical reaction, not just a physical liberation of preexisting gas. It is likely that the oxygen was released when the water vapor decomposed an oxygen-rich compound such as a peroxide. Peroxides are known to decompose if they are exposed to water in the presence of iron compounds, and according to the X-ray fluorescence spectrometer aboard each Viking lander, the Martian soil is 13 percent iron.

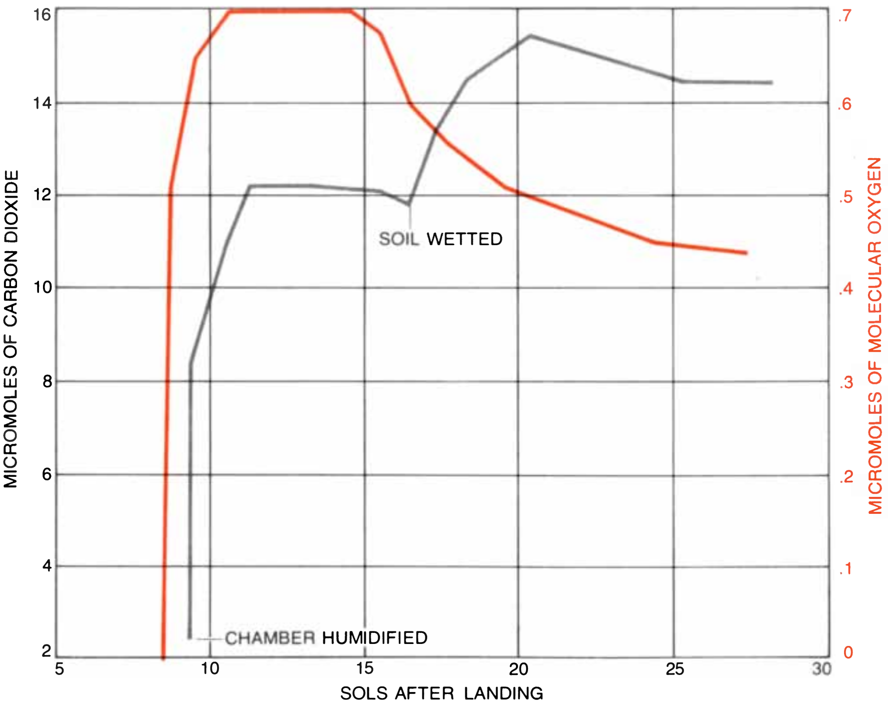
At both landing sites the second phase of the gas-exchange experiment was anticlimactic. When the soil sample was saturated with the nutrient medium and incubated, carbon dioxide continued to be released. The production of the carbon dioxide gradually tapered off, however, and the oxygen gradually disappeared. The slow increase in the amount of carbon dioxide was probably a continuation of the reaction in the humid stage of the experiment. The disappearance of the oxygen also can be easily explained: one of the ingredients of the nutrient medium was ascorbic acid, which combines readily with oxygen. And so after seven months it became clear that everything of interest had happened in the humid stage of the experiment, before the soil came in contact with the nutrient! What the gas-exchange experiment detected was not metabolism but the chemical interaction of the Martian surface material with water vapor at a pressure that has not been reached on Mars for many millions of years.

The labeled-release experiment differed from the gas-exchange experiment in several ways. The nutrient medium employed was a simpler one containing only a few cosmically abundant organic compounds such as formic acid (HCOOH) and the amino acid glycine (NH_2CH_2COOH). All the compounds were labeled with atoms of the radioactive isotope carbon 14. The labeled-release instrument was designed to detect radioactive gases, principally carbon dioxide, released when the nutrient medium was added to a sample of soil. The number of radioactive disintegrations in gases can be counted quite efficiently, so that the labeled-release experiment is faster and more sensitive than the gas-exchange experiment in detecting microbial activity in terrestrial soil. The labeled-release experiment's sequence of operations did not include a humid stage as such, but it attempted to accomplish the same end by injecting a volume of nutrient medium that was insufficient to wet the entire soil sample but sufficient to humidify the chamber. If the experiment worked on Mars as planned, subsequent injections of the medium, which were controlled by commands sent from the earth, brought the medium into contact with some soil that had previously been wetted and with other soil that had been humidified but not wetted.

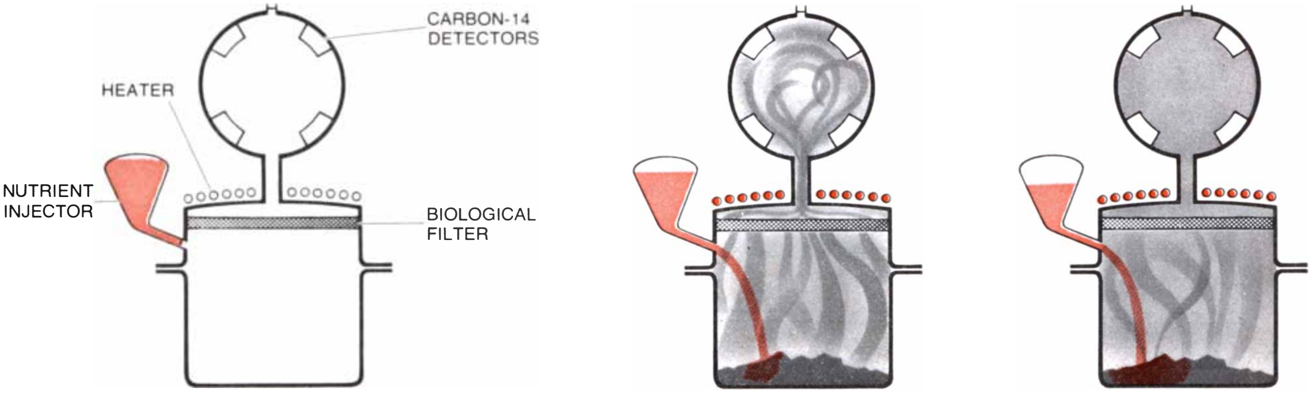
As in the gas-exchange experiment, immediately after the nutrient medium was added to the soil in the labeled-release experiment, gas surged into the chamber. The release of gas tapered off soon after the first sol. The gas, undoubtedly carbon dioxide, was radioactive, showing that it had been formed from the radioactive compounds of the medium and not from compounds in the Martian soil. Nonradioactive gases, which also must have formed when the aqueous medium came in contact with the soil, were not detectable in the experiment.

The production of radioactive carbon dioxide in the labeled-release experiment is understandable in the light of the evidence from the gas-exchange experiment suggesting that the surface material of Mars contains peroxides. Formic acid, one of the compounds of the labeled-release nutrient medium, is oxidized with particular ease: if a molecule of formic acid (HCOOH) reacts with one of hydrogen peroxide (H_2O_2), it will form a molecule of carbon dioxide (CO_2) and two molecules of water ($2H_2O$). The amount of radioactive carbon dioxide given off in the labeled-release experiment was only slightly less than what would have been expected if all the formic acid in the medium had been oxidized in this way.

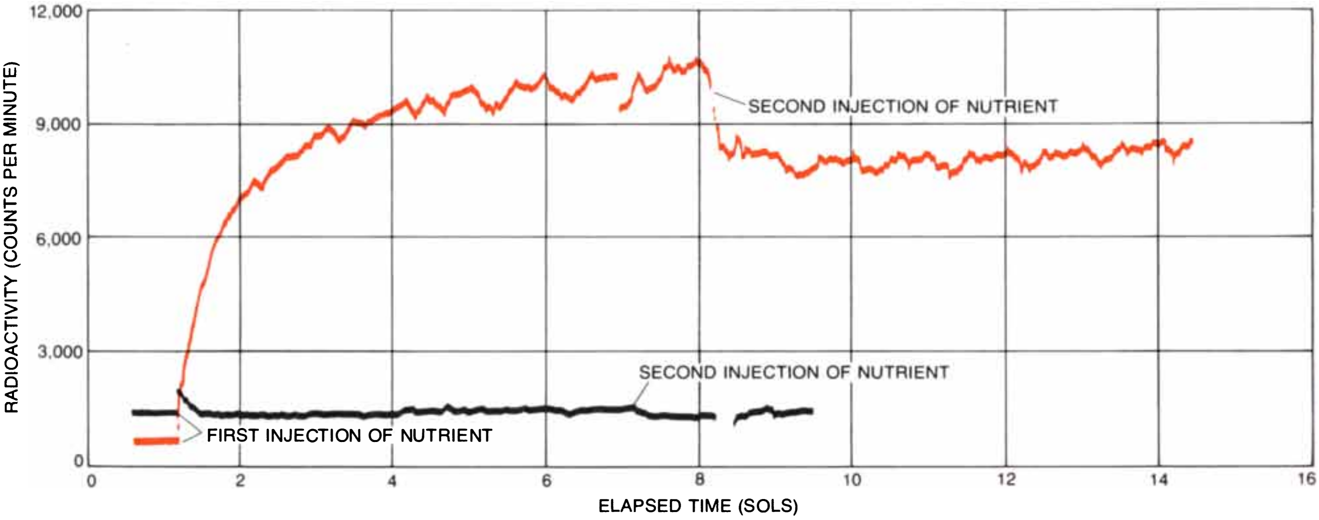
If the source of the oxygen released in the humid stage of the gas-exchange experiment was indeed peroxides in the soil decomposed by water vapor, then in the labeled-release experiment all the peroxides should also have been decomposed by the first injection of nutrient. Thus the next injection should have evolved no additional radioactive gas in spite of the fact that part of the sample presumably had not yet been wetted by the medium. That proved to be the case. When a second volume of medium was injected into the chamber, the amount of the gas in the chamber was not increased; indeed, it decreased. The decrease is explained by the fact that carbon dioxide is quite soluble in water; when fresh nutrient medium was added



RESULTS OF THE GAS-EXCHANGE EXPERIMENT, according to data of Vance I. Oyama of the Ames Research Center of the National Aeronautics and Space Administration, showed that in the first humid stage of the experiment a large amount of carbon dioxide (*black*) and molecular oxygen (*color*) surged into the test chamber. In the second wet stage the amount of carbon dioxide continued to rise at a decreasing rate and then declined. The amount of oxygen, however, quickly fell. It is believed the gases were released by physical and chemical processes, not by biological ones. One micromole is a millionth of a mole, where one mole is the amount of a substance that has a weight in grams equal to its molecular weight. Oxygen curve is displaced to the left by one sol so that the curves do not overlap. A sol is one Martian day.



LABELED-RELEASE EXPERIMENT on the Viking landers tested the Martian soil for microorganisms that could metabolize simple organic, or carbon, compounds. The nutrient medium was composed of several organic compounds that are widely abundant in the universe. The compounds were labeled with radioactive carbon. If microorganisms exist in the Martian soil, they might consume the labeled nutrient and give off radioactive gases (particularly carbon dioxide), which would be detected by the carbon-14 counters. Before the soil was tested the background level of radiation was measured (*left*). The soil was dumped into the test chamber, injected with a small amount of medium (*middle*) and incubated for up to 11 sols. The amount of nutrient in this first injection was planned to wet only part of the soil but to humidify the entire chamber. A subsequent injection of the nutrient (*right*), controlled by signals from the earth, thus brought the medium into contact with soil that had already been wetted and with other soil that had been humidified but not wetted. If the labeled-release experiment worked on Mars as planned, its results would serve as a check on the results of the gas-exchange experiment.



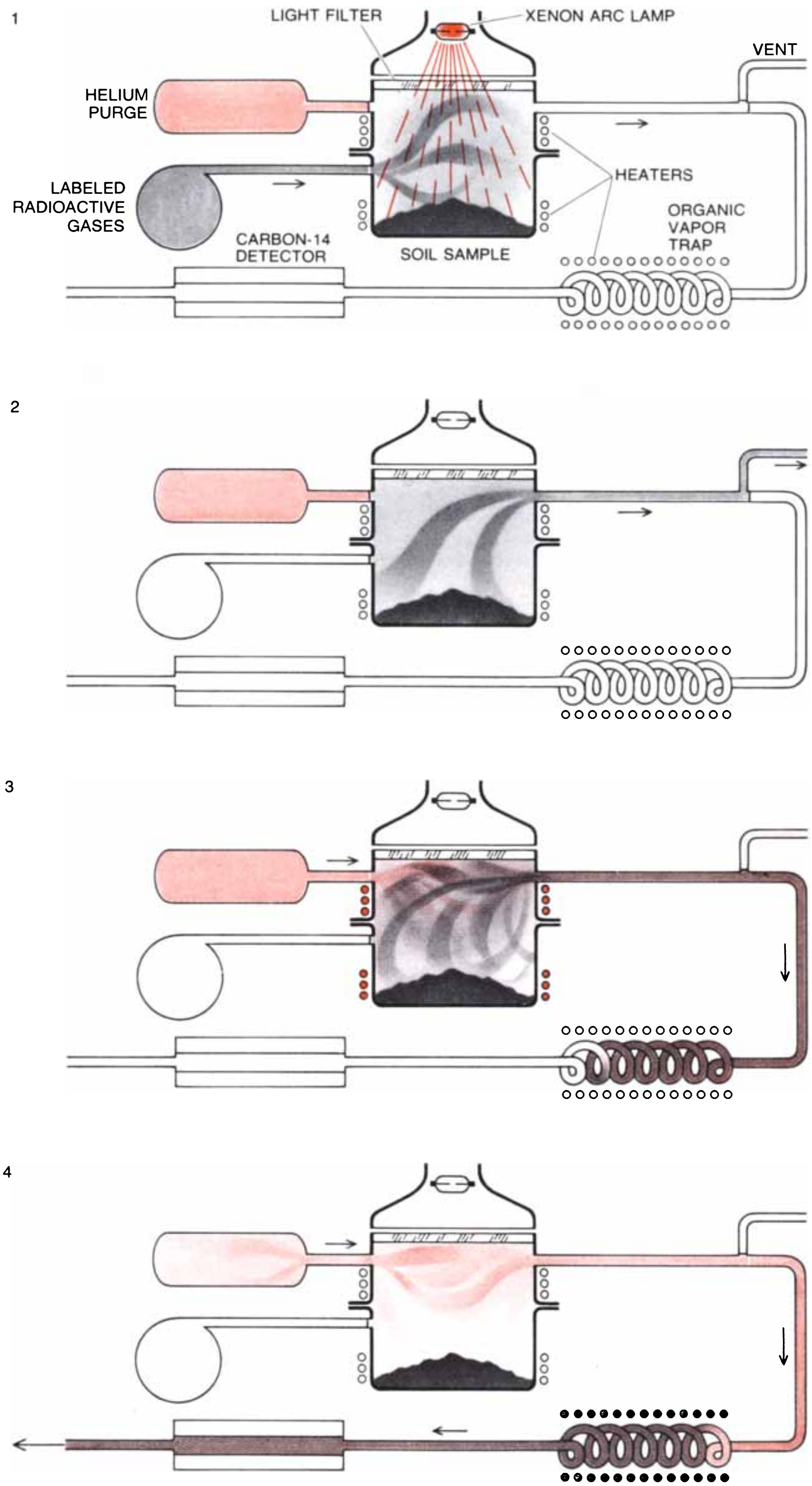
RESULTS OF THE LABELED-RELEASE EXPERIMENT for the first sample of soil analyzed at the Chryse site (*curve in color*) were indeed consistent with the results of the gas-exchange experiment, according to data from Gilbert V. Levin and Patricia A. Straat of Biospherics Inc. Immediately after the first injection of the nutrient, radioactive gases surged into the chamber. The radioactivity was measured at 16-minute intervals throughout the experiment except for the first two hours after the first injection, when measurements were made every four minutes. After the second injection the amount of gas in the chamber dropped, then remained at a nearly constant level until the end of the experiment. In order to test the sensitivity of reaction to heat a second portion of the soil sample was sterilized at a temperature of 160 degrees Celsius for three hours and the experiment was repeated (*curve in black*). The reaction was abolished. Although such behavior is consistent with a biological process, it is more likely that experiment again detected only a chemical reaction.

to the chamber, it absorbed some of the carbon dioxide in the head space above the sample.

This result was obtained with all the samples tested by the labeled-release experiment at both Viking sites. In that respect the results of the labeled-release experiment did not parallel the results of the gas-exchange experiment. At both sites both experiments tested soil gathered from the ground's exposed surface; at the Utopia site the experiments also tested soil gathered from under a rock. Although the labeled-release experiment found essentially no difference in the amount of gas released by any of the samples, the gas-exchange experiment recorded about three-fourths as much carbon dioxide from the surface samples at the Utopia site as it had from the surface samples at the Chryse site, and it recorded even less carbon dioxide from the sample from under the rock.

The gas-exchange experiment also recorded less oxygen from the samples from the Utopia region, but the interference of the ascorbic acid in the complex nutrient medium of that experiment makes it difficult to quantify the difference. In every case, however, the gas-exchange experiment detected considerably more gas than the labeled-release experiment did with portions of the same sample. Those results, however, do not contradict the thesis that the production of oxygen detected by the gas-exchange experiment and the production of radioactive carbon dioxide detected by the labeled-release experiment are simply different measurements of the same surface chemistry. The gas-exchange experiment measures the total amount of oxidant in the surface; the labeled-release experiment measures only a fraction of it.

The labeled-release experiment also tested the stability of the reaction to heat. When the soil was preheated to 160 degrees C. for three hours before incubation, the reaction was abolished. When it was heated to 46 degrees for the same length of time, the magnitude of the reaction was reduced by about half. These results have been regarded by



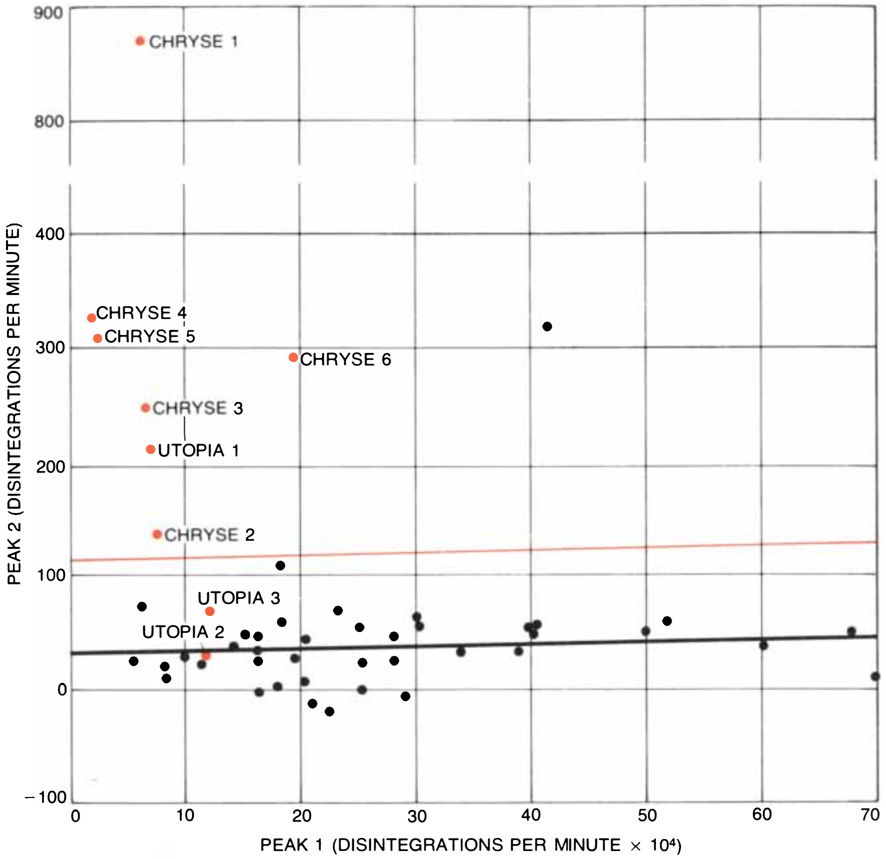
PYROLYTIC-RELEASE EXPERIMENT tested the Martian soil (*dark gray*) to see if there were microorganisms in it that would create organic compounds out of atmospheric gases by either a photosynthetic process or a nonphotosynthetic process. A sample of soil was sealed into a chamber along with some Martian atmosphere and a small amount of radioactive carbon dioxide and carbon monoxide (*light gray*). A xenon arc lamp irradiated the soil with simulated Martian sunlight (*1*). After five days lamp was turned off and the atmosphere was removed from the chamber (*2*). Soil was heated to a temperature high enough to pyrolyze (decompose) into small volatile fragments any radioactive organic compounds produced. Fragments (*light gray*) were swept out of the chamber (*3*) by a stream of helium (*light color*) into a column designed to trap organic molecules but pass carbon dioxide and carbon monoxide. In column trapped radioactive organic molecules were released by raising column's temperature; the molecules were oxidized to form carbon dioxide, which was carried into a radiation counter (*4*).

some as evidence in favor of the hypothesis that the reaction is biological. The results are of course consistent with such a hypothesis, but they are also consistent with a chemical oxidation in which the oxidizing agent is destroyed or evaporated at relatively low temperatures. A variety of both inorganic peroxides and organic peroxides could probably have produced the same results.

The third microbiological experiment, the pyrolytic-release experiment, differed from the gas-exchange and labeled-release experiments in two respects. First, it attempted to measure the synthesis of organic matter from atmospheric gases rather than its decomposition. Second, it was designed to operate under the conditions of pressure, temperature and atmospheric composition that actually obtain on Mars, since those are the conditions under which any form of Martian life must exist. In practice the conditions in the chamber were a reasonably good approximation of Martian conditions except for the temperature, which stayed warmer than the outside temperature because of heat sources within the spacecraft.

A sample of Martian soil was sealed in a chamber along with some Martian atmosphere. A quartz window in the chamber admitted simulated Martian sunlight from a xenon arc lamp. Into this Martian microcosm small amounts of radioactive carbon dioxide and radioactive carbon monoxide were introduced. Both gases are present in the Martian atmosphere but not in radioactive form. After five days the lamp was turned off, the atmosphere was removed from the chamber and the soil was analyzed for the presence of radioactive organic matter.

First the soil was heated in the pyrolysis furnace to a temperature high enough to crack any organic compounds into small volatile fragments. The fragments were swept out of the chamber by a stream of helium and passed through a column that was designed to trap organic molecules but allow carbon dioxide and carbon monoxide to pass through. The radioactive organic molecules were thus transferred from the soil to the column and at the same time were separated from any remaining gases of the incubation atmosphere. The organic molecules were released from the column by raising the column's temperature. Simultaneously the radioactive organic molecules were decomposed into radioactive carbon dioxide by copper oxide in the column. The carbon dioxide was then carried by the stream of helium into a radiation counter. If organic compounds had been synthesized in the soil, they would be detected as radioactive carbon dioxide; if no organic compounds had been synthesized, no radioactive carbon dioxide would have been formed.



RESULTS OF PYROLYTIC-RELEASE EXPERIMENT are shown for all the samples tested on Mars (*dots in color*). The axis labeled Peak 1 shows how much radioactivity in the form of carbon dioxide and carbon monoxide passed through the column during the pyrolysis of each sample. The axis labeled Peak 2 shows how much radioactivity, representing newly synthesized organic matter, remained attached to the column in each case. Each dot in color is labeled and numbered according to the site at which it was tested and which experiment it represents. (For example, "Chryse 1" means the result of the first experiment at Chryse, "Utopia 1" means the result of the first experiment at Utopia, and so on.) The dots in black are the data obtained from tests of sterilized soil samples in a duplicate of the Viking pyrolytic-release instrument on the earth. The black line drawn through those points represents the best fit to the points. The colored line above the black line is a statistically significant dividing line; any point lying above the colored line is a positive result. The single black point above the colored line is believed to be due to a technical error in performing that particular test. Seven of the nine pyrolytic-release experiments performed on Mars, however, yielded firmly positive results.

Surprisingly, seven of the nine pyrolytic-release tests executed on Mars gave positive results. The two negative results were obtained at the Utopia site, but a third sample tested at Utopia was positive. This third sample was actually incubated in the dark, implying that light may not be required for the reaction. The amount of carbon fixed in the soil by the experiment was small: enough to furnish organic matter for between 100 and 1,000 bacterial cells. The quantity is so small, in fact, that it could not have been detected by the organic-analysis experiment. The quantity is nonetheless significant; it was surprising that in such a strongly oxidizing environment even a small amount of organic material could be fixed in the soil.

Even more significant, the pyrolytic-release instrument had been rigorously designed to eliminate nonbiological sources of organic compounds. During the development of the experiment it had been found that in the presence of short-wavelength ultraviolet radiation, carbon monoxide spontaneously combined with water vapor to form organic molecules on glass, quartz and soil surfaces in the experimental chamber. In order to avoid those reactions and the confusion they would have caused, the short-wavelength ultraviolet was filtered out of the radiation allowed to enter the incubation chamber. To receive positive results from the soil on Mars in spite of that precaution was startling.

Nevertheless, it appears that the findings of the pyrolytic-release experiment must also be interpreted nonbiologically. The reason is that the reaction detected was less sensitive to heat than one would expect of a biological process. In two of the nine pyrolytic-release experiments performed on Mars the soil sample was heated before the radioactive gases were injected and the incubation was begun. In one case the sample was held at 175 degrees C. for three hours and in the other it was held at 90 degrees for nearly two hours. The effect of the higher temperature was to reduce the reaction by almost 90 percent but not to abolish it. The effect of the lower temperature was nil. When it is recalled that the temperature at the surface of Mars at the two landing sites does not rise above zero degrees C. at any time, and that the temperature below the surface is even lower, it becomes difficult to reconcile the results with a biological source. Any organisms living in the Martian soil should have been killed by those temperatures.

On the other hand, it is not easy to point to a nonbiological explanation for the positive results. Investigations into the problem are now under way in terrestrial laboratories with synthetic Martian soils formulated on the basis of the data from the inorganic analyses carried out by the Viking landers. The solution to the puzzle will probably also explain why the organic-analysis experiment detected no organic material in the Martian surface. Until the mystery of the results from the pyrolytic-release experiment is solved, a biological explanation will continue to be a remote possibility.

Even though some ambiguities remain, there is little doubt about the meaning of the observations of the Viking landers: At least those areas on Mars examined by the two spacecraft are not habitats of life. Possibly the same conclusion applies to the entire planet, but that is an intricate problem that cannot yet be addressed. The most surprising finding of the life-seeking experiments is the extraordinary chemical reactivity of the Martian soil: its oxidizing capacity, its lack of organic matter down to the level of several parts per billion and its capacity to fix atmospheric carbon (presumably into organic molecules) at a still lower level. It seems Mars has a photochemically activated surface that, due to the low temperature and the absence of water, is maintained in a state far from chemical equilibrium.

These conclusions drawn from the results of the life-seeking experiments on the Viking landers are undeniably disappointing. The discovery of life would have been much more interesting, to say the least. There are doubtless some who, unwilling to accept the notion of a lifeless Mars, will maintain that the interpretation I have given is unproved. They are right. It is impossible to prove that any of the reactions detected by the Viking instruments were not biological in origin. It is equally impossible to prove from any result of the Viking experiments that the rocks seen at the landing sites are not living organisms that happen to look like rocks. Once one abandons Occam's razor the field is open to every fantasy. Centuries of human experience warn us, however, that such an approach is not the way to discover the truth.

Drip Irrigation

In this system plastic pipes laid on the surface of the ground deliver water to plants drop by drop. The system reduces stress on the plant, conserves water and works well with saline water

by Kobe Shoji

Some 40 years ago Symcha Blass, an Israeli engineer, observed that a large tree near a leaking faucet exhibited a more vigorous growth than the other trees in the area, which were not reached by the water from the faucet. Blass knew that conventional methods of irrigation waste much of the water that is applied to the crop, and so the example of the leaking faucet led him to the concept of an irrigation system that would apply water in small amounts, literally drop by drop. Eventually he devised and patented a low-pressure system for delivering small amounts of water to the roots of plants at frequent intervals. The technique, as developed by Blass and subsequently refined by him and various manufacturers, consists in laying a plastic tube of small diameter on the surface of the field alongside the plants and delivering water to the plants slowly but frequently from holes or special emitters located at appropriate points along the tube. The concept, which is now called drip irrigation or trickle irrigation, has gained wide acceptance, proving to be particularly valuable in areas that are arid and have high labor costs. An unforeseen benefit is that the system works well with water that is highly saline, as water in arid regions often is.

In much of the world farmers still irrigate as they did 5,000 years ago, either by flooding their fields or by diverting water to the crop through parallel furrows. In these methods of irrigation the plants take up only from 30 to 60 percent of the water that is applied. Moreover, the preparation of the field and the management of the irrigation system require much labor. If water is plentiful and labor is not too costly, the furrow method may have an economic advantage in spite of its inefficiency. In areas such as California and Hawaii, however, which face not only water shortages but also rising labor, power and water costs, drip irrigation has been rapidly and successfully adopted. Indeed, California, where last year was the third-driest on record, now has 15 percent of the worldwide total of some 162,000 hectares (400,000 acres) with drip-irrigation systems.

The basic idea underlying drip irrigation can be traced to experiments in Germany in the 1860's. Farmers laid clay pipes with open joints about .8 meter below the surface of the soil in an effort to combine irrigation and drainage as the water table rose and fell during the year. In the 1930's growers in Australia with limited water supplies devised a system for irrigating peach orchards with five-centimeter galvanized-iron pipes in which holes had been cut with a chisel. Greenhouse operators in the United Kingdom began to try a similar method in 1948 for the growing of tomatoes.

Drip-irrigation techniques were first introduced into the U.S. in the early 1960's, when a number of operators in the nursery industry installed the system in greenhouses. It was applied to orchards and row crops in California beginning in 1968; since then it has been adapted to other crops, including tomatoes, grapes, strawberries, corn, pineapples and sugarcane. (Drip irrigation is not suitable for closely planted crops, such as cereal grains and alfalfa, because the amount of tubing they require makes the system uneconomic.)

When Blass conceived the idea of drop-by-drop irrigation in the 1930's, the materials needed to build a low-pressure system at reasonable cost were not available. Only with the rapid development of the plastics industry after World War II could appropriate materials for making chemically resistant, flexible lines of small diameter be produced economically. The earliest drip-irrigation systems consisted of plastic capillary tubes of small diameter (one millimeter) attached to larger pipes. Friction in the tube restricted the flow of water into the soil from a given discharge point to between two and four liters per hour. The system was initially installed underground, but because of the primitive filtration techniques of the time and frequent clogging the distribution apparatus was moved aboveground. This change made it easy to check the tubes for clogging and maintained the chief advantage of the system: the direct application of water to the root zone of the plant.

One of the refinements made by Blass in his original system was a coiled emitter that he designed to prevent clogging. It consisted of a spiral tube in a hard casing. The tube served to reduce the discharge pressure by lengthening the flow path of the water, thereby making it possible to discharge the water through a larger hole.

In the 1960's experimenters in Israel reported spectacular success when they applied the Blass system in the desert areas of the Negev and the Arava. Yields there had been poor with both furrow and sprinkler irrigation. The main reason was that the water was quite saline. Drip irrigation can generally utilize water of higher salinity than would be acceptable with other methods of irrigation, a subject to which I shall return.

The conditions for agriculture in the desert areas were distinctly adverse: not only saline water but also high temperatures, low relative humidity and sandy soil. In spite of these difficulties the drip-irrigation technique brought about a substantial improvement in crop yields. For example, a field trial in the Arava produced annual harvests of almost 58.3 metric tons of winter tomatoes per hectare with drip irrigation, compared with 35.8 metric tons with sprinkler irrigation. In another trial the yield of muskmelons was increased by 70 percent, and salt-sensitive crops such as cucumbers showed significant yields for the first time. Moreover, drip irrigation demonstrated such additional advantages as a diminished consumption of water, a reduction in labor costs and an improved distribution of fertilizer. A soluble fertilizer can easily be distributed in the irrigation system along with the water. Since a drip system delivers the water only near the plant, the fertilizer is applied where it is most useful.

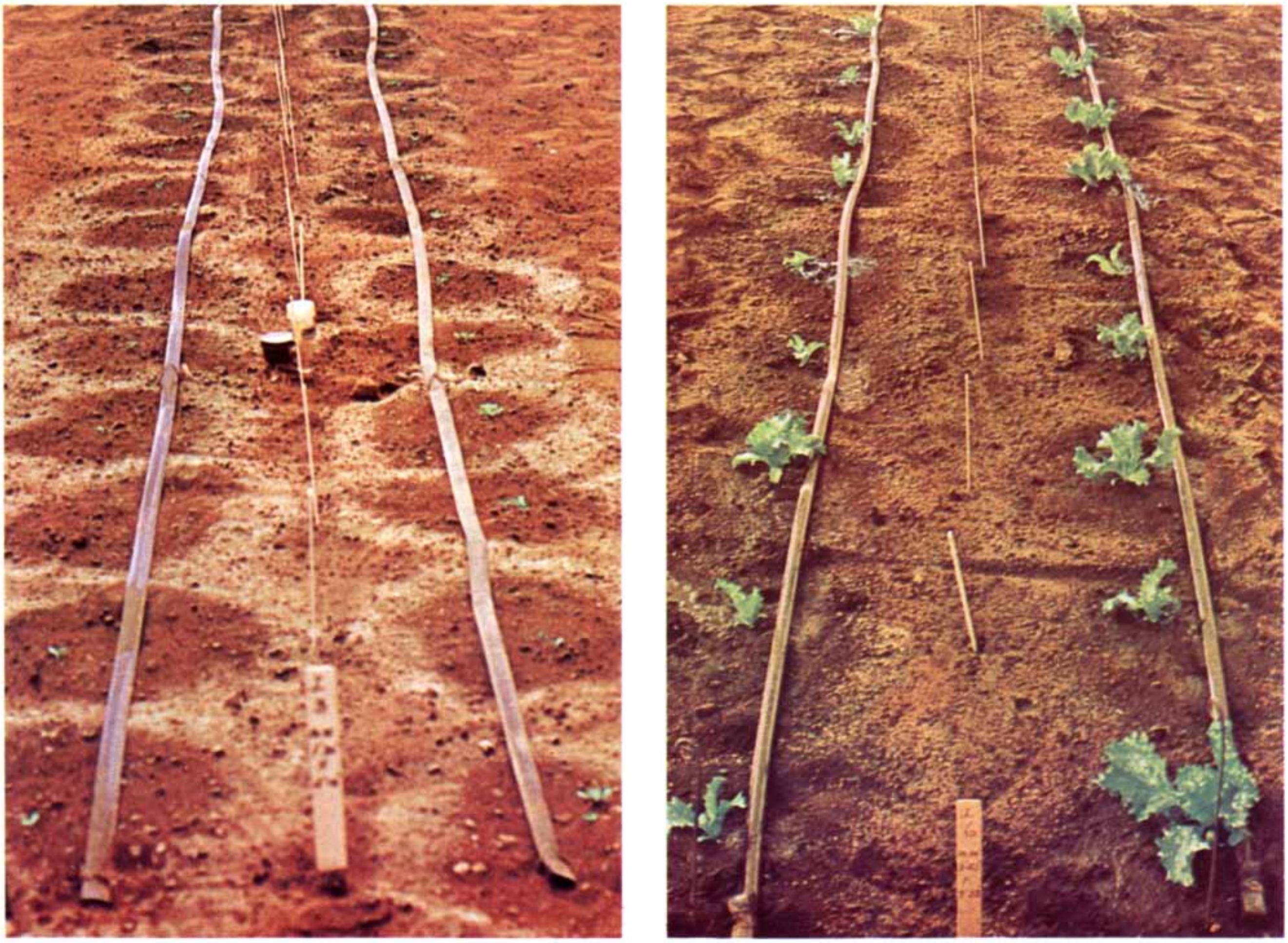
Over the past decade an entire industry devoted to designing and manufacturing equipment for drip irrigation has arisen. As a result of this activity the equipment designed for drip irrigation has changed rapidly. Drip irrigation is applied to a wide variety of soils under many topographic conditions, so that the design of a system for maintaining uniform flows is a challenge to the engineer. Even though any drip system is based on the hydraulics of flow in pipes, however, an installation must be designed specifically for the crop it will supply and the conditions under which the crop is to be grown.

A typical modern drip-irrigation system is made up of a network of plastic pipes and tubes of graduated sizes. A fairly large pipe brings the water to the edge of the field. A series of main lines of smaller diameter takes it out into the field without discharging it onto the crop. Submains of still smaller size carry it to the lateral lines, from which it is applied to the plants through emitters or holes. The supply line (about 30 centimeters in diameter) and the main lines (15 centimeters) are rigid plastic pipes and are normally installed under the surface. If submains are included, they are likely to range from 7.6 to 15.2 centimeters in diameter. In some systems the lateral lines are attached directly to the main line.

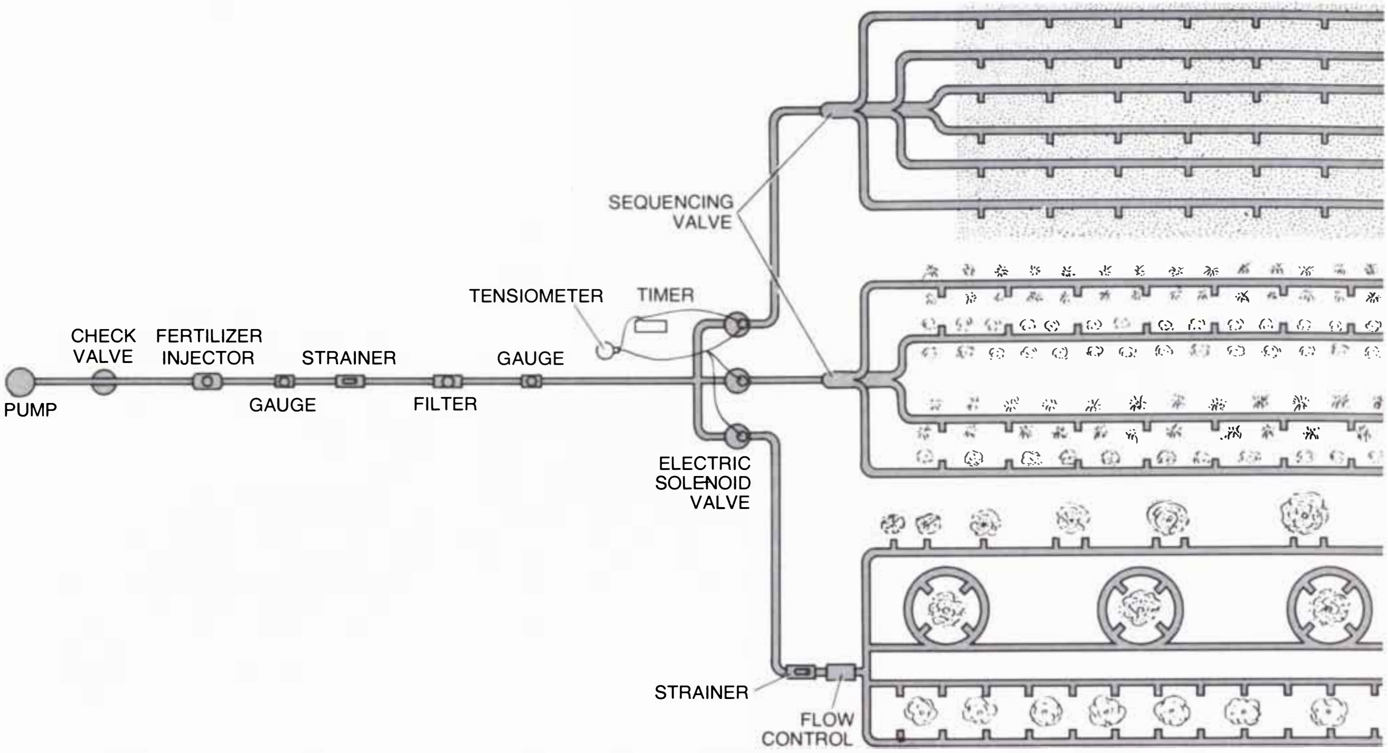
The flexible lateral lines are from 12 to 32 millimeters in diameter. They are installed beside the planting, on or just below the surface of the ground. Emitters attached to the lateral line (or holes spaced along it) administer water to the plant at a rate of from one liter to six liters per hour. In an orchard or a vineyard there are from one to six water-discharge points per plant, depending on the size and spacing of the plants, and the points are arranged either parallel to the row of plants or in a circle around each plant. For a row crop the lateral lines are either porous hoses or tubes with pinhole-size orifices and are installed parallel to the crop.

The system also requires a control station at the edge of the field. Typically the station includes units to filter the water and remove particles that might otherwise clog the lateral lines, an injector that can add fertilizer or chemicals to the water, pressure regulators, water meters and of course the valves and pumps needed to control the flow of water. Usually a system is designed so that it can be operated either manually or automatically (by means of timers and valves). It can also be designed to irrigate a number of fields in any desired sequence.

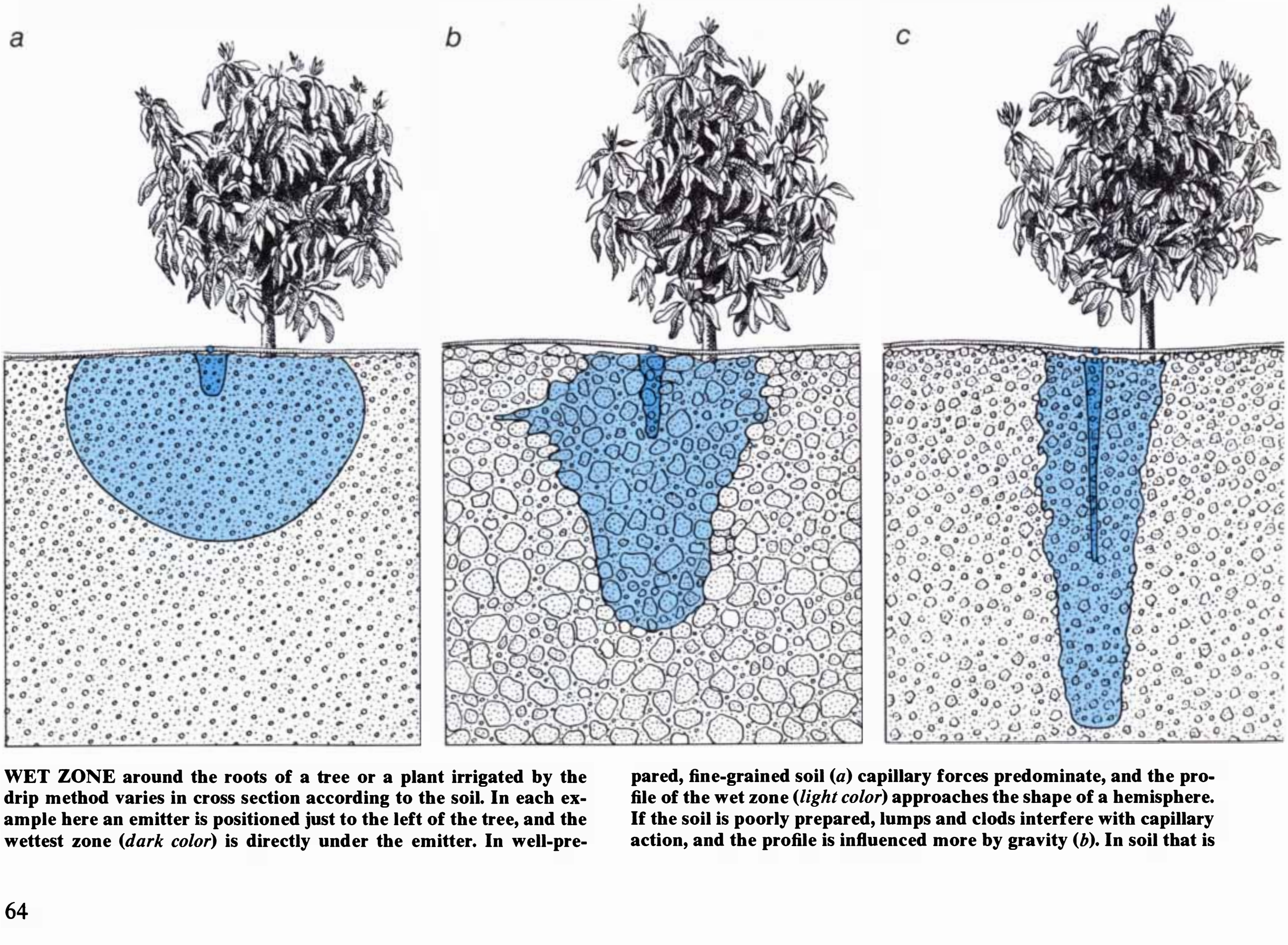
Although the number of hectares under drip irrigation in the U.S. has risen from 40 in 1960 to more than 54,600 today, the total is still small compared with the amount of land under irrigation by other methods. The trend, however, is strongly expansionary. According to a survey of drip irrigation conducted in 1975 by C. Don Gustafson of the Uni-



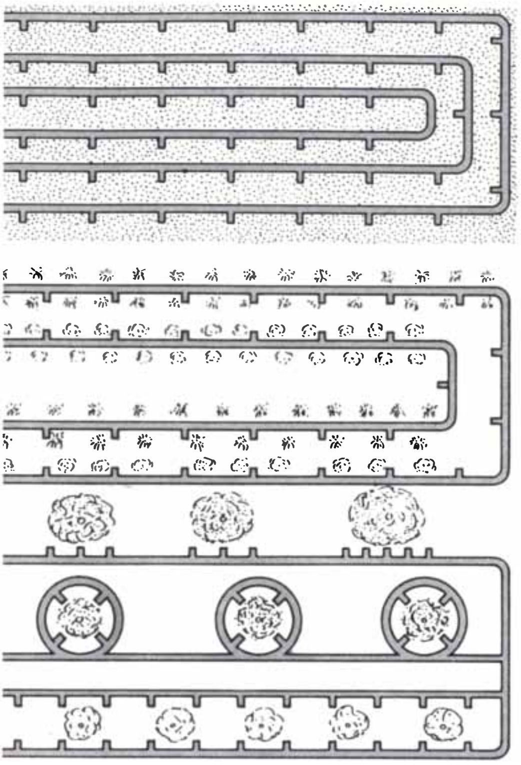
DRIP-IRRIGATION SYSTEM appears in photographs made in an experimental plot at the University of Hawaii. In the photograph at the left narrow plastic tubes deliver water to individual lettuce seedlings by means of tiny holes made at appropriate intervals in the tubes. The wet spots on the soil indicate the precision with which the water is applied. In the photograph at the right the lettuce plants in a nearby plot are shown after growing under drip irrigation for four weeks. In some systems more complex emitters are installed in the pipes.



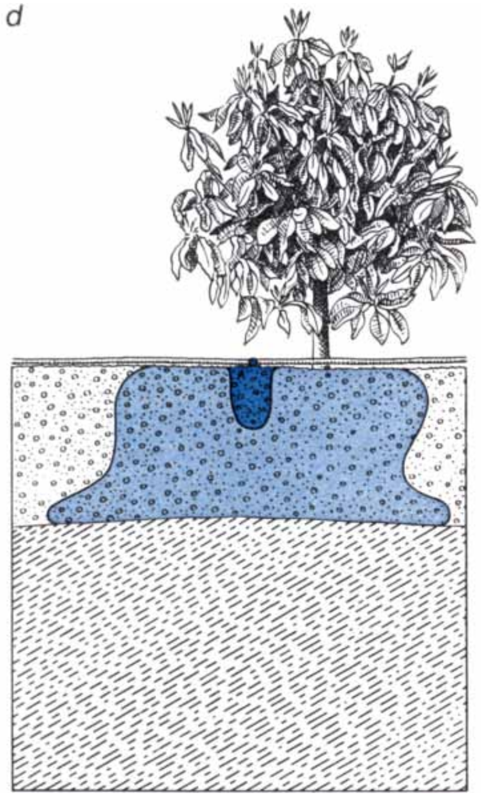
PIPING PATTERNS employed in drip irrigation are shown in a stylized arrangement that emphasizes how pipes and emitters are set up differently for different crops. In an orchard where the trees are small and close together the pipes can be laid parallel to the rows of trees with numerous orifices or emitters. With large trees the pipe is looped around each tree, again with several emitters. For a row crop the pattern may be one pipe per row or one pipe in every other row. When a crop is closely planted, as alfalfa and cereal grains are, drip irrigation may not be the best way to irrigate, since the quantity of pipe required may make the method uneconomic. If drip irrigation is used with such



WET ZONE around the roots of a tree or a plant irrigated by the drip method varies in cross section according to the soil. In each example here an emitter is positioned just to the left of the tree, and the wettest zone (*dark color*) is directly under the emitter. In well-prepared, fine-grained soil (*a*) capillary forces predominate, and the profile of the wet zone (*light color*) approaches the shape of a hemisphere. If the soil is poorly prepared, lumps and clods interfere with capillary action, and the profile is influenced more by gravity (*b*). In soil that is



a crop, the pipes and emitters are spaced evenly. Sequencing valves make it possible to water different areas in sequence. Tensiometers measure the moisture in the soil so that the delivery of water can be scheduled efficiently.



quite coarse (*c*) gravitational forces predominate. A layer of hardpan (*d*), being fairly impermeable, restricts the water's downward movement and improves its lateral movement.

versity of California Agricultural Extension, California had the largest amount of land (24,290 hectares) irrigated by drip methods, with smaller but still substantial amounts in Texas, Hawaii, Florida, Arizona and Michigan. Drip systems had also been installed widely in Australia, Israel, South Africa and Mexico and to a lesser extent in Canada, Cyprus, France, Iran, New Zealand, the United Kingdom and some countries of West Africa. It is estimated that some 350,000 hectares will be under drip irrigation worldwide by 1980.

What makes drip irrigation attractive economically in many agricultural situations is that it provides more benefits than other methods of irrigation. Probably the principal benefit, which is not matched in other techniques, is that drip irrigation supplies plants with the precise amount of water they need. Just enough water is delivered to the root zone of a plant to replenish the amount consumed in evapotranspiration (the water evaporated from the soil and transpired by the plant), and an additional amount to leach salts from the region of the soil close to the roots. This procedure is far more efficient than wetting an entire field or supplying water through furrows.

Much work has been done in the past to determine equations that represent the amount of water required by plants of various species. The factors that go into such an equation include the nature of the evaporating surface and the effects on vapor pressure of wind, temperature, the quality of the water and the amount of energy available. Once the water needs of a crop have been determined the water is metered to each plant through the drip-irrigation installation. As the water flows from the drip emitters it moves underground, creating a potlike formation of moisture around the plant's roots.

The size and shape of the wet zone, as it would be seen in cross section, vary according to the characteristics of the soil, the rate at which the plant extracts moisture from the soil, the number and location of emitters near the plant and the rate at which they discharge water. Through the larger pores of the soil the irrigation water moves downward by gravity; through the smaller pores it spreads in all directions by capillary action. In a fine soil the capillary forces are stronger than the gravitational ones, and the cross-sectional pattern of the wet zone is more or less circular. In a coarse soil, which is not likely to retain water well, the cross section becomes more elliptical.

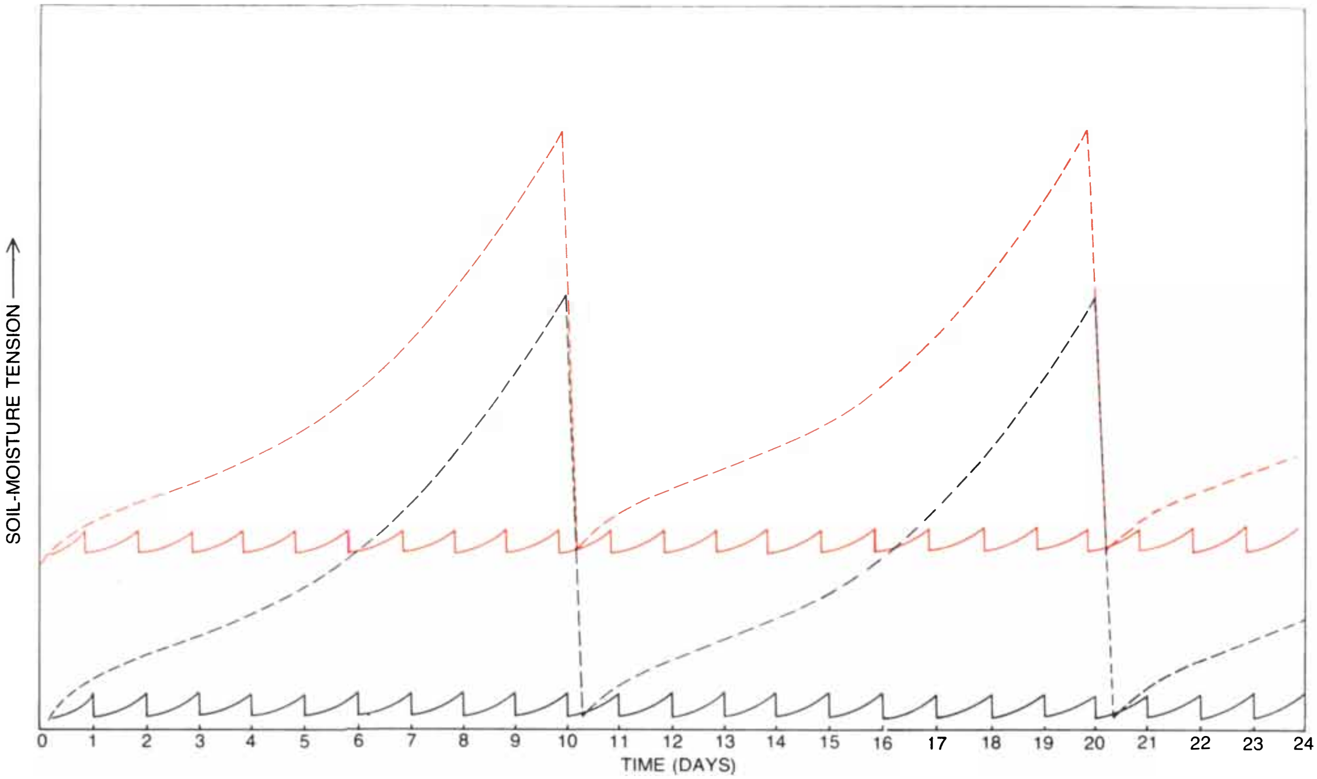
Because drip irrigation slowly and frequently supplies water at a predetermined rate the content of moisture in the wet zone remains fairly constant. Hence the plant grows without stress in an environment of favorable moisture. Drip irrigation thus effectively eliminates the wide fluctuations in the moisture content of the soil that typically result when water is applied periodically by other methods of irrigation. Between applications of water by sprinklers or through furrows, for example, water evaporates from the soil and is transpired by the plant, and the water that remains becomes increasingly difficult for the plant to extract. Soil-moisture tension (the force with which water is held in the soil matrix) rises; if it is unduly prolonged at a high level, the plants suffer stress and eventually begin to wilt.

With drip irrigation, however, a grower can schedule applications of water to maintain a narrow, predetermined range of levels of soil-moisture tension. The optimum level is termed field capacity; it is the level at which excess water is drained from the soil by gravity and the remaining water is held in the soil by capillary action. At field capacity, when the soil-moisture tension is from zero to .3 atmosphere, plants can absorb water from the soil with minimal stress. Because the water requirement of a crop in a field is basically an estimate, notwithstanding the equations that have been worked out for evapotranspiration, measuring devices are often put in the field to monitor the content of moisture in the root zone in order to ensure that it is held as close as possible to field capacity.

The concept of maintaining the soil-moisture tension at an optimum level for the growth of a crop is not new. Before the development of drip irrigation, however, it was economically impractical to try to maintain such a condition because of the excessive amounts of water and labor required with conventional methods of irrigation. A bonus from the elimination of plant stress by drip irrigation is that the plants frequently reach bearing age sooner than comparable plants irrigated by other methods. An early crop can often be sold at higher prices than a crop put on the market at the peak of the harvest.

Another advantage of drip irrigation is its ability to make the maximum beneficial use of the available water. This benefit has attracted interest in water-short areas throughout the world.

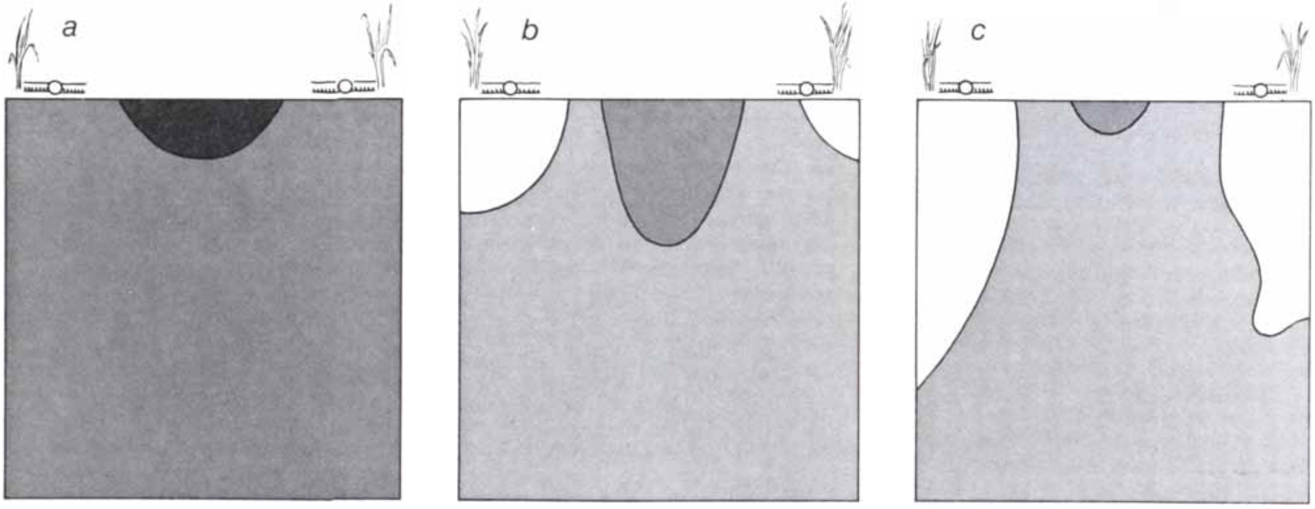
With drip irrigation the parts of the field that are between the rows of plants remain dry, so that little water is lost through evaporation, runoff and percolation. (Sometimes an additional form of loss arises in irrigation with sprinklers because water is carried off by wind before it reaches the plants.) Plants utilize as much water in drip irrigation as they do in other methods, but with drip techniques losses are minimized. The effi-



SOIL-MOISTURE TENSION, a measure of the force by which water is held in the soil and thus of the effort required of a plant to extract water, is compared for drip irrigation (*solid curves*) and sprinkler or furrow irrigation (*broken curves*). In drip irrigation water is applied daily. The soil-moisture tension rises slightly during the period of from 12 to 18 hours between applications. With sprinkler or furrow irrigation, which is more likely to be done at longer time intervals, the soil-moisture tension builds up considerably between applications. The upper set of curves shown here represents irrigation with saline water, the lower set irrigation with relatively fresh water.

ciency of water use varies according to how well a drip system is managed. With good management growers of sugarcane in Hawaii have reported increases in efficiency of from 40 to 60 percent through drip irrigation.

In Hawaii, which provides about 10 percent of the sugar consumed in the U.S., some 48,600 hectares of the total of 89,700 planted to sugarcane are irrigated. Each irrigated hectare requires 46,700 cubic meters of water over the two-year growing period of the cane. Because supplies of fresh water in Hawaii are severely limited and the cost of water is usually high, the efficient use of irrigation water is essential. Efficiency in irrigation is measured by the ratio of the amount of water available to the plant to the amount applied. The traditional furrow-irrigation systems in Hawaii are



BUILDUP OF SALT in the root zone of plants irrigated with drip irrigation is depicted for three conditions in which plants are separated by one meter and each plant has an emitter next to it. Four degrees of salt buildup, ranging from insignificant to severe, are represented by the spectrum from white through shades of gray to black. If the amount of water applied during irrigation is less than the amount lost through evaporation and transpiration (*a*), a high concentration of salt builds up in the area between the plants, and the entire root zone contains a significant amount of salt. In the other two conditions depicted irrigation equals (*b*) and exceeds (*c*) evapotranspiration.

highly inefficient, wasting about half of the water applied. Sprinkler systems are more efficient, with an efficiency rate of from 70 to 80 percent, but the operating and equipment costs are high. With drip irrigation efficiencies of from 80 to 95 percent are obtained.

The third major benefit from drip irrigation is the fact that it works well even if the water is quite saline. Most crops under irrigation will tolerate water that has a total content of dissolved salts amounting to 600 milligrams per liter or less. If drainage and leaching are adequate, irrigation will work with water containing from 500 to 1,500 milligrams per liter of dissolved salts. If the salinity is between 1,000 and 2,000 milligrams per liter, irrigation must be frequent to promote leaching. Water with a salinity of between 3,000 and 5,000 milligrams per liter normally produces a crop yield only if the plants being grown are highly tolerant of salt.

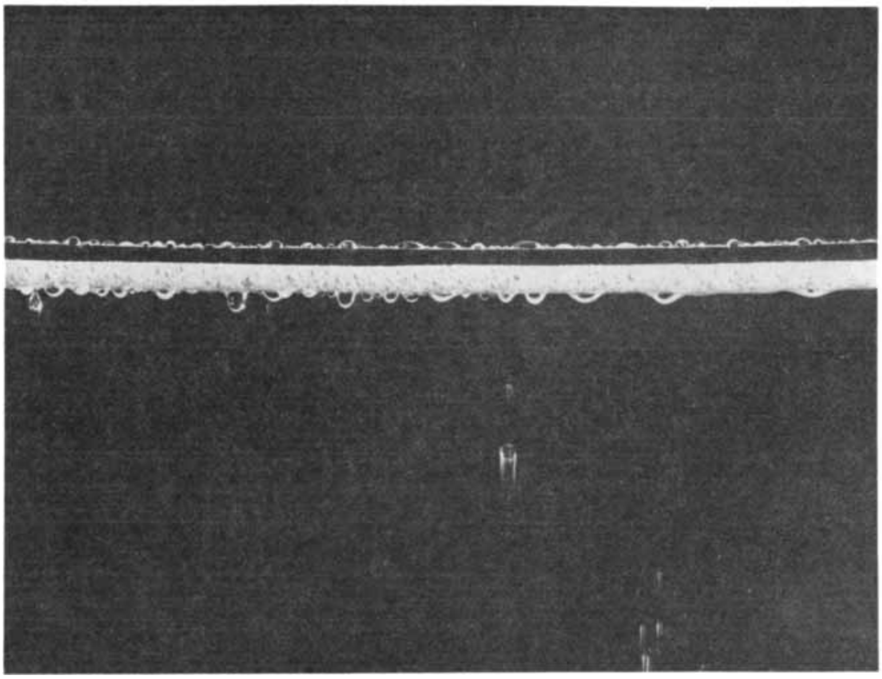
When irrigation is done with saline water, the concentration of salt in the soil increases as the soil dries out between applications of water. At such times the soil-moisture tension rises, making it difficult for the plants to extract the remaining irrigation water from the soil. The salts gradually accumulate, and plant growth and crop yields decline. The usual practice among growers is to rely on rainfall or additional heavy applications of irrigation water to leach out the salts. Only with careful management of the relations between the plant, the soil and the water, however, can adequate productivity be maintained, particularly in arid regions. Even with careful management good yields sometimes cannot be obtained when irrigation is done with saline water by conventional methods.

With drip irrigation, on the other hand, the buildup of salt is controlled by what is effectively continuous leaching. Salts are pushed out to the periphery of the root profile by an advancing front of water emitted from the orifices of the tube. The roots are able to take up water freely from the middle of the wet zone, where soil-moisture tension is low and the salt level remains nearly the same as it is in the irrigation water.

Drip irrigation frequently brings about larger yields and a more uniform growth of the crop. The uniform growth, which results from the application of approximately the same amount of water to every plant in the field, greatly facilitates mechanical harvesting. Drip irrigation, as I have mentioned, requires little in the way of special preparation of the land. Moreover, the system is adaptable to a wide variety of soil types and terrains. Since moisture can be applied frequently, the fact that soils such as sand will not hold water between irrigation cycles ceases to be important. Because drip irrigation eliminates the

COUNTRY	ACREAGE IN 1975	CROPS
ARGENTINA	375	VINEYARD PLANTS
AUSTRALIA	42,840	DECIDUOUS FRUIT, VEGETABLES, AVOCADOES, BANANAS, CITRUS FRUIT, NURSERY PLANTS, NUTS
BRAZIL	909	DECIDUOUS FRUIT, VEGETABLES, NURSERY PLANTS, NUTS
CANADA	1,000	DECIDUOUS FRUIT, VEGETABLES, NURSERY PLANTS, ORNAMENTALS
CYPRUS	1,000	VEGETABLES, VINES, BANANAS, CITRUS FRUIT
COSTA RICA	25	OIL PALMS (EXPERIMENTAL)
FRANCE	3,050	DECIDUOUS FRUIT, FLOWERS, GREENHOUSE PLANTS
HONDURAS	5	BANANAS, PALMS
INDIA	50	DECIDUOUS FRUIT, VEGETABLES
IRAN	2,000	CITRUS FRUIT, VEGETABLES
ISRAEL	25,000	DECIDUOUS FRUIT, VEGETABLES, AVOCADOES, BANANAS, CITRUS FRUIT, GREENHOUSE PLANTS, ORNAMENTALS
JAPAN	10	CITRUS FRUIT, GRAPES, VEGETABLES
MEXICO	13,826	DECIDUOUS FRUIT, CITRUS FRUIT, ROW CROPS, OLIVES
MARTINIQUE	1,000	BANANAS, AVOCADOES, SUGARCANE
NEW ZEALAND	2,682	DECIDUOUS FRUIT, VEGETABLES, CITRUS FRUIT, AVOCADOES, GREENHOUSE PLANTS
PANAMA	2	DECIDUOUS FRUIT, VEGETABLES
PUERTO RICO	181	MANGOES, CHERRIES, PLANTAINS
SOUTH AFRICA	18,000	DECIDUOUS FRUIT, VEGETABLES, GREENHOUSE FLOWERS
U.K.	4,000	DECIDUOUS FRUIT, VEGETABLES, GREENHOUSE FLOWERS
U.S.	133,717	DECIDUOUS FRUIT, VEGETABLES, CITRUS FRUIT, SUGARCANE, NUTS, GREENHOUSE PLANTS, NURSERY PLANTS, ORNAMENTALS, ROW CROPS, AVOCADOES
WEST AFRICA (SENEGAL)	1,000	VEGETABLES

EXTENT OF DRIP IRRIGATION in 1975 is charted. The data are based on a survey made by C. Don Gustafson of the University of California Agricultural Extension. In the U.S. the largest amount of land (60,000 acres) under drip irrigation was in California. Seven other states had more than 1,000 acres under drip irrigation. Gustafson found the system in 35 states.

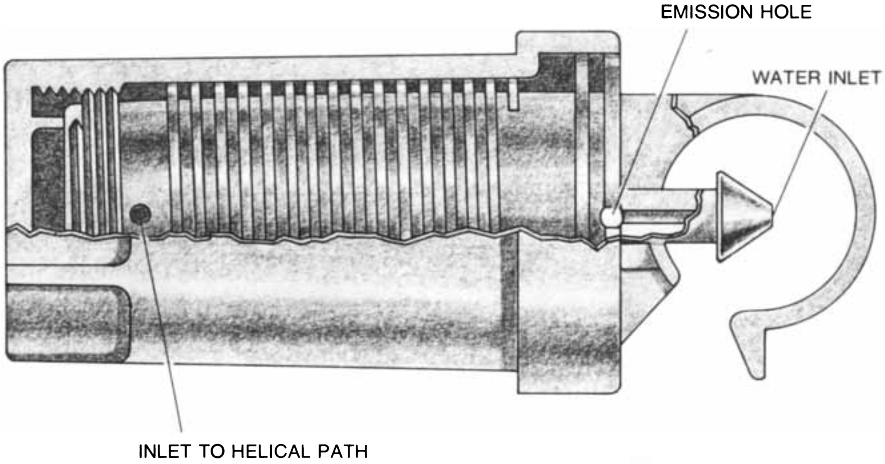


POROUS HOSE drips water slowly along its length to provide a form of drip irrigation to a row crop. For this photograph the hose was lifted off the ground in order to reveal more clearly the emission of the water. The black strip along the top of the hose is a seal made of resin.

problem of runoff, it can be installed in hilly areas. With drip irrigation sugarcane is planted in Hawaii on slopes of from 20 to 30 percent, and avocado orchards are planted in San Diego on slopes of from 50 to 60 percent without problems of erosion.

Drip irrigation also makes the maximum beneficial use of fertilizer. Applying soluble fertilizer directly through the drip-irrigation installation not only achieves a more accurate and even delivery of nutrients but also reduces costs by eliminating the loss of fertilizer through deep percolation and waste between rows. The system also diminishes the environmental problems associated with the contamination of underground water by agricultural chemicals. Moreover, plants never experience "fertilizer burn" in a drip system, because the chemicals in the fertilizer are greatly diluted by irrigation water before they reach the plant.

Since most of the soil surface stays dry with drip irrigation, the growth of weeds and fungi is inhibited. Weeds can be a problem, however, in the wet areas near the emitters. Experiments in California have indicated that such weeds can be controlled satisfactorily with herbicides.



NOZZLELIKE EMITTER is designed to reduce water pressure by causing the water to move along an elongated helical path. With low pressure the emission hole can be larger, so that its tendency to become clogged is diminished. An emitter of this design is preset at the factory to emit one, 1.5 or two gallons of water per hour. The hook at the right attaches the emitter to the drip-irrigation pipe at a right angle; water enters the conical tip from the center of the pipe.

A final advantage of the system is that it can reduce significantly the amount of money spent on power and equipment. At the edge of the field the pressure of a typical drip-irrigation system is from .4 kilogram to one kilogram per square centimeter (from five to 14 pounds per square inch), whereas with sprinkler irrigation it is between three and eight kilograms per square centimeter (40 and 110 pounds per square inch). Less power is needed for pumping in the drip system, and the low pressures of the system also reduce the cost for hardware because the mains and submains can be of lighter gauge than is required for sprinkler irrigation.

Drip irrigation is not without problems. Perhaps the most serious one is the plugging of holes and emitters, which can impair the efficiency of distribution throughout the system. The low pressure, small orifices and low velocity of flow exacerbate the clogging, which can be caused by particles in the water or by slime that collects around the orifices or line the inside of the tubes.

Research has shown that the particles can be dealt with by filtering. Settling basins can remove particles larger than 75 microns in diameter. Smaller particles can be removed with screen filters or, in severe cases, with sand filters. Clogging can also be minimized by certain field practices, such as orienting the orifices upward and flushing the tubes regularly. The slime problem can be dealt with by chlorinating the water for 20 minutes per day at a rate of 10 parts per million. Chlorine simultaneously serves to control the bacteria that flourish on the iron and sulfur in the water of certain areas.

Another problem sometimes associated with drip irrigation is that the tubes are attacked by ants seeking water and rodents sharpening their teeth. The present method of controlling these assaults is to apply chemicals. Research is under way to incorporate repellents into the tubing materials.

At the World Water Conference (convened by the United Nations in Argentina in March) it was pointed out that although 70 percent of the earth's surface is covered by water, only 1 percent of the water is fresh and 99 percent of the fresh water is underground. As it becomes more expensive in water-short areas to build up supplies by digging wells, diverting rivers, desalting seawater and seeding clouds, the conservation and efficient utilization of the available resources become increasingly important. Drip irrigation is a promising technology for helping to solve shortages of water and food by improving the efficiency of irrigation and increasing the productivity of land.

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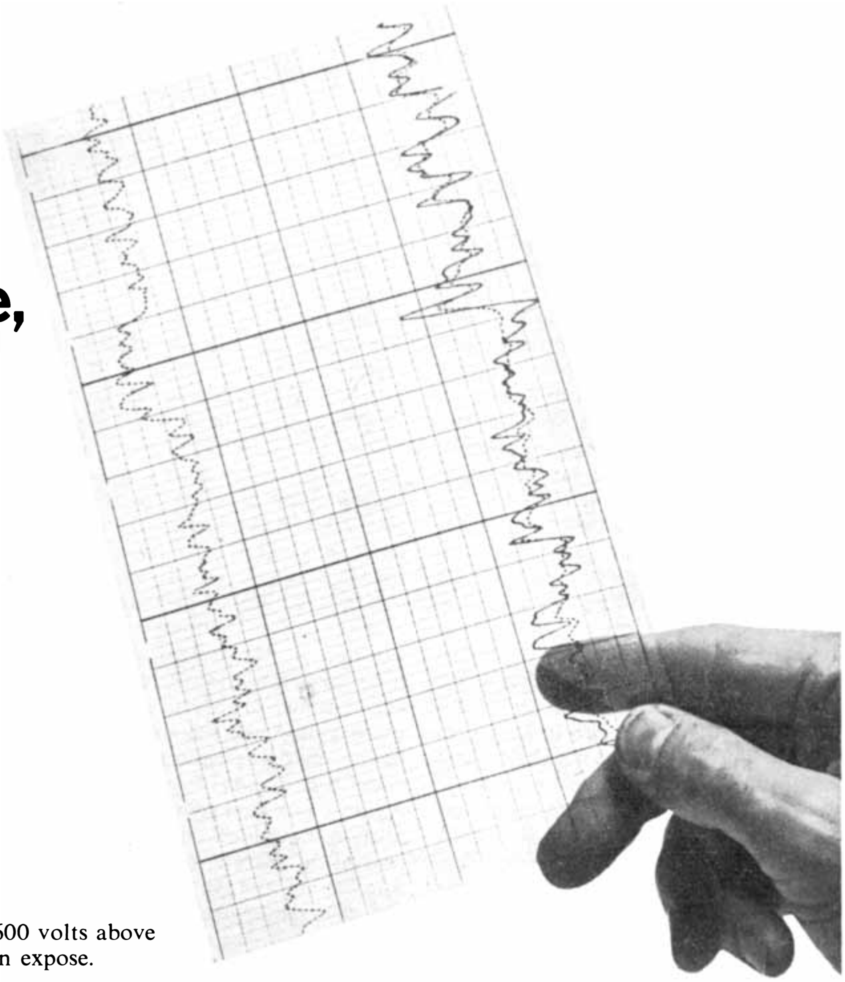

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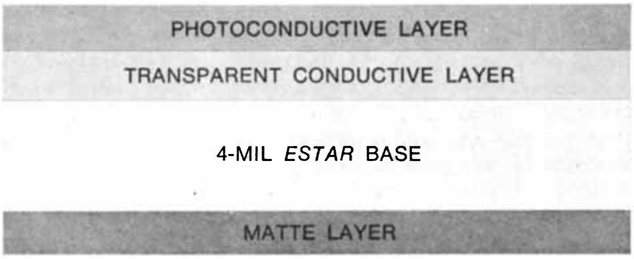

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SCIENCE AND THE CITIZEN

Armament Decade

The 1970's, proclaimed at their beginning by the United Nations General Assembly as the Disarmament Decade, have seen the consolidation of détente between the main protagonists in the arms race, the U.S. and the U.S.S.R., and the adoption of a number of partial arms-limitation agreements, both bilateral and multilateral. The Helsinki Conference on Security and Co-operation in Europe is in particular widely regarded as an important step toward the easing of international tensions. These results, however, "have been far from sufficient to turn or even to stem the tide of the arms race," according to the report of a study conducted for the UN by an international group of disarmament experts. The 13-member study group, which was appointed by UN Secretary General Kurt Waldheim nearly two years ago to help prepare for the General Assembly's special session on disarmament next May, goes on to say: "It is already apparent that the Disarmament Decade is not likely to produce the results hoped for, and that in planning for the next the reasons for that failure will have to be carefully considered."

The new UN report, titled "Economic and Social Consequences of the Armaments Race and Its Extremely Harmful Effects on World Peace and Security," was originally intended to bring up to date the first such report, which was submitted to the General Assembly by the Secretary General in 1971. The main features of the earlier report, the study group remarks, "retain their entire validity today. Indeed, arsenals have been growing in size and sophistication, and new types of weapons of even greater destructive power have been developed or have become operational in the meantime. The threat inherent in vast accumulations of weapons, and of nuclear weapons in particular, continues to grow. The cost of the arms race for the world as a whole and for the vast majority of countries has continued its rise, while the problems of development and the urgency of social needs are as acute as ever."

Adding to the urgency of the need for disarmament, the new report finds, are a number of features of the arms race that have changed in the intervening two-thirds of a decade. For one thing, the report says, "as the major powers have made no progress in actual reductions of their arsenals but have continued to expand and refine them, the arms race has proven increasingly difficult to confine geographically. New powers are emerging with a regional military preeminence and the number of countries on all continents which are being drawn into the overall arms buildup . . . is increasing."

Although world military expenditures, after rising rapidly during the 1960's, appear to have leveled off in recent years at approximately $350 billion annually (in today's prices), the situation has in fact been "changing for the worse. In the 1970's many countries experienced deep recession and severe inflation. Most others were affected indirectly by [the] impact on international trade and by the disruption of the international system of payments. As a result, government programs in the social and economic fields have in many cases had to be revised downward. At the same time, though for partly different reasons, problems of environment preservation and resource conservation have gained a new prominence and have been the cause of growing concern. Against this background of a darkened economic outlook and a greater awareness of the scarcity of resources and the fragility of the physical environment, the continued mindless and uninhibited wastage of the arms race becomes ever more incongruous and unacceptable."

"All of this," the report concludes, "points to one of the serious shortcomings of disarmament efforts for over a decade: the lack of a comprehensive scheme in which partial measures would find their place and, supplementing each other, would add up to a coherent strategy. General and complete disarmament under effective international control must remain the ultimate goal. Agreements to regulate and confine the arms race in the meantime are means and, in some cases, preconditions for achieving that goal, but they cannot take its place. Effective restraining measures in one field, even if they are adopted, can be circumvented, and in the longer run new countries would be likely to enter the competition. In this context, it is imperative that negotiations on general and complete disarmament should receive greater and more urgent attention than has been the case in the past."

The task of elaborating an overall "strategy for disarmament," the report's authors believe, falls naturally to the UN, which "should be able to fulfill its role of overall guidance in the field of disarmament more effectively than it has been able to do in the past." In this respect, the report adds, the upcoming special session of the General Assembly could be "of great importance," possibly leading to the convocation of a World Disarmament Conference.

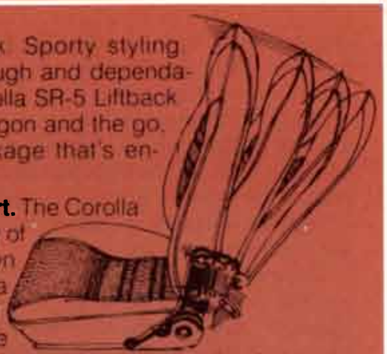
The members of the Secretary General's study group, who approved the report unanimously, were Simón Alberto Consalvi, permanent representative of Venezuela to the UN; Hendrick de Haan, professor of international economic relations at the University of Groningen in the Netherlands; Dragomir Djokic, a member of the permanent mission of Yugoslavia to the UN office in Geneva; Gheorghe Dolgu, professor of economics and president of the Academy of Economic Studies in Bucharest (chairman); Vasily S. Emelyanov, corresponding member of the Academy of Sciences of the U.S.S.R.; Plácido García Reynoso, former professor of economics at the National University of Mexico; Saad M. Hashmi, deputy permanent representative of India to the UN; Ronald H. Huisken, visiting fellow at the Strategic and Defence Studies Centre of the Australian National University; Ladislav Matejka, deputy minister of the Presidium of the Government of the Czechoslovak Socialist Republic; Isaac M. Randolph, a former government official in Liberia; Kurt W. Rothschild, professor of economics at the University of Linz in Austria, and Yves Ullmo, director of the National Institute of Statistics and Economic Studies in Paris. The Secretary General was represented in the group's deliberations by Rolf Björnerstedt, Assistant Secretary General and head of the UN Center for Disarmament.

It Moves

That the earth moves is no longer subject to controversy. In addition to the planet's daily rotation and its yearly revolution around the sun, however, there is now evidence for a much grander motion. It seems the earth moves with respect to the universe as a whole.

Of course the universe itself is not static: galaxies in all distant regions are receding from us and from one another. In the cosmological theory that is most widely accepted today this general expansion is said to result from an explosive event some 15 to 20 billion years ago: the "big bang." The best available evidence for that theory is a background of faint radiation that seems to bathe the entire universe. The radiation was emitted when the universe was much denser and hotter, but today the spectrum is characteristic of radiation emitted by a colorless body with a temperature of 2.7 degrees Kelvin (2.7 degrees Celsius above absolute zero). The outstanding

SPORTS CARGO GO GO



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characteristic of the background radiation has been its isotropy: its intensity has apparently been the same in all directions of observation. Now, however, a small anisotropy, or directional bias, has been found. A straightforward interpretation of that bias is that it represents a Doppler shift in wavelength caused by the motion of the earth.

The anisotropy is reported in *Physical Review Letters* by George F. Smoot, Marc V. Gorenstein and Richard A. Muller of the Lawrence Berkeley Laboratory and the Space Sciences Laboratory of the University of California at Berkeley. They monitored the directional characteristics of the background radiation with a microwave receiver mounted in a U-2 aircraft flown at an altitude of 20 kilometers (65,000 feet).

The background radiation presents only a small signal to a receiver and the directional bias is a still smaller modulation of that signal, so that extraordinary measures were required to eliminate noise. The experiment was conducted at high altitude in order to reduce contamination by atmospheric sources of radiation. The receiver compared signals from two horn antennas, mounted at an angle of 60 degrees to each other, and switched between them 100 times a second in order to eliminate spurious signals resulting from variations in gain. The antennas themselves were interchanged every 64 seconds, and the airplane reversed its course every 20 minutes. Residual atmospheric noise was compensated for by monitoring radiation at another frequency where such emissions are stronger.

Data obtained during eight flights, made between December, 1976, and May, 1977, gave clear evidence of the anisotropy. Moreover, the variation was found to have a simple pattern. The apparent temperature of the radiation is higher in one direction and lower in the opposite direction, and it has intermediate values in between. This is precisely the pattern that would be expected if the earth is moving with respect to the source of the background radiation. The motion is toward the point of highest temperature.

A similar experiment is being conducted by B. E. Corey and David T. Wilkinson of Princeton University. Their preliminary results differ somewhat from those of Smoot, Gorenstein and Muller, but the possible errors in the experiments are sufficiently large for the inconsistency not to be alarming. Several other groups are attempting to measure the motion of the earth with respect to galaxies.

The results obtained by Smoot, Gorenstein and Muller suggest that the earth is moving toward a point in the constellation Leo with a velocity of 390 ± 60 kilometers per second. The orbital motion of the earth around the sun is only a small component of that velocity, about 30 kilometers per second. (Although that is less than the possible error in the measurement, examination of data gathered six months apart does reveal a signal of the correct magnitude.) A larger component is the motion of the sun in its orbit within the Milky Way. From independent measurements, that velocity is known to be about 300 kilometers per second, but in the other direction: the spin of the galaxy is taking us away from Leo. Summing the components of the velocity suggests that the Milky Way is moving toward the constellation Hydra at about 600 kilometers per second.

The measurements of Smoot, Gorenstein and Muller superficially resemble the famous "aether drift" experiment of A. A. Michelson and E. W. Morley, who attempted in the 1880's to measure variations in the speed of light caused by the motion of the earth. The new experiment, however, does not suppose a "luminiferous aether" that defines an absolute frame of reference in the universe. It measures the velocity of the earth with respect to the matter that emitted the background radiation, and thus with respect to the oldest and most distant parts of the universe.

Packaged DNA

The precise manner in which the DNA molecules of higher organisms are arranged within the chromosomes of the cell nucleus has long been a controversial subject in cell biology. The packaging problem is a formidable one: in human cells nearly four meters of DNA are packed into 46 paired chromosomes whose total length is only 200 microns—a ratio of about 10,000 to one. Moreover, the fact that certain genes on a chromosome can be expressed while others are not means that the chromosomal DNA must be arranged in such a way that each functional segment is independently accessible for transcription into messenger RNA.

Biochemical studies have shown that a single long DNA molecule is complexed with the positively charged proteins called histones to form the fiber called chromatin; this fiber is in turn coiled and folded into the cylindrical shape of the chromosome. Determining how the histones are complexed with the DNA, however, has not been an easy task. The problem is that chromatin structure is both beyond the resolving power of the electron microscope and insufficiently ordered to lend itself to analysis by X-ray diffraction.

Until recently it was generally assumed that the chromatin fiber consisted of a superhelix—a helix of the double helix of DNA—with histone molecules continuously wrapped around it. Then in 1974 Marcus Noll and Roger D. Kornberg, working at the British Medical Research Council's Laboratory of Molecular Biology in Cambridge, found that when they digested chromatin with DNA-cleaving enzymes, they obtained DNA fragments mostly 200 base pairs long, suggesting that chromatin is composed of repeating subunits. Kornberg and others subsequently proposed that the DNA superhelix is wound around globular complexes of histone. These complexes, termed nucleosomes, are separated by straight segments of DNA and are spaced out evenly along the linear molecule like beads on a string. Now John T. Finch, Aaron Klug and their colleagues, also working at the MRC Laboratory of Molecular Biology, have determined the overall shape of the nucleosome "core particle," that is, the histone-DNA complex minus the straight chain of DNA that links one nucleosome to the next.

Writing in *Nature*, the MRC investigators report that the core particle contains a segment of double-helical DNA about 140 base pairs long. This DNA segment is associated with an aggregate of eight histone molecules, two from each of the four principal classes of histones: *H2A* and *H2B*, which are rich in the amino acid lysine, and *H3* and *H4*, which are rich in the amino acid arginine. (A fifth histone, *H1*, is also present but is readily removed.) By means of a large-scale preparation method the investigators were able to obtain enough purified core particles to grow crystals of them for X-ray-diffraction analysis.

The low-resolution electron-density map they have obtained provides a picture of the overall shape of the core particle; features less than 20 angstroms across cannot be distinguished. The particle is roughly disk-shaped with a hole in its center. It has a diameter of 110 angstroms and a thickness of 57 angstroms, and it is divided into two symmetrically arranged halves along its short axis. Although it is not possible to distinguish between DNA and protein at this resolution, it appears that the DNA double helix is wound around the outside of the histone complex like a "helical tire," with nearly two turns of superhelix per particle. Since the DNA can bend smoothly to a radius of about 40 angstroms without undue strain, it is not necessary to postulate that the winding of the DNA onto the particle requires "kinks" in the double helix at periodic intervals to render it more compact.

How is the nucleosome assembled? Reconstitution experiments have shown that DNA can be folded into a superhelical structure with many of the features

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of the nucleosome core by simply adding the two arginine-rich histones to a suspension of DNA, without the need for the lysine-rich histones. An attractive model for assembly is therefore that four arginine-rich histone molecules act as a "spool" around which two turns of double-helical DNA are wound, a process analogous to "wrapping a garden hose around one's forearm." Once the appropriate length of DNA has been measured out, the lysine-rich histones associate with and further stabilize the complex.

The MRC investigators have also observed an interesting parallel between the packing of the DNA in the chromosomes of eukaryotic cells (cells with a nucleus) and the packing found in prokaryotic cells (such as the bacterium *Escherichia coli*), which lack discrete chromosomes. In both types of cell the DNA is stored in superhelix form. The coiling of the *E. coli* DNA appears to be achieved by a complex of two small positively charged proteins, which stabilize the superhelix by binding together two adjacent turns of it at a single point. As eukaryotic cells evolved from prokaryotic cells, the investigators conclude, "further basic proteins may have been introduced to produce a more regular, better protected particle—the nucleosome—capable of being organized into higher-order structures."

Deep Pastures

Surveying a rift zone on the Pacific floor roughly midway between the coast of Ecuador and the Galápagos Islands last February and March, research vessels of the Woods Hole Oceanographic Institution encountered four separate oases of marine life at a depth in excess of 1,300 fathoms, a zone of perpetual darkness where the water temperature is normally no more than three or four degrees Fahrenheit above freezing. The oases, each one 150 feet or more in diameter, were populated by various mollusks, including clams as much as a foot in length, mussels and limpets, marine worms sheltered in tubes 14 to 18 inches long, unidentified marine animals about an inch in diameter tethered to the bottom not by a stalk but by a radiating array of fibers, and such transient inhabitants as crabs, fishes and one octopus. The oases were all located in a five-mile stretch along the central axis of the rift where the Cocos plate, moving slowly to the northeast, is breaking away from the Nazca plate, moving slowly to the southeast.

According to Robert D. Ballard of Woods Hole, writing in the institution's journal *Oceanus*, the upwelling lava that is filling the gap between the sea-floor plates provides the mechanism supporting these improbable aggregates of marine life. As the hot lava rises into the rift zone it heats the cold bottom water; the water wells up from temporary vents, its temperature raised as high as 60 degrees F. Sulfate in the warmed seawater is converted into hydrogen sulfide, which is taken up by sulfur-metabolizing bacteria; the bacteria multiply and furnish the nutrients needed by the filter-feeding mollusks, either directly or by nourishing some bacteria-eating intermediate in the food chain. The mollusks in turn may feed the transient animals and the transients may also feed on one another; for example, crabs are a natural prey for the octopus.

In any event, once the lava cools, the ecosystem collapses. The Woods Hole investigators found a fifth oasis where the vent no longer supplied warm water. The bottom was covered with hundreds of empty clam and mussel shells, slowly dissolving as the chill ocean water carried their constituent calcium carbonate away into solution.

Invisible Crater

Throughout its history the earth must have been bombarded with meteorites as the moon has been. Erosion and the evolution of the earth's crust have erased most traces of the bombardment, although in recent years many meteorite craters have been recognized in photographs made from artificial satellites and high-altitude airplanes. One large crater, however, is not visible on any photograph. Located in France near the village of Rochechouart, some 40 kilometers west of Limoges, the crater is not marked by a raised circular rim or a lake in its interior. In fact, all topographic evidence of it has been erased by glacial abrasion and thick vegetation. Yet the meteorite's impact was so violent that even though the crater itself has been obliterated the record of the impact and the history of the crater is preserved in the shocked structure of the underlying rocks.

P. Lambert of the Bureau de Recherches Géologiques et Minières in Orléans has collected some 1,000 samples of minerals from the area and has analyzed them in order to map the way in which the rocks were shocked in different zones at various distances from the site of the impact. According to Lambert, writing in *Earth and Planetary Science Letters,* the geological evidence indicates that the most probable point of impact is about four kilometers west of Rochechouart. The evidence indicates that the original crater had a diameter of at least 13.5 kilometers and perhaps as much as 25 kilometers. The breccias, or fragmented rocks, that fell back from the impact into the center of the crater were contaminated by molten material from the impacting body, which appears to have been an iron meteorite.

The shock zones around the point of impact are not circular but approximately elliptical. To Lambert the lack of circular symmetry implies that the original land excavated by the meteorite may have been hilly and uneven, and that the meteorite may have struck it at a grazing angle. Lambert also suggests that one reason the crater is not depressed in the middle is that soon after the impact the entire floor of the crater was somehow uplifted, raising the floor to the level of the surrounding landscape. When the rim of the crater was eroded away, all external traces of the crater were erased.

Measurements of the abundance of krypton and argon in the shock-metamorphosed rocks indicate that the crater was formed some 165 million years ago in the Middle Jurassic period. Lambert's analyses of the rocks in the area reveal something of the geography of France at that time. Marine sediments found in the rim of a feature known as the Aquitaine Basin some 20 kilometers west of Rochechouart reveal that during the Triassic and Lower Jurassic periods the basin was part of the ocean floor. There are no sedimentary rocks in the Rochechouart crater, however, suggesting that at the time of the impact the Rochechouart region was either dry land or part of a very shallow sea.

Coke

Fashions change in drugs that make people feel good (although alcohol and tobacco seem to go on forever), and in the past decade or so the status drug appears to have come to be cocaine: it dependably produces euphoria, it is apparently not physically addictive, it is expensive enough to be stylish and has a reputation for being relatively safe or even harmless. Various lines of evidence indicate that cocaine use and abuse have been increasing. Cocaine is far from being a mass-consumption street drug, but some two million Americans are thought to be taking it. All the same not much has been known about its psychoactive effects and toxicity or the extent and sociology of its use. In an attempt to learn more about the drug and make that knowledge available the National Institute on Drug Abuse has financed a four-year research effort, the results of which were published recently in a research monograph.

The leaves of the shrub *Erythroxylon coca* have been chewed by the Indians of the Andes for well over 1,000 years, not primarily for recreation but as a source of energy and a sense of well-being (or at least toleration) while working. The Spaniards brought the plant to Europe, but it could not be propagated there. It was not until the active principle was isolated in Germany in the 1860's that Europeans became interested in the medical and psychoactive potentialities of cocaine. Sigmund Freud was an early investigator of the drug's properties; he tried it on himself, prescribed it and prompted experiments by two ophthalmologists that established its value as a local anesthetic. In the U.S. the drug was given to overcome morphine addiction and as a psychic energizer. There were reports of incapacitating cocaine dependence, but according to Robert C. Petersen of the Institute on Drug Abuse that did not prevent the proliferation at the end of the century of commercial cocaine-containing products "ranging from ointments, nose powders, suppositories, throat lozenges and sprays to wines and coca cigarettes." Coca-Cola, originally introduced as a patent medicine in 1886, contained cocaine until 1903. Cocaine was increasingly discredited after the turn of the century by the recognition of its side effects, by a general reaction against the excesses of patent medicines and by racist myths attributing crime to the "coke-crazed Negro brain." As a result of increasing regulation cocaine became expensive and could be afforded only by an affluent minority; the renewal of interest in it during the 1960's appears to have been prompted by increased affluence as well as widespread experimentation with psychoactive drugs.

Cocaine strongly constricts blood vessels, and so it is still the best local anesthetic for surgery of heavily vascularized areas in the nose and throat. Illicit cocaine, a white crystalline powder commonly adulterated with various sugars or with synthetic anesthetics, ranges in price from $60 to $100 per gram. It is usually "snorted," or inhaled, but is also taken orally or intravenously. The effects vary widely with the individual, the route of ingestion and the circumstances under which it is taken. The desirable effects are said to include "a sense of intense stimulation and of psychic and physical well-being accompanied by reduced fatigue." Moderate doses significantly increase both blood pressure and heart rate. Heavy, prolonged use of the drug can produce dependence, intense anxiety or depression and sometimes a cocaine psychosis characterized by tactile hallucinations, in particular a feeling that insects are crawling over the skin. Overdoses can cause death, resulting from a central-nervous-system response usually involving seizures followed by respiratory or cardiac arrest. Contrary to widespread cocaine lore, even snorting can result in a lethal overdose.

The Clustering of Galaxies

Galaxies tend to form small groups, which in turn form larger clusters, and so on. Such a hierarchical organization has long been suspected, but only recently has it been clearly perceived

by Edward J. Groth, P. James E. Peebles, Michael Seldner and Raymond M. Soneira

Modern cosmology is based on the concept that matter is uniformly distributed throughout the universe. This principle is supported by much observational evidence; on the other hand, it cannot be the whole truth. In our own vicinity matter is distributed quite unevenly: it is dense inside stars and scarce in the spaces between stars. The stars in turn are concentrated in galaxies and are essentially absent in the vast volumes between the galaxies. Even the distribution of galaxies is not smooth. The galaxies are organized into clusters, and the clusters tend to form superclusters. Thus there is a hierarchy of astronomical structures, and only in an average computed over many thousands of galaxies does the distribution of matter approach uniformity.

We have recently been able to show that the clustering of galaxies has a remarkably simple and regular underlying pattern. The discovery of such patterns in nature is always exciting, since they often bring an advance in understanding. In this case the pattern not only describes the present large-scale structure of the universe but also imposes constraints on models that attempt to describe how the universe may have begun. The hierarchy of galaxy clusters observed today is what one might expect to see in a universe that has evolved from an earlier state of higher density, in other words from a "big bang."

The Local Supercluster

Our own galaxy has one large nearby companion, the Great Nebula in Andromeda. Within a radius of about two million light-years there are several dozen smaller galaxies, all of which are probably bound gravitationally to one another. These galaxies, together with our own, are collectively known as the Local Group. A similar cluster, called the M81 group after its most prominent member, happens to lie relatively nearby. The M81 group provides an excellent illustration of an informal, empirical rule: The best place to look for a galaxy is right next to another galaxy. Few galaxies are as close to us as M81 is, and yet where we find that one galaxy we find at least two more in the same neighborhood.

A much larger collection of galaxies, the Virgo cluster, is centered on a position about 50 million light-years from us. A comparatively dense cloud of galaxies extends from the Virgo cluster to roughly our own position. Hence an observer in a distant part of the universe would immediately see that our galaxy is near the edge of a concentration of many thousands of galaxies centered on the Virgo cluster. The entire system is called the Local Supercluster.

Studies of the aggregation of galaxies generally begin with the preparation of maps of all the galaxies in a region of the sky that exceed some arbitrary level of apparent brightness. This approach has one serious limitation: the galaxies are distributed throughout three-dimensional space, but in a map their arrangement is reduced to a two-dimensional plane. Two galaxies that are adjacent in such a map might actually lie at vastly different distances from us along the line of sight and therefore would not be close together at all. The distances to the galaxies can be estimated, but when positions must be calculated for thousands of galaxies, the measurements are much too time-consuming to be practical.

As it happens, we can avoid the problem of unknown distances when a great many galaxies are being mapped; in fact, the distances can be ignored precisely because the sample of galaxies is large. Angular separation in a map of the sky is not a reliable indication of the distance between any particular pair of galaxies, but it is meaningful when it is averaged over thousands of pairs.

Maps of the distribution of galaxies are based on apparent brightness, which is usually expressed in terms of magnitude. The higher the magnitude of an astronomical object is, the fainter it appears. The scale of magnitude is a logarithmic one, calibrated so that an increase of five magnitudes corresponds to a hundredfold decrease in brightness. Bright stars are of the first magnitude; the dimmest objects that can be seen with the unaided eye are of approximately the sixth magnitude. Because galaxies are distant objects most of them are extremely faint and hence of high magnitude.

Data collected by the late Fritz Zwicky and his colleagues at the California Institute of Technology can be presented in the form of galaxy maps covering most of the northern celestial hemisphere. One such map includes galaxies brighter than the 13th magnitude, which is about 600 times fainter than the dimmest objects that can be seen with the unaided eye. The map includes about 500 galaxies with an average distance of some 140 million light-years. The Virgo cluster appears as a dense knot of galaxies in this map, and the band of galaxies extending from the Virgo cluster to our own position can be perceived.

Another map based on Zwicky's data includes galaxies brighter than the 15th magnitude, about 4,000 times fainter than the limit of unaided vision. At that apparent brightness more than 5,000 galaxies can be distinguished, with a typical distance of 340 million light-years. The Local Supercluster now appears to include many more galaxies, simply because more of the intrinsically faint members of the supercluster are included. What is more, the distribution of galaxies everywhere in the sky is smoother in the deeper map. Clustering is no less pronounced at great distances; the distribution merely seems smoother because we see more clusters overlapping along the line of sight.

An even more extensive collection of galaxies has been compiled by C. Donald Shane and Carl A. Wirtanen of the Lick Observatory. Their map covers essentially the same region of the sky as the Zwicky sample, but it includes galaxies brighter than the 19th magnitude; an object of the 19th magnitude is about 160,000 times fainter than one barely visible to the unaided eye. The galaxies lie at an average distance of 1.4 billion light-years, which is about 4.4 times farther than those in the 15th-magnitude

Zwicky survey. The volume of space surveyed is $(4.4)^3$, or roughly 85, times larger. As would be expected if the average density of matter is the same throughout the universe, the Shane-Wirtanen map includes about 85 times as many galaxies as the 15th-magnitude Zwicky map—approximately a million in all. Counting them took 12 years, and it was done with such meticulous care that the Shane-Wirtanen map has become an indispensable source of information on galaxy clustering.

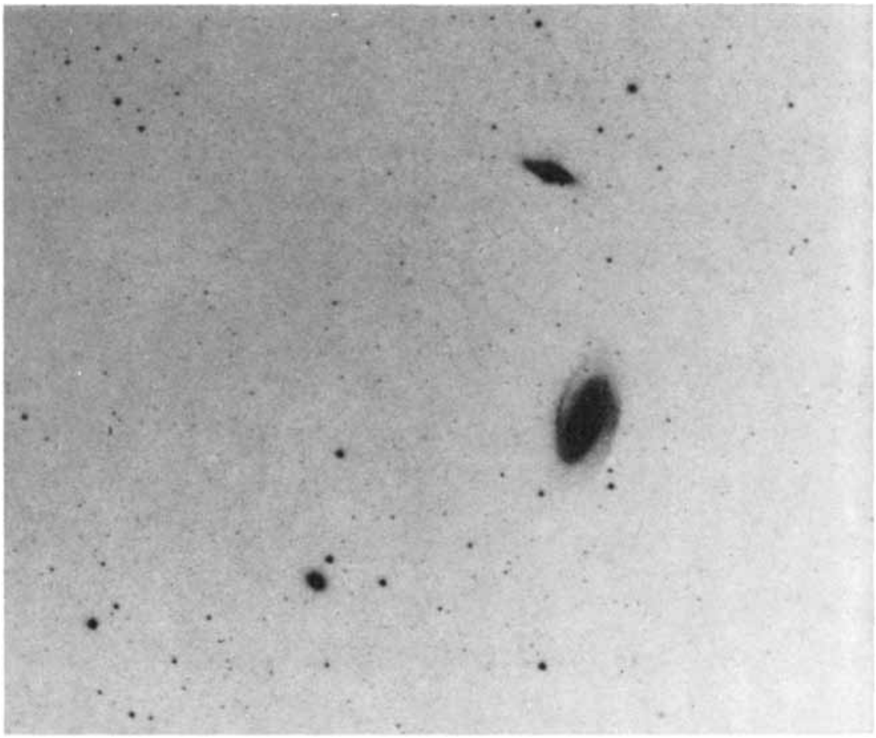
Statistical Measures

To count a million objects, even in 12 years, one cannot spend much time on each one. Shane and Wirtanen divided the sky into cells a sixth of a degree on a side and simply counted the number of galaxies brighter than the 19th magnitude in each cell. They examined about a million of these cells on photographic plates. On the average they found about one galaxy per cell, but there were significant variations; for example, 1,600 cells were found to contain 10 or more galaxies.

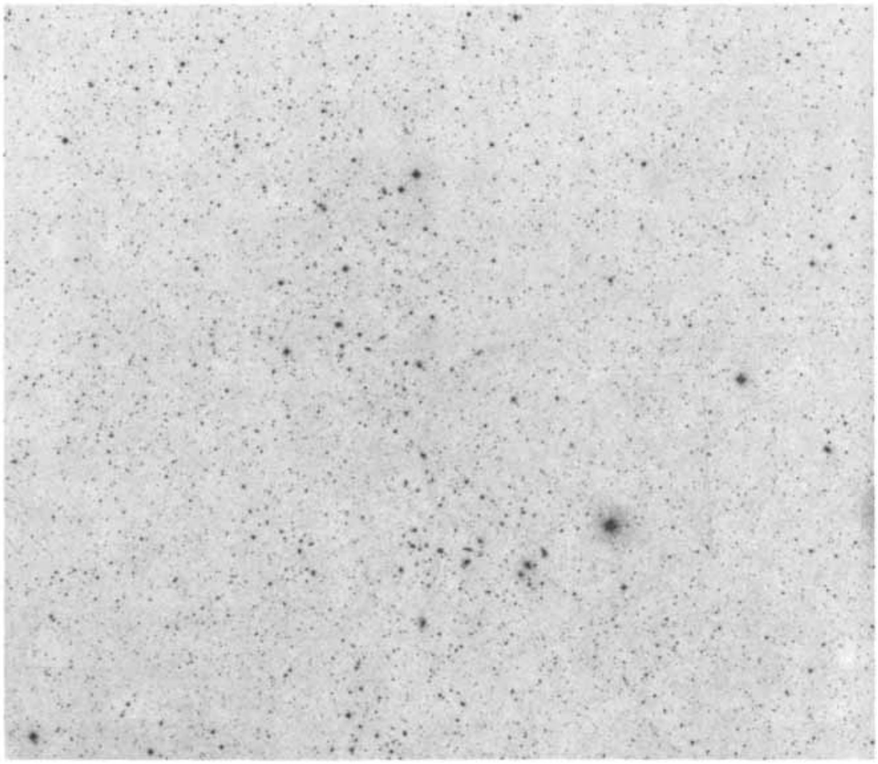
The galaxies of the Local Supercluster are included in the Shane-Wirtanen map, but there are so many other galaxies at greater distances that such nearby features are lost in the multitude. Other clusters, however, are discernible. One dense, elliptical knot of galaxies falls in the constellation Coma Berenices and is called the Coma cluster. It is about six times as distant as the Virgo cluster and has 10 times as many galaxies. A more general feature of the Shane-Wirtanen map is a curious filamentary pattern that seems to cover the entire sky. The interpretation of the filaments is somewhat uncertain.

At least one galaxy map that extends even deeper into space than the Shane-Wirtanen survey has been prepared. It is based on information compiled by Konrad Rudnicki and his colleagues at the Jagellonian University in Cracow. The map includes galaxies as faint as magnitude 20.5, with a typical distance being about twice that of the Shane-Wirtanen sample. At this distance there are so many galaxies that one could not hope to survey an entire celestial hemisphere. Rudnicki and his colleagues confined their study to a square section of sky six degrees on a side. Even within this modest area they were able to distinguish about 10,000 galaxies. In the Rudnicki map clusters are not conspicuous features. Many clumps and clouds of galaxies are superposed, so that the clustering is almost completely averaged out and the galaxies approach the smooth distribution assumed in cosmological models.

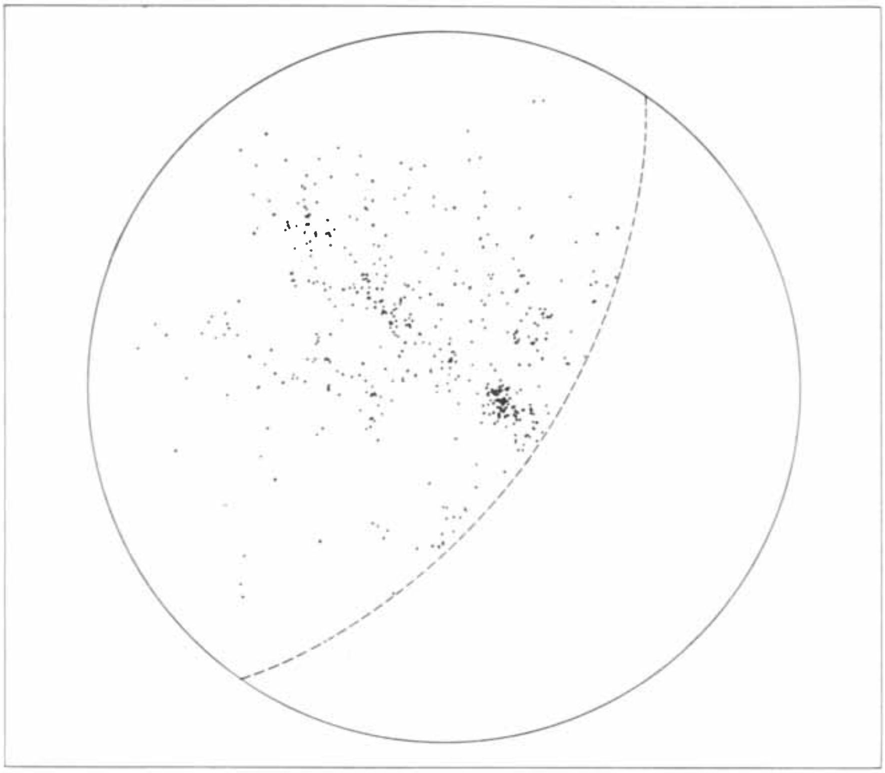
A theory of the distribution of galaxies must be guided by quantitative measurements of the distribution. Two general approaches to obtaining such



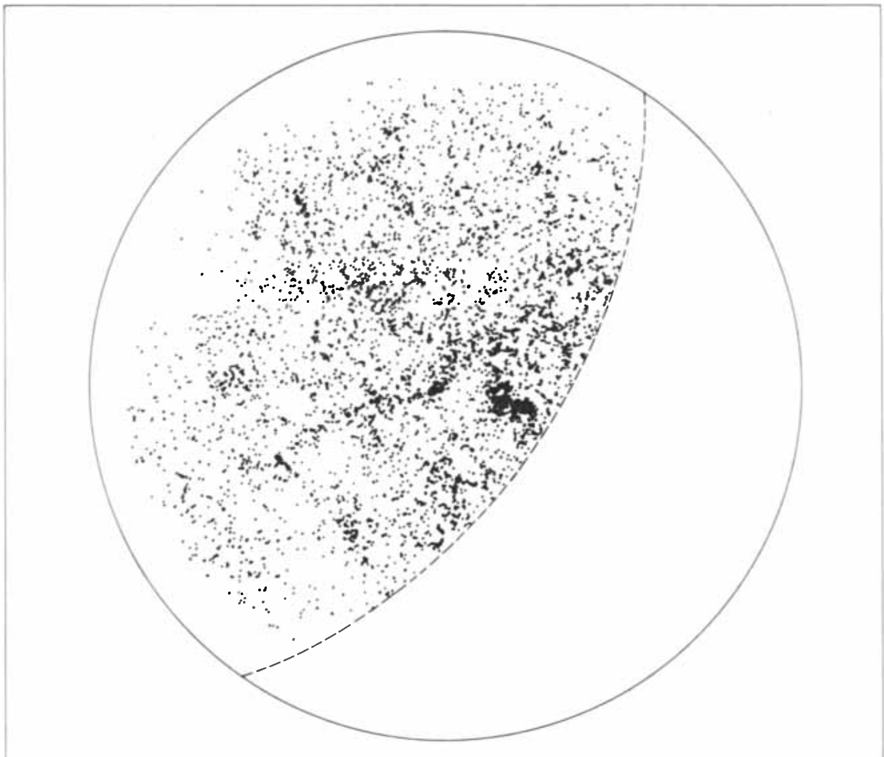
NEARBY CLUSTER of galaxies is called the M81 group after its most prominent member, which is listed as No. 81 in the catalogue of galaxies compiled by Charles-Joseph Messier. M81 is the large galaxy to the right of center. It is much like our own galaxy, and the M81 group is similar to the Local Group, the cluster that includes our galaxy. M81 is about 10 million light-years from us. This photograph and the one below were made with 48-inch Schmidt telescope on Palomar Mountain in the National Geographic Society–Palomar Observatory Sky Survey.



LARGE CLUSTER of galaxies in the constellation Hercules is about 700 million light-years from us. Some 20 or 30 galaxies can be identified in the photograph, but the cluster also includes hundreds of fainter galaxies that can be seen only in longer exposures. The images of galaxies can be distinguished from those of stars (which are in our own galaxy) by the slight fuzziness that surrounds the galaxies. In the hierarchy of astronomical structures the Hercules cluster is a much larger entity than the M81 group; at a distance of some 700 million light-years the area of sky that is shown in the photograph measures some 20 million light-years across.



DISTRIBUTION OF GALAXIES in the northern celestial hemisphere was mapped from data compiled by the late Fritz Zwicky of the California Institute of Technology. Each dot represents one galaxy; there are about 500 in all. The map includes galaxies that exceed the 13th magnitude in apparent brightness. The galaxies have an average distance of 140 million light-years. The knot of galaxies near the center is the Virgo cluster; the band extending toward the 10-o'clock position connects Virgo cluster with Local Group, forming the Local Supercluster.



LARGER SAMPLE of galaxies compiled by Zwicky includes those brighter than the 15th magnitude. There are more than 5,000 galaxies in the map, with a typical distance of 340 million light-years. Virgo cluster now appears to be much denser, but most features of the Local Supercluster are less conspicuous, since more clusters at greater radial distances overlap.

quantitative information have been employed. We might label them loosely as the botanical and the statistical methods. In the botanical approach the observed aggregations of galaxies are classified according to their distinguishing features. For example, one prominent and important species consists of very large clusters such as the Coma cluster. George O. Abell of the University of California at Los Angeles has catalogued almost 3,000 clusters of this kind, extending to a distance about equal to that of the Rudnicki sample. Abell has found that these clusters are themselves clustered, and recently it has been discovered that many of them are strong sources of X rays.

Although these observations are of great interest, they do not seem to lead to a general theory of clustering. The overall distribution of galaxies is so rich and varied that the classification of all the knots and clumps of galaxies seems to be of doubtful practicality. We have therefore adopted the alternative statistical method.

In order to formulate a statistical theory one needs a means of expressing in simple, quantitative terms the tendency of galaxies to form clusters. A reasonable assumption with which to begin is that galaxies within a cluster are closer together than the average. This tendency can be expressed quantitatively in terms of correlation functions. The two-point correlation function measures the tendency for pairs of galaxies to be closer than the average. The three-point and four-point correlation functions measure the same tendency among triplets and quadruplets of galaxies. In principle a correlation function for any number of galaxies could be determined, but we have not found it practical to go beyond the four-point function.

The calculation of the two-point correlation function begins with the counting of all the pairs of galaxies in a sample that are separated by some selected angle, such as one degree. (In practice all the pairs that fall within a small range of angular separations, such as .8 degree to 1.2 degrees, must be included.) This number is then divided by the number of such pairs that would be expected if the galaxies were distributed randomly but uniformly across the sky. If the distribution were truly uniform, with no clustering at all, the result of the division would be 1; since this condition is intended to signify no correlation between the pairs, the result is adjusted to zero by subtracting 1. The remainder is the two-point correlation function for an angular separation of one degree. It is the ratio of clustered pairs to pairs formed by accidents of superposition. In the absence of clustering the function is zero; if clusters are present, the function is greater than zero and measures the strength of the clustering.

For a complete analysis of galaxy

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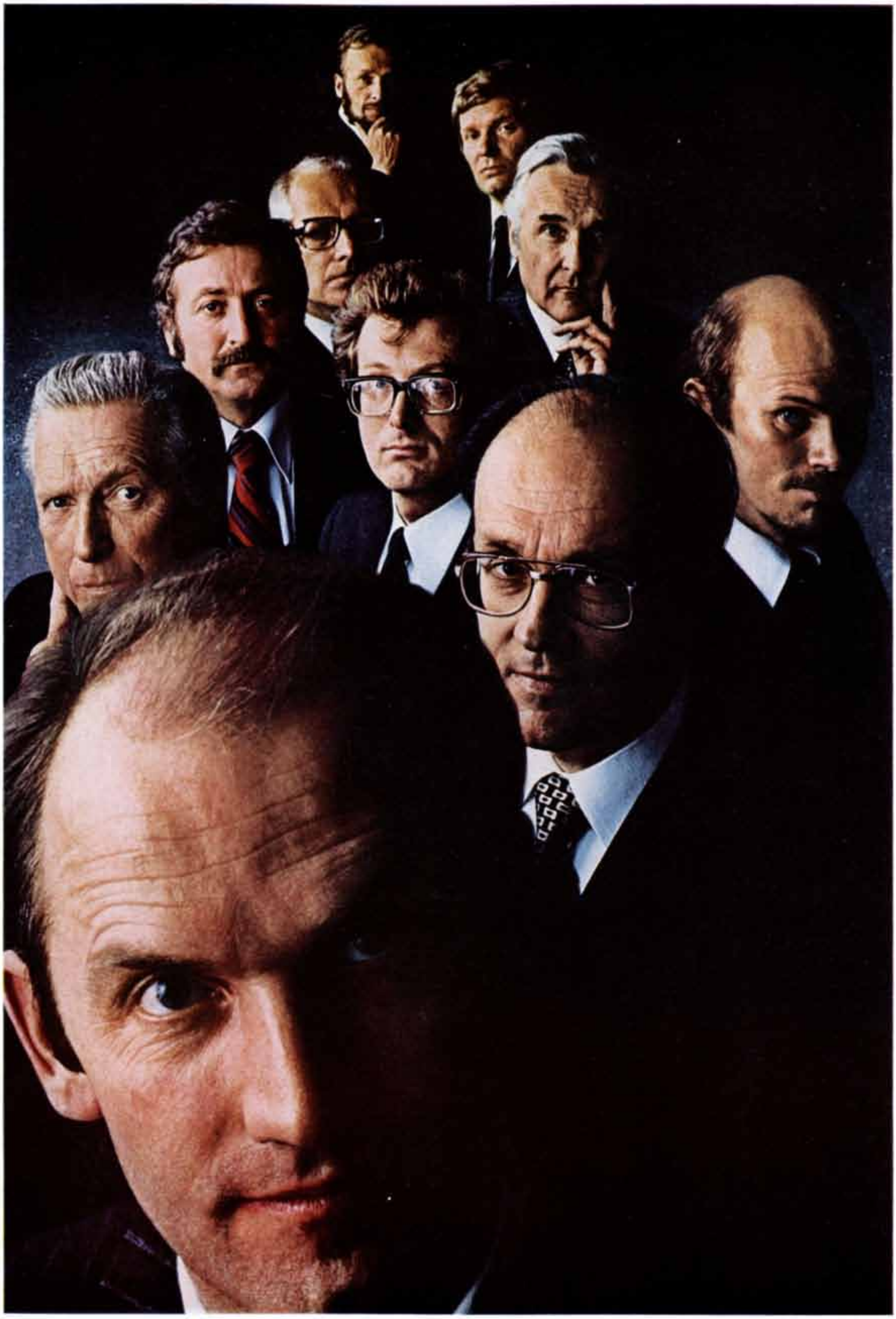
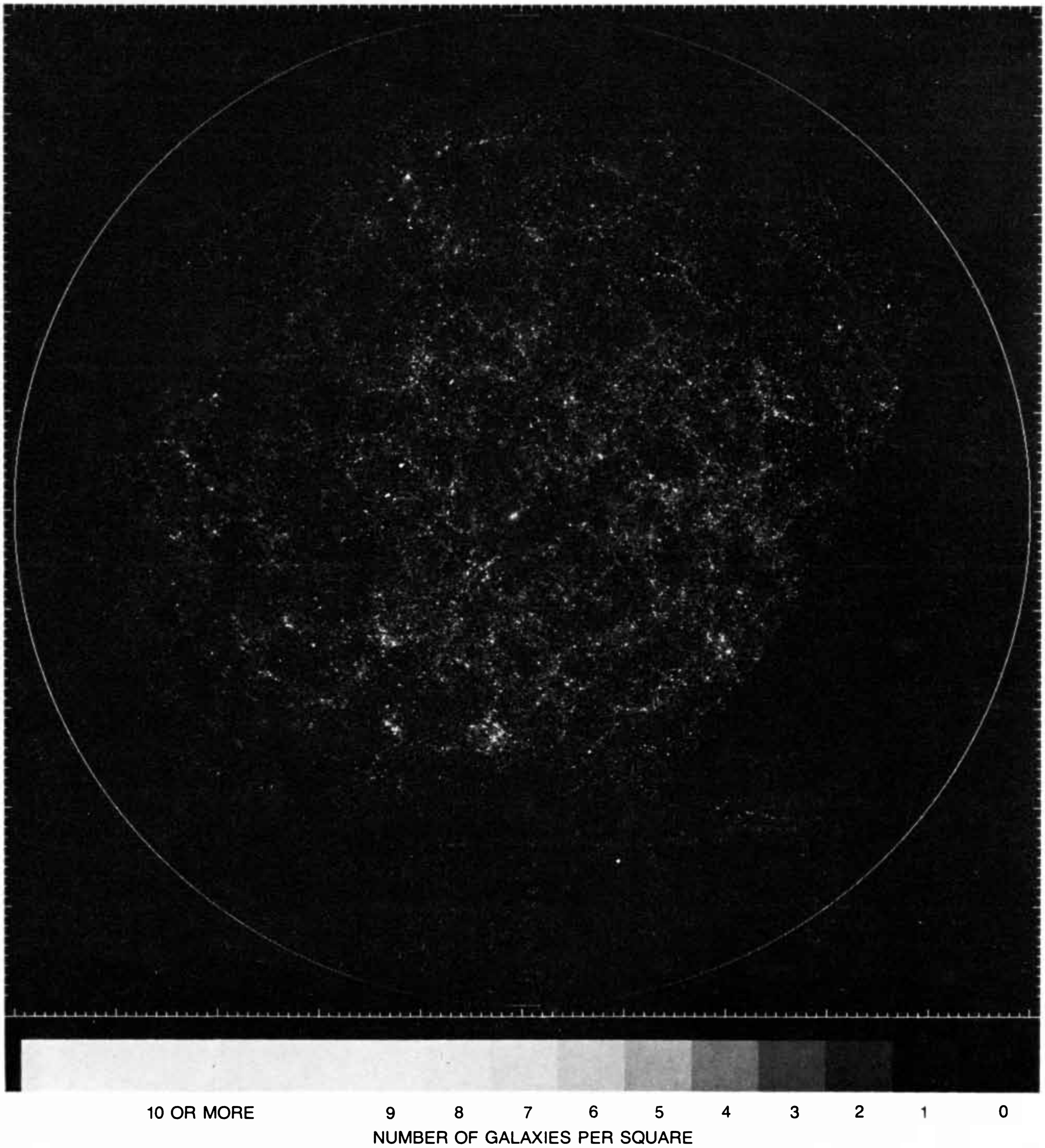


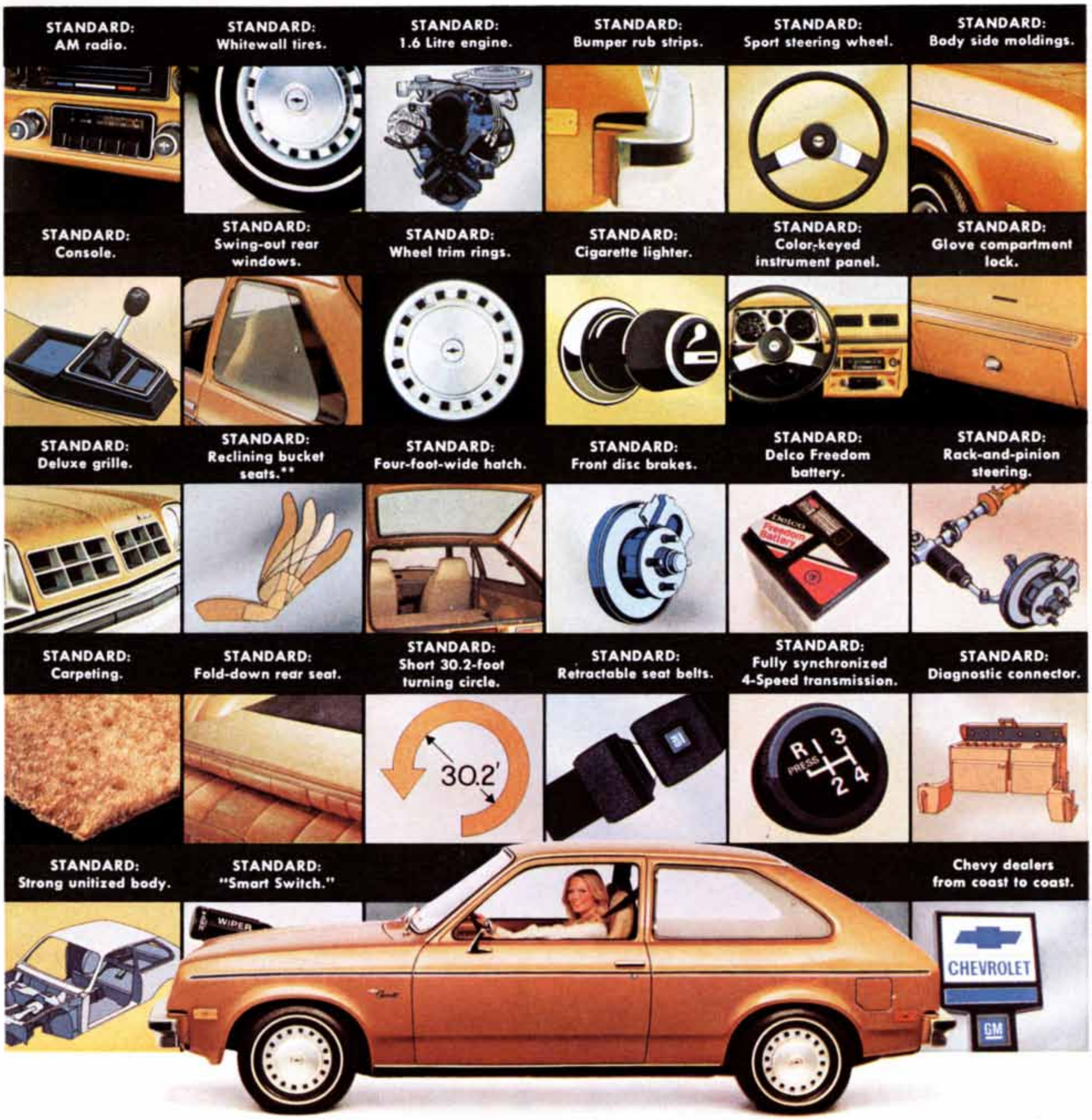
Rosamond W. Purcell

clustering the correlation function must be calculated for a broad range of pair separations. The 13th-magnitude map based on Zwicky's data includes too few galaxies for a reliable estimate of correlation, but we have calculated the two-point function at various angles for the 15th-magnitude Zwicky sample and for the Shane-Wirtanen and the Rudnicki maps. Most of our findings are based on these calculations.

One unmistakable trend is that the correlation function decreases as the angular separation being examined increases. In other words, the greater the angle between two galaxies, the smaller the probability that they are truly a clustered pair. In the Zwicky sample, galaxies separated by .05 degree exhibit a two-point correlation function of about 10. This number can be interpreted as meaning that 10 times out of 11 a pair of galaxies with this angular separation will be members of a single cluster rather than an accidental grouping of galaxies with similar angular positions but different distances along the line of



A MILLION GALAXIES brighter than the 19th magnitude are included in a map that extends to an average distance of some 1.4 billion light-years. The map is based on a survey made by C. Donald Shane and Carl A. Wirtanen of the Lick Observatory. The map does not record the positions of individual galaxies. It was constructed by dividing the sky into small squares and counting the galaxies in each square. The numbers obtained were then represented by shades of gray. Only the largest clusters are readily distinguished in the Shane-Wirtanen map because many are superposed. Nevertheless, the statistical properties of the distribution of galaxies are easily measured.


STANDARD: AM radio.
STANDARD: Whitewall tires.
STANDARD: 1.6 Litre engine.
STANDARD: Bumper rub strips.
STANDARD: Sport steering wheel.
STANDARD: Body side moldings.
STANDARD: Console.
STANDARD: Swing-out rear windows.
STANDARD: Wheel trim rings.
STANDARD: Cigarette lighter.
STANDARD: Color-keyed instrument panel.
STANDARD: Glove compartment lock.
STANDARD: Deluxe grille.
STANDARD: Reclining bucket seats.**
STANDARD: Four-foot-wide hatch.
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STANDARD: Rack-and-pinion steering.
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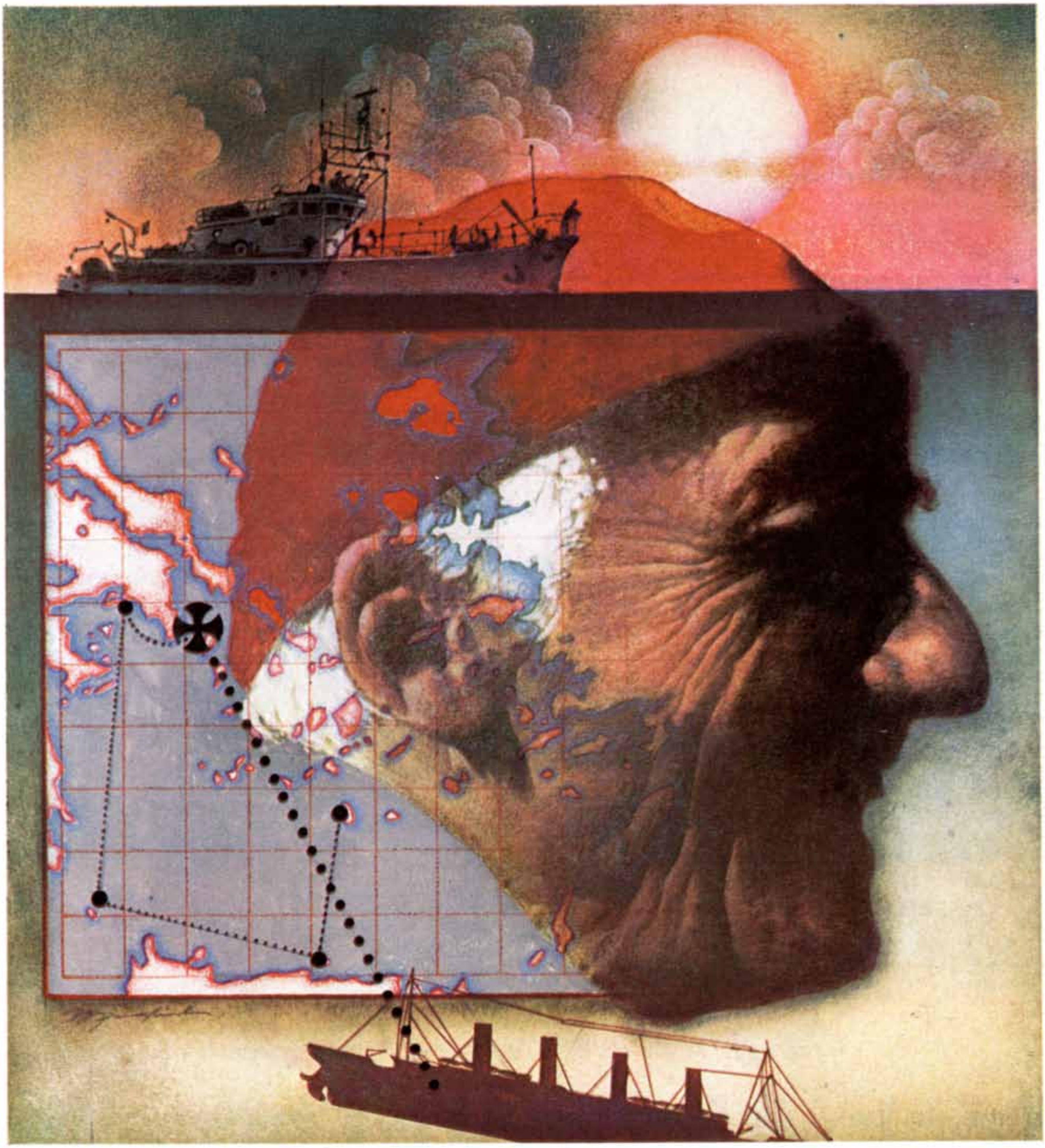

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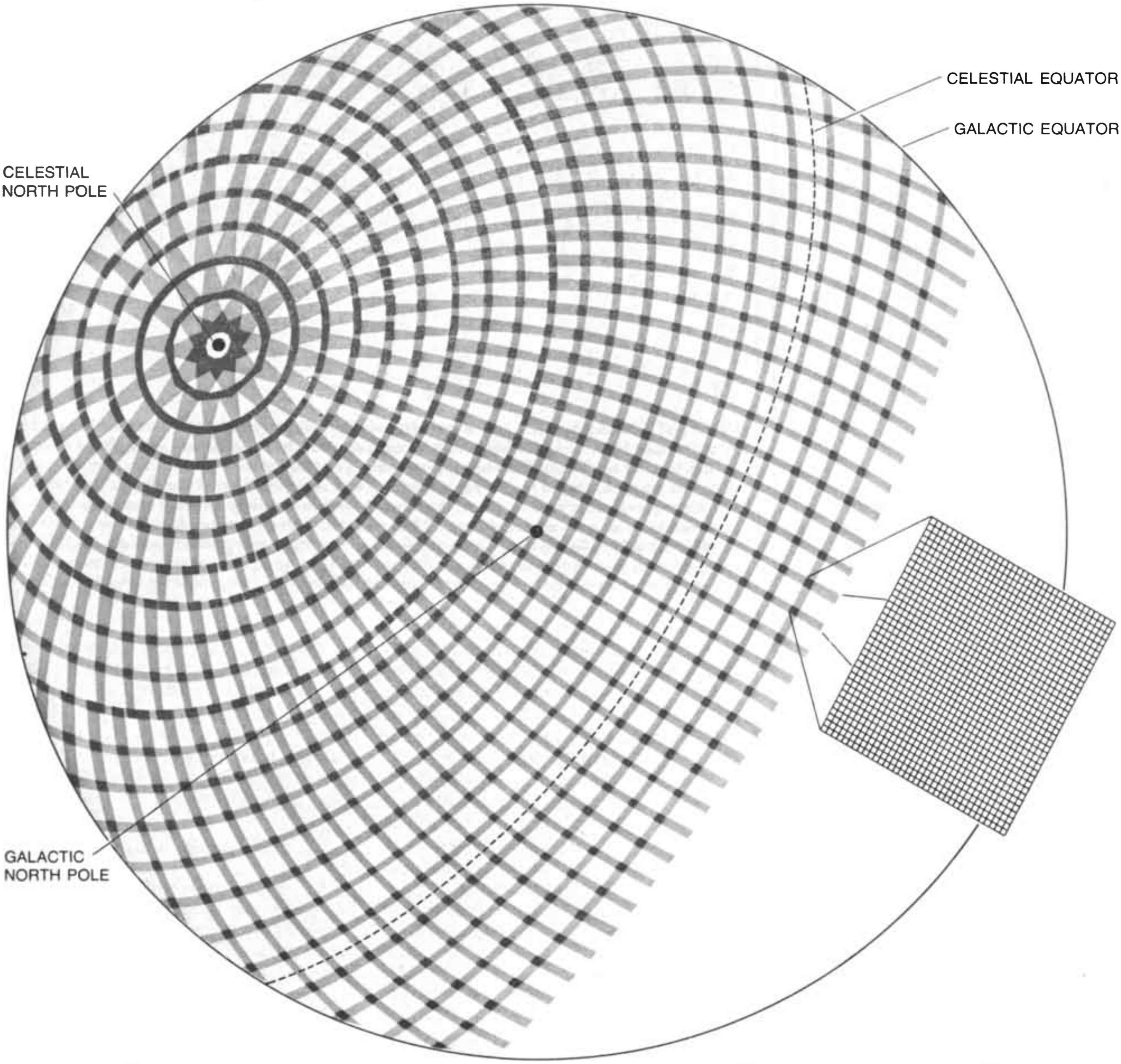
sight. As the angular separation in the Zwicky sample increases to 10 degrees the correlation function drops to about .1, meaning that in only one case out of 11 does a pair with this separation belong to a cluster.

A second trend apparent in the data is that the strength of the clustering seems to decline as the depth of the sample increases. This result could be expected, since the inclusion of more distant galaxies necessarily increases the overlapping of clusters at different distances. In fact, since we know the average distance of the galaxies in each sample, we can calculate the expected effects of increasing depth. Since a typical pair of galaxies in the Shane-Wirtanen sample is 4.4 times as far away as an equivalent pair in the 15th-magnitude Zwicky map, pairs in the Shane-Wirtanen map having an angular separation of one degree should properly be compared with those in the Zwicky map having a separation of 4.4 degrees. Similarly, galaxies that are one degree apart in the Rudnicki map are comparable with those that are 8.1 degrees apart in the Zwicky map. By applying these factors to the deeper samples we can compare the correlation functions of galaxies with the same linear separation.

The extent to which independent clusters overlap along the line of sight is also proportional to the depth of a sample. A measured correlation function of 1 in the Shane-Wirtanen sample is equivalent to one of 4.4 in the Zwicky map; a correlation function of 1 in the Rudnicki sample corresponds to a value of 8.1 in the Zwicky map. Thus a measurement made with the Shane-Wirtanen sample



PROJECTION OF THE SKY employed in the Shane-Wirtanen map transforms the coordinates of galaxies from a frame of reference based on the orientation of the earth to another frame of reference based on the orientation of our galaxy. The map is derived from a photographic survey in which the sky visible from the Lick Observatory was divided into overlapping sections six degrees on a side, each section corresponding to one photographic plate. This array of plates is centered on the celestial north pole and extends to 20 degrees south latitude. Because the earth's axis is inclined by about 60 degrees with respect to the axis of our galaxy, all the points in the map must be shifted by that amount in order to create a map based on galactic coordinates. The resulting projection has the galactic north pole at the center and the galactic equator at the circumference. Since the perimeter of the map corresponds to the plane of the Milky Way, few galaxies can be seen there. In conducting their survey Shane and Wirtanen divided each six-degree photographic plate into squares a sixth of a degree on a side, then counted the galaxies in each of these smaller squares. The map itself was constructed with the aid of a computer.

DEEPEST GALAXY MAP, which includes galaxies brighter than magnitude 20.5, is based on data obtained by Konrad Rudnicki and his colleagues at the Jagellonian University in Cracow. At this level of brightness there are far too many galaxies for their distribution over the entire sky to be mapped, and so the survey is confined to a square section of the sky six degrees on a side and equivalent in area to one of the large squares in the diagram on preceding page. Even in this small area there are more than 10,000 galaxies, with an average distance from the earth of some 2.8 billion light-years. Clustering is not a conspicuous feature of the map; on the contrary, the distribution appears to be almost random. The reason is not that more distant galaxies are less likely to form clusters but merely that more clusters are seen along the same line of sight.

should be equivalent to one made with the Zwicky sample if both the measured angles and the calculated correlation functions are multiplied by a factor of 4.4. A similar adjustment, employing a factor of 8.1, should bring the Rudnicki sample into agreement with the others. (An additional small adjustment is needed. We see the galaxies in the deeper samples not only at greater distances but also at progressively earlier times. Since the universe is expanding, the factors 4.4 and 8.1 must be slightly modified in order to compensate for the movement of the galaxies.)

When these adjustments are made, the correlation functions for the Shane-Wirtanen and the Zwicky samples are in almost exact coincidence. The function for the Rudnicki sample has a similar set of values but seems to be slightly low. This small discrepancy is not disturbing; the Rudnicki survey is the most uncertain because the distances are so great that the clustering is almost completely obscured by the accidental pairing of overlapping galaxies. The approximate agreement of the correlation functions for the three maps is an important and reassuring result; it indicates that the functions are not seriously disturbed by possible errors in the surveys. Moreover, it provides quantitative evidence that the clustering of very distant galaxies is statistically identical with the clustering of nearby ones.

A Hierarchy of Clusters

For small angular separations the two-point correlation function has a simple dependence on the angle. If both the correlation function and the angles are plotted on logarithmic scales, the correlation function decreases along a straight line as angular separation increases. The fact that the line is straight indicates that each time the distance between galaxies is doubled the correlation function declines by a fixed factor. The slope of the line indicates that the factor is .59.

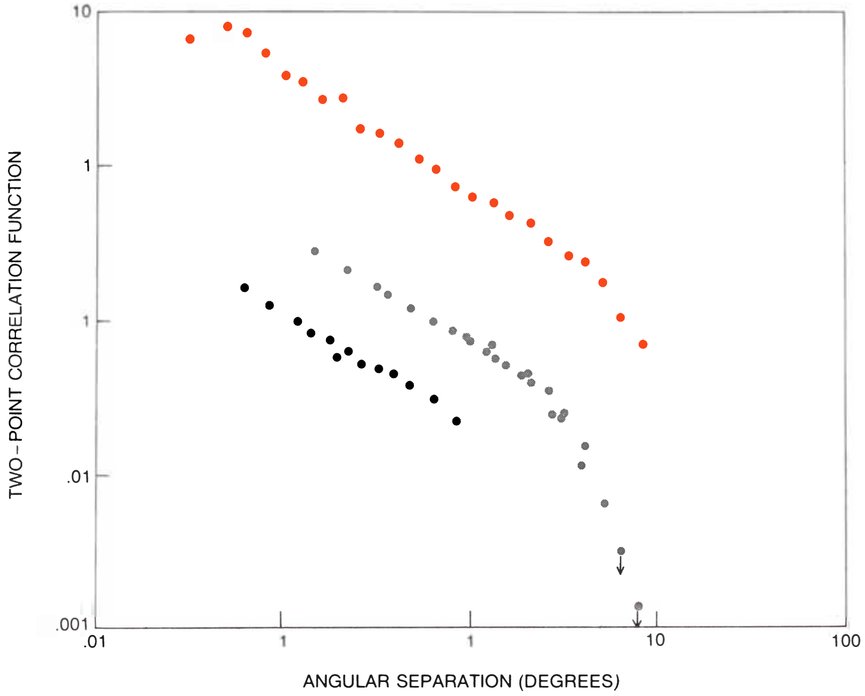
At a separation of about 10 degrees for the 15th-magnitude Zwicky map, and at correspondingly smaller angles for the other samples, the straight-line dependence of the correlation function on separation abruptly changes. At these larger angles the correlation function drops more steeply as the angle increases. The point at which the slope changes corresponds to a linear distance between galaxies of about 60 million light-years. Thus as the distance between galaxies increases, the probability that they are members of a single cluster declines smoothly and regularly up to a separation of about 60 million light-years; beyond that distance the tendency of galaxies to form clusters declines more rapidly.

This regularity in the correlation function was our first indication that the clustering of galaxies might follow some simple pattern. On the other hand, the two-point correlation function alone does not specify what the pattern might be. That is not surprising, since the two-point correlation function condenses all the information in the galaxy maps into a single graph.

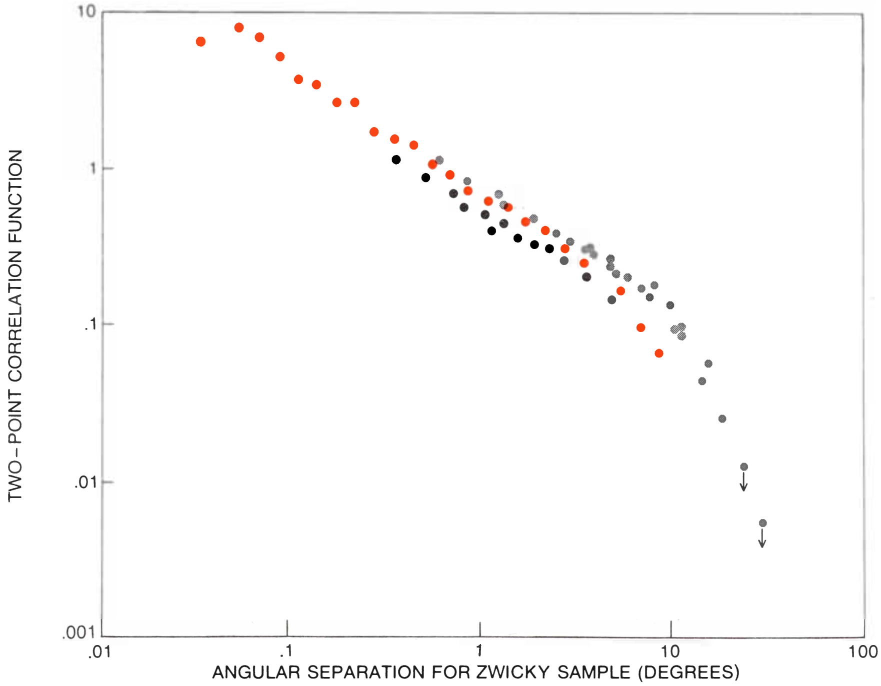
The range of possible interpretations can be narrowed by considering the three-point and four-point correlation functions. These functions are calculated by counting the triplets and quadruplets of galaxies at each of several angular separations, then comparing the result with the number of triplets and quadruplets that would be expected in a uniform distribution. We have found that the three-point function also behaves in a simple way: it is directly proportional to the square of the two-point function, and the constant of proportionality is the same for all three of the surveys. James Fry, one of our colleagues at Princeton University, has found that for the Shane-Wirtanen sample the four-point function is proportional to the cube of the two-point function. (The Zwicky and Rudnicki samples are too small for a reliable estimate of the four-point function.) The physical meaning of these findings can be simply stated: If a good place to look for a galaxy is right next to another galaxy, then a better place to look is near a pair of galaxies and a still better place is near a triplet of galaxies.

With this information in hand we can specify the clustering pattern with reasonable confidence. Galaxies are arranged in a hierarchy of clusters. The galaxies tend to be found in small, dense knots; the knots form clusters, the clusters form larger clusters and so on, until the size of the cluster reaches the scale at which the correlation function begins to decline steeply—about 60 million light-years. Beyond that range clustering is on the average comparatively weak.

Although quantitative evidence supporting this conclusion has been gathered only recently, it is certainly not the first time a hierarchy of structures has been proposed in astronomy. Hierarchical clustering was suggested as long ago as 1761 by the mathematician J. H.



EXTENT OF CLUSTERING can be expressed in terms of correlation functions, which measure the probability that a pair or a group of galaxies are members of a single cluster. Here the two-point correlation function is graphed for the 15th-magnitude Zwicky sample (*colored dots*), the Shane-Wirtanen sample (*gray dots*) and the Rudnicki sample (*black dots*). The two-point correlation function can be interpreted as the ratio of clustered pairs, which are truly close to each other in space, to accidental pairs, which appear to be close together but are actually at different distances along the line of sight. Thus for the Zwicky sample 10 out of 11 pairs separated by .05 degree are clustered, but at 10 degrees only one out of 11 is a clustered pair.



ADJUSTED CORRELATION FUNCTIONS reflect the different average distances at which galaxies are seen in the three samples. Galaxies separated by one degree in all three maps are much farther apart (in linear measure) in the Shane-Wirtanen sample than they are in the Zwicky sample, and they are still more distant in the Rudnicki sample. The number of clusters overlapping along the line of sight is also greater in the deeper samples. After adjustments for these two effects the measured correlation functions for the three samples are in good agreement with one another. As the separation between galaxies increases, the correlation function decreases, and for small angles it follows a straight line. From the slope of the line one finds that each time the angular separation is doubled the correlation function is reduced by a fixed factor of .59. Beyond about 10 degrees the correlation function declines more steeply, suggesting that at distances greater than about 60 million light-years clustering is comparatively weak.

Lambert. The idea was taken up again by the science writer E. E. Fournier d'Albe in 1907 and again in 1922 by the astronomer C. V. L. Charlier.

The discovery of the true nature of the galaxies in the 1920's led to theories more like our own. An example is Abell's observation that large clusters such as the Coma cluster tend to form clusters. In recent years the strongest advocate of a hierarchical organization has been Gérard de Vaucouleurs of the University of Texas at Austin. Now our statistical methods have led to a similar conclusion. There is an important distinction, however, between the clustering hierarchy that our measurements imply and the one proposed by some earlier workers. The clustering hierarchy revealed by the correlation functions does not continue indefinitely. Rather, it begins to fade out when the size of the clusters reaches about 60 million light-years.

A Model Universe

If we have correctly interpreted the pattern of galaxy clustering, we should be able to construct a model universe that looks the same as the real one. We have constructed such a model by a method that automatically reproduces the observed two-point correlation function. At a randomly chosen point in space we place an imaginary bar and assign it a random orientation. At each end of the bar we attach smaller bars that also have random orientations; the second-level bars are shorter than the first bar by a fixed factor, which we have calculated should be equal to .57. At the ends of the second-level bars we attach still smaller third-level bars, which again are randomly oriented and are shorter than the second-level bars by the factor .57. This procedure is continued until the length of the bars is comparable with the size of galaxies; then an imaginary galaxy is placed at the ends of each of the smallest bars. Of course, we do not actually assemble these tinkertoy galaxy clusters; instead we employ a computer to calculate the positions of the galaxies. We place the ball-and-stick galaxy clusters at random positions throughout the model universe and then instruct the computer to project the galaxies onto the sky of an imaginary observer. The computer takes into account variations in distance and intrinsic brightness, and so many of the galaxies are too faint to be seen by the observer.

This procedure is certain to reproduce the observed straight-line decrease in the two-point correlation function because the length of the bars determines the number of clustered pairs that can form at any given pair separation. Why this is so can be understood by considering the hierarchy in reverse order, from the smallest bars to the largest ones. At each higher level the length of the bars

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New
Vivitar Series 1® 90mm f2.5 macro lens

The Vivitar Series 1 90mm f2.5 macro lens may well be the sharpest lens in 35mm photography. The lens utilizes the floating group concept to maintain optimum performance throughout its focusing range. Tests for resolution and contrast from infinity to life-size (1:1 reproduction) give the Series 1 90mm f2.5 lens some of the highest overall axial to corner ratings obtained for macro lenses.

A 90mm macro lens yielding good performance could have been produced using a normal double Gauss design. To achieve and maintain very high levels of performance from infinity to life-size, however, Vivitar Series 1 designers used a unique 8 element/7 group configuration to bring aberrations to an absolute minimum and to stabilize them throughout focusing distances from a reproduction ratio of 1:2 to infinity. The extremely stringent performance demands to eliminate aberrations in the lens also required the use of optical glass of a very high index of refraction and some uncommonly thick elements.

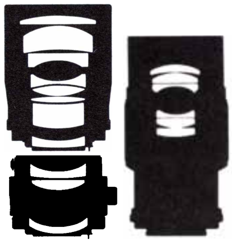
Using the concept of a null lens, borrowed from astronomical optics, the designers created a 3 element macro corrector-lens adapter that achieves a true flat-field image, high resolution and excellent contrast in the 1:2 to 1:1 reproduction range. The macro corrector-lens adapter is not a magnifying lens. Its sole function is to compensate aberrations produced when the lens is moved away from the film plane for life-size photography.

The selection of 90mm as the focal length of this lens provides two distinct benefits to photographers. It is an ideal focal length for portraiture and general purpose photography. When used with its macro adapter the lens allows life-size photography at a greater working distance from the subject than shorter focal length macro lenses. This greater working distance increases the photographer's options in illuminating macro subjects and lessens chances of disturbing live subjects.

As with all Vivitar Series 1 lenses, the mechanical configuration has been as carefully engineered and manufactured as the optics. The lens engravings give the photographer maximum information and legibility. The lens barrel styling is entirely functional, all controls being placed in the most appropriate positions for precise, comfortable operation.

Optical Specifications

Elements/Groups:	
Main lens	8 elements, 7 groups.
Macro Adapter	3 elements, 3 groups.
Lens coating:	VMC Vivitar multicoating.
Angle of acceptance:	27°
Aperture range:	f2.5 to f22
Minimum focus distance from film plane:	39.3cm (15.5 in.) without Adapter, 35.5cm (14 in.) with Adapter.
Maximum reproduction ratio:	1:2 without Adapter, 1:1 with Adapter.



Vivitar Series 1 design *conventional design*

Mechanical Specifications

Length at infinity	90mm (3.5 in.) without Adapter 138mm (5.4 in.) with Adapter.
Maximum barrel diameter:	70mm (2.8 in.)
Weight	
Main lens	644 gms. (23 oz.)
with Adapter:	936 gms. (33 oz.)
Filter size	58mm
Lens case	Semi-hard, 2 compartment case

Available in mounts to fit Nikon, Canon, Minolta, Olympus OM, Pentax K, M, Vivitar and other universal thread mount cameras.

Vivitar®

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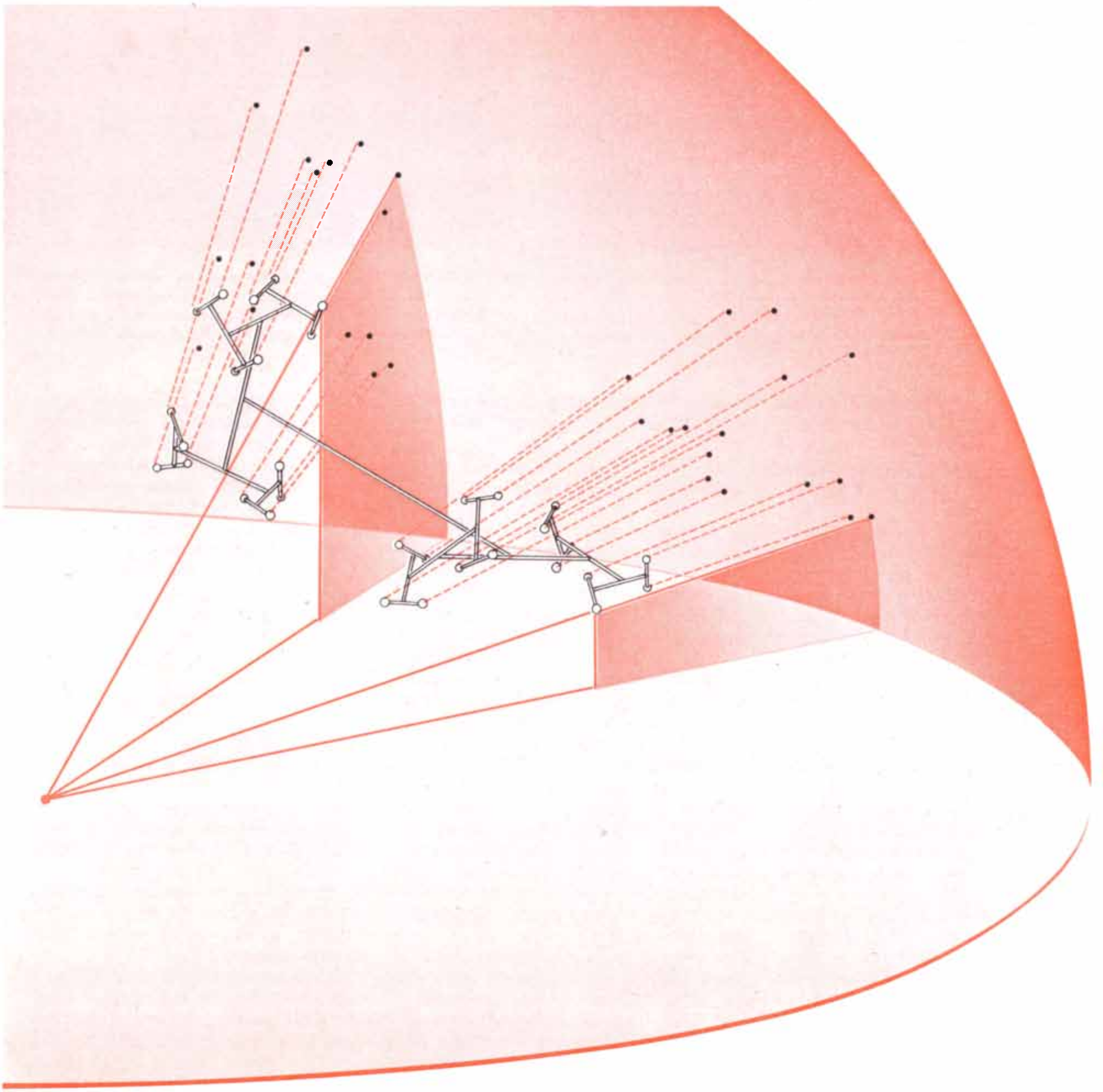
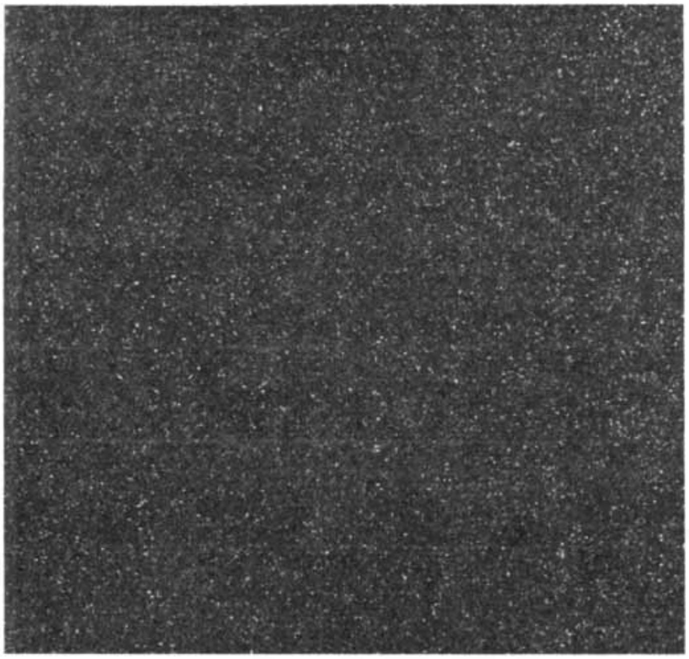
increases by the inverse of .57, or by 1.75. At the same time the number of clustered pairs doubles, since each higher level connects twice as many galaxies by rigid bars. The number of accidental pairs, on the other hand, is proportional to the area of sky surveyed; thus at each higher level the number of accidental pairs increases by $(1.75)^2$, or 3.06. Since the correlation function is simply the ratio of clustered pairs to accidental ones, the correlation function decreases by the factor 2/3.06, or .65, each time the pair separation increases by the factor 1.75. This rate is equivalent to a decrease of .59 for each doubling of the pair separation, which was the behavior observed in the real universe.

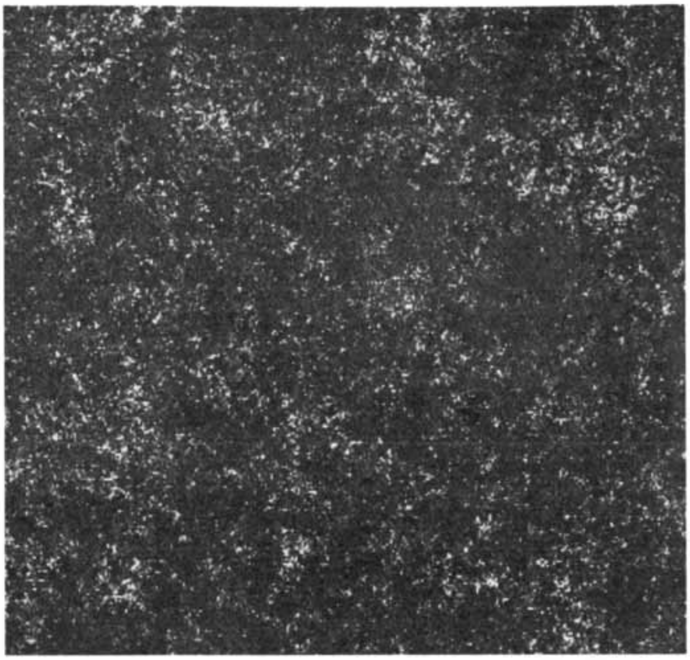
The model universe also reproduces the observed three-point and four-point correlation functions, at least in an approximate way, since a galaxy that is a member of n clustered pairs contributes to $n^2/2$ clustered triplets and $n^3/6$ clustered quadruplets. (The approximation is valid if n is large.) Hence the three-point and four-point correlation functions are proportional to the square and the cube of the two-point function, as they are in the real universe.

In our first attempt to construct a model universe we filled the imaginary space with thousands of statistically identical cluster balls. Each one began with a largest bar of the same length and each had a total of nine levels, with 512



MODEL UNIVERSE was designed to reproduce the correlation functions measured in maps of galaxy distribution. The model is constructed by placing a large, imaginary bar at a random position and in a random orientation in space. Smaller bars are attached to the ends of this bar and again are randomly oriented, then still smaller bars are attached to the ends of these. At each level the bars are shorter by a fixed factor calculated to reproduce the observed two-point correlation function. When the desired number of levels has been completed, imaginary galaxies are attached to the ends of the smallest bars. The result is a collection of galaxies distributed in a known clustering hierarchy. The model is built with the aid of a computer, which as a final step projects the positions of the galaxies onto the sky of an imaginary observer. Their distribution can then be mapped. Only one cluster ball is shown here; a realistic model requires several thousand balls.





VISUAL EVALUATION of various models of universe is accomplished by comparing the galaxy distribution they predict with the real distribution, as represented by a segment of Shane-Wirtanen map (*far right*). A completely random and uniform distribution of galaxies, with no clustering at all, yields a pattern (*far left*) that is distinctly different from the real one; difference in appearance can be expressed quantitatively in terms of a correlation function, which for a random pattern is by definition zero. Model made up of cluster balls, all of

galaxies at the ends of the smallest bars. The distribution of galaxies when they were projected on the sky was then plotted in the same graphic format we had employed for the Shane-Wirtanen sample. The resulting map is easily distinguished from a random galaxy distribution and has some interesting features, but judged simply by appearance it is disappointing. The main flaw in this model is that it has too few bright regions, or in other words too few dense clumps of galaxies. The difference can be detected in the higher-order correlation functions, since dense clumps contribute more to the count of triplets and quadruplets than to the count of pairs. Although the three-point and four-point correlation functions for the model universe are proportional to the square and to the cube of the two-point function, the constants of proportionality are incorrect: they are too small by factors of three and 19.

In a second model universe we created more dense regions by including cluster balls with a varying number of levels and hence with a varying number of galaxies. After some experimentation we settled on a model with 24,000 seven-level balls, 8,000 eight-level balls and diminishing numbers of higher-level balls, down to 40 12-level balls. Each ball begins with a largest bar of the same size, but some clusters terminate before others. To within the accuracy with which we can measure them the two-point, three-point and four-point correlation functions of this model are identical with those of the Shane-Wirtanen sample. What is more, the appearance of the distribution is similar to that of the Shane-Wirtanen map. Even some wispy filaments like those that are so conspicuous in the sky maps can be seen. Many of our colleagues believe these filaments are real lines or sheets of galaxies in space. It is not yet clear how common such structures might be, but the model illustrates the risk of hasty judgment in these matters. The filaments in the model are not built in but result from accidents in the random arrangement of the galaxies, accentuated by the sensitivity of human vision to linear features. Some of the filaments in the real distribution of galaxies may be similar artifacts.

A hierarchical organization is incorporated in our model by design, but some other aspects of the clustering are ignored. For example, in a great concentration of galaxies such as the Coma cluster gravitational interactions can be so strong that small groups of galaxies are disrupted, leaving a smooth distribution without distinct subclusters. Only a small fraction of all galaxies are members of such great clusters, however.

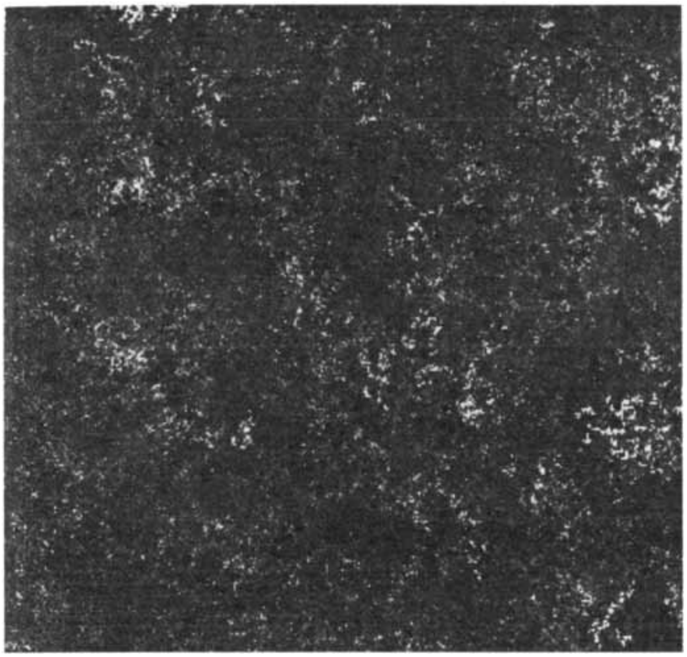
A somewhat subtler flaw of our model is that the clustering terminates abruptly at pair separations somewhat greater than the length of the longest bar, whereas in the real universe comparatively weak clustering of galaxies persists at larger scales. Even with these defects the model reproduces much of the visual texture of the galaxy distribution. The agreement between model and observation suggests that a hierarchical organization of clusters must be a reasonable approximation of the large-scale structure of the universe.

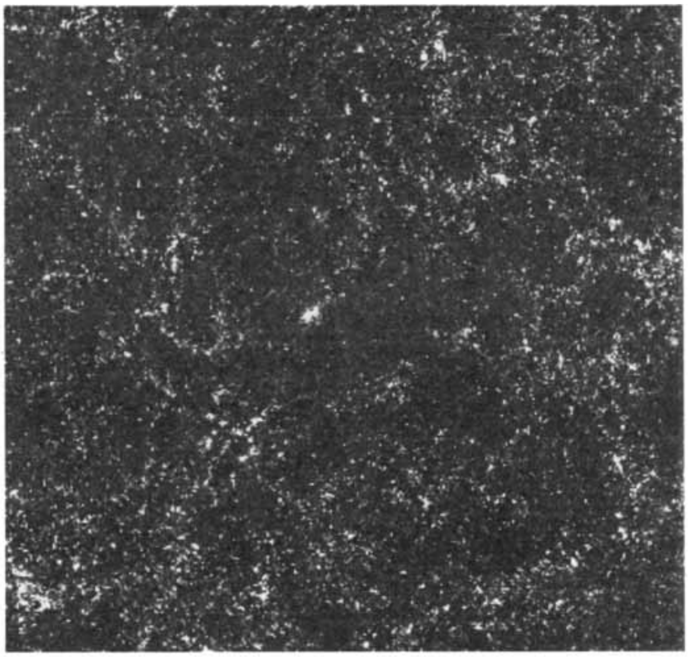
The demonstration that a hierarchy of galaxy clusters exists today immediately raises the question of how the hierarchy developed. We can describe a possible pattern of evolution that seems plausible in the light of our present knowledge. It must be emphasized, however, that these ideas are speculative.

The Evolution of Clusters

The basis of the big-bang theory of cosmic evolution is the observation that all distant galaxies are receding from us with velocities proportional to their distance from us. In the standard big-bang theory this general expansion of the universe can be traced back to an enormously dense state of matter that began expanding some 15 billion years ago. The theory requires that the original distribution of matter be almost exactly uniform; in the early universe there were no clusters.

An important variable in this theory is the average mass of a galaxy, in other words the average density of the universe. If the galaxies are quite massive, then their mutual gravitational attraction must eventually halt the expansion and the universe will begin a general contraction. If the galaxies are lighter than some critical mass, then the present expansion of the universe must continue indefinitely. As we shall see, the galaxy masses also have a significant influence on the development of galaxy clusters.





which have the same number of levels (*second from left*), gives a much better approximation, but it still differs from the real distribution in certain statistical properties. There are also differences apparent to the eye; in particular, there are too few bright regions in the model. This deficiency is corrected in a model that includes cluster balls of various sizes (*third from left*). The map that has been generated by this model resembles the Shane-Wirtanen map in its general appearance, and the correlation functions for the two maps are in agreement.

We have employed a computer model in studying the development of clustering. The model includes representations of 2,000 galaxies, which initially are packed at high density into a spherical volume of space. The galaxies are distributed randomly but uniformly and are assigned velocities that cause the entire sample to expand. With the aid of the computer we can trace the subsequent motions of the galaxies under their mutual gravitational attraction. An important property of the real universe is that all observed space is filled with galaxies, but we cannot reproduce this property in the model; our sample of galaxies exists in isolation. Ignoring the galaxies outside our selected sphere represents an approximation, but it is an acceptable one for small clusters.

As the model universe expands and the galaxies recede from one another, gravity slows the expansion. Small, random differences in the density of galaxies are magnified: where the density is slightly higher than average the gravitational field is slightly stronger, and so the density declines more slowly. As a result small irregularities in the original distribution grow into clusters. When the clusters first form, their distribution is more or less random, reflecting the random initial distribution. The clusters themselves, however, represent regions of higher than average density, and hence gravitation tends to gather them into somewhat larger clusters. As the process repeats at even larger scales the expanding universe develops a natural hierarchy of clusters.

The development of a clustering hierarchy in a model of cosmic evolution is an encouraging result, but it is only a qualitative one. The model would be far more satisfying if it could make quantitative predictions. Our computer model cannot make such predictions chiefly because it is too small. By treating the sample of 2,000 galaxies as if it were isolated we ignore most of the universe. Bigger models would be more accurate, but for now they are not practical. Each of the 2,000 galaxies in our model moves under the influence of gravitational forces from 1,999 other galaxies; hence for each moment at which the positions of the galaxies are calculated we must evaluate 2,000 × 1,999, or almost four million, interactions. If we were to increase the number of galaxies by a factor of 10, the number of interactions would increase by a factor of 100, which would tax the fastest computer.

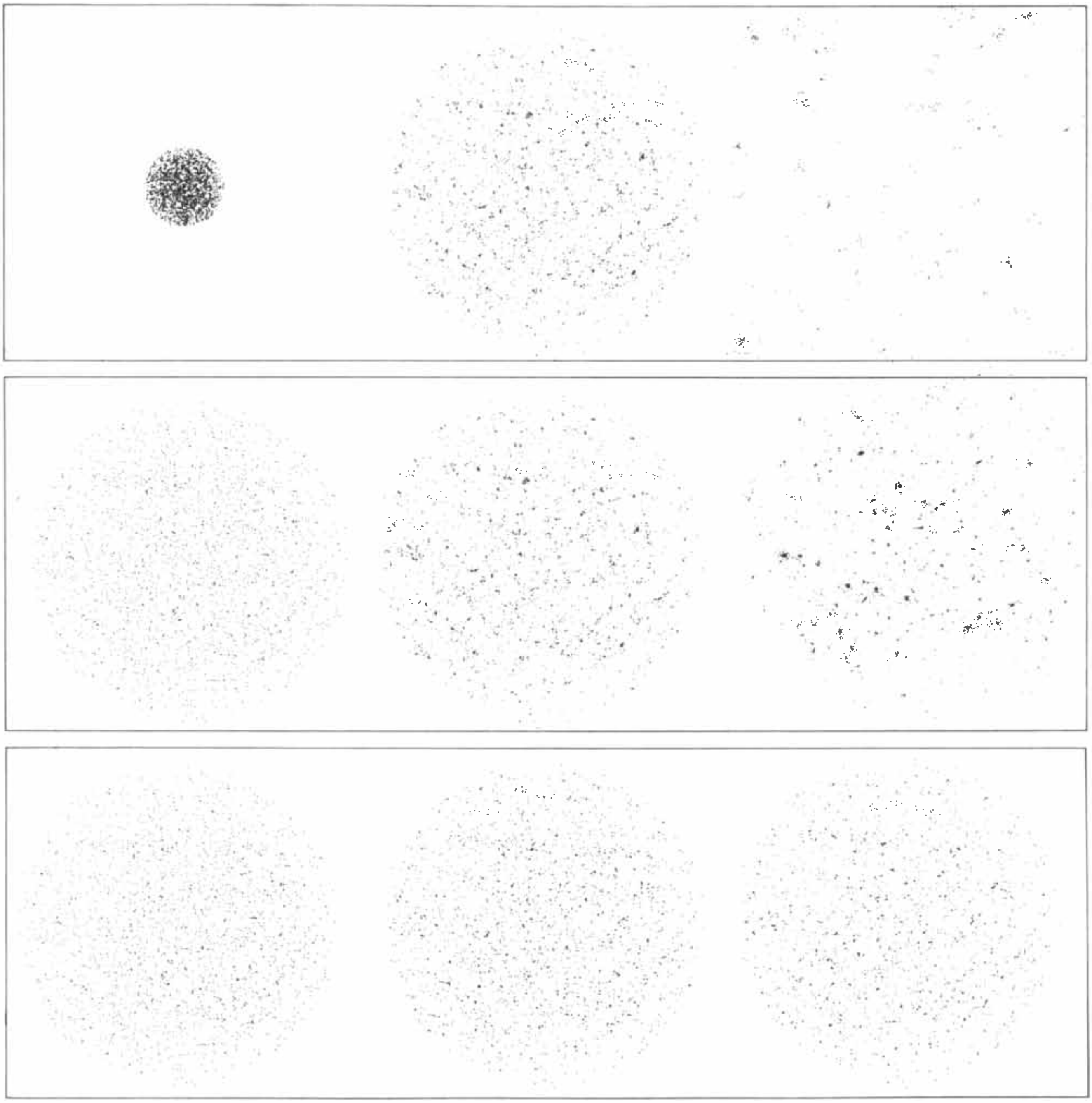
A Gas of Galaxies

Because a straightforward simulation of cosmic evolution seems to be beyond our means we have adopted another approach to the problem, in which the galaxies in an expanding universe are regarded as the particles of a gas. This too represents an approximation, but it may be a more successful one. A theory that describes the clumping of particles in gases has been developed in plasma physics, the discipline concerned with the behavior of hot, ionized gases. Ironically the theory has not proved to be very useful in plasma physics; in its exact form the theory is too complicated for results to be calculated with it, but simplified versions are not adequate to describe many phenomena of interest. In applying the theory to the evolution of galaxy clusters, however, we have a significant advantage: we already know certain important properties of the "gas," such as the two-, three- and four-point correlation functions. With this knowledge we can try to simplify the theory without discarding its essential details. Marc Davis of Harvard University, working in collaboration with us, has recently completed a study of cosmic evolution employing this method. The results agree with two essential features of the observed galaxy distribution: the predicted three-point correlation function is of the correct magnitude with respect to the two-point function, and the two-point function follows a logarithmically straight line and then declines sharply.

The consistency of these results supports our model of the development of the observed clustering hierarchy. Not all observations, however, are consistent with this model; indeed, there is one measurement of great importance that is in direct conflict with our results.

As pointed out above, the average mass of galaxies has a strong influence on the development of clustering. In the calculation based on the theory borrowed from plasma physics the mass was just enough to stop the expansion. Estimates of the true masses of the galaxies, however, suggest that they are too light to stop the expansion by a factor of between 10 and 30. If the masses are that small, then our models make somewhat different predictions: small, dense clusters could form, but not the larger clusters of clusters. The hierarchy stops much sooner, or in other words the correlation functions decline faster with increasing separation.

At the moment we cannot account for the discrepancy between the masses apparently needed to explain the hierarchy of galaxy clusters and the masses astronomers have estimated by independent methods. On the other hand, we are not greatly discouraged by the contradiction: there are large uncertainties in both calculations. Indeed, the conflict is intriguing. If the galaxies turn out to be very massive, then we may well have formulated a successful theory of galaxy clustering, but we shall be left with the problem of finding the missing mass. If the estimated masses are found to be correct, we face the equally interesting problem of finding some other way to account for the simple pattern that underlies the clustering of galaxies.



EVOLUTION OF CLUSTERS from a homogeneous universe can be traced in a computer simulation. The model employs a spherical sample of the universe containing 2,000 galaxies. The sphere of galaxies is expanding, as is required by the "big bang" theory of the origin of the universe, but the expansion is slowed by gravitation. At the top such a sample is shown soon after the big bang and after it has expanded by a factor of four and then by a factor of 16. The same sequence of events is shown in the middle panel, but with the scale artificially adjusted in each case so that the size of the sphere seems to remain constant. Small fluctuations in density in the initial distribution are magnified by the expansion and give rise to clusters; with further expansion the clusters in turn aggregate to form larger clusters. The clustering is a result of gravitational interactions and is therefore determined by the masses of the galaxies, which in this model are just large enough for the expansion of the universe to stop. Smaller masses yield a significantly different structure. In the evolutionary sequence at the bottom the total mass is half that needed to halt the expansion, with the result that small clusters form but not larger clusters of clusters. The observed hierarchy of clusters thus implies that the universe is rather dense, a finding in conflict with some other observations.

Cats and Commerce

Cats have had a long association with people but have rarely been intentionally bred for specific characteristics. The distribution of their mutants thus reflects certain human tastes and movements

by Neil B. Todd

At first cats would not seem to offer a likely clue to human history. Yet when one considers that the writing of adequate histories of human populations began scarcely 200 years ago, that writing itself dates back only about 6,000 years and that for many populations historical, linguistic and cultural records are inadequate or nonexistent, cats appear in a different light. They have been associated with human beings for a long time, but they have never had any economic significance and only rarely have they had much social significance. Genetically they, unlike other domesticated animals, have been left largely to themselves. The study of the population genetics of cats is therefore rewarding not only for what it reveals about the evolution of cats but also for what it suggests about the movements of human populations.

The study of population genetics has in general become a powerful tool for unraveling human history and prehistory and particularly for solving problems of the origin and dispersal of plants and animals. Each individual study, however, brings out limitations in both the organism being investigated and the approach made to the study. To obtain greater precision in the interpretation of complex events it is therefore desirable to study a number of species. Cats would qualify for this reason alone, but they have several advantages in addition to the ones I have already mentioned.

One advantage is that cats display visible polymorphisms, or variable traits, for which the genetic bases are reasonably well understood. Most of the polymorphisms relate to the color, pattern and texture of the fur and so can be diagnosed and recorded at a glance. Hence the accumulation of data is a relatively inexpensive procedure, unencumbered by sophisticated techniques and technologies.

Cats are cosmopolitan, thanks to the exploratory and commercial activity of human beings. The animals have been spread from their homelands in the Old World to every inhabited part of the earth. They even persist in areas that people have abandoned. In addition to being ubiquitous cats are numerous. Most populations number at least in the hundreds, and many of them doubtless reach the millions. As a result the geneticist has both abundance and inherent genetic stability to work with.

Although further observations are required to assess certain complexities, most cat populations approximate what is known in genetics as the Hardy-Weinberg equilibrium. The expression means that the frequencies of various genetic factors can be stated in terms of theoretical mathematical distributions applying when it is assumed that populations are very large, randomly breeding and free from the complexities introduced by mutation, selection and migration. In the real world, of course, these criteria are never met. If they were, geneticists would have nothing to study. The apparent conformity of cat populations to the Hardy-Weinberg equilibrium does not mean that the influences of mutation, selection and migration are not important; rather, it means they take a relatively long time to bring about changes. Hence differences between populations can be ascribed to systematic forces rather than erratic ones. With cats one such force has been man, who in taking cats with him wherever he has gone has inadvertently conducted a series of experiments in population genetics that can now be evaluated.

The basic strategy in population genetics is the survey of a population. In practice the survey is usually a sampling. A sample can be gathered in a variety of ways, but the object always is to tabulate the frequency of phenotypes (observable characteristics of the organism) controlled by mutant alleles (variable genes). From seven to 10 such characteristics can be scored simultaneously in cat populations by simply looking at the cats.

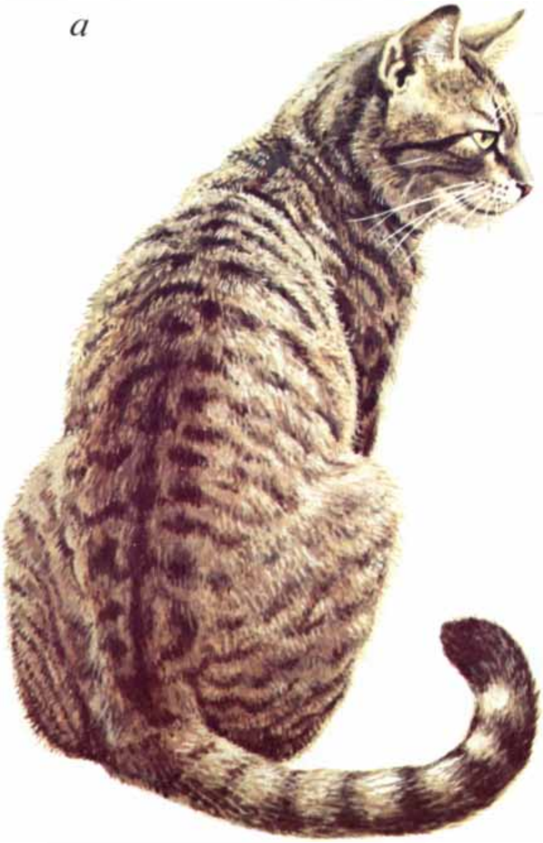
The cats, of course, are only a transient packaging of genetic information. In the final analysis it is the gene pool that is evolving. Therefore the geneticist is seeking not phenotype frequencies but mutant-allele frequencies, which are usually quite different from what is actually seen because of the ways in which each trait is inherited and interacts with other traits. A discussion of the mathematical manipulations whereby phenotype frequencies are translated into mutant-allele frequencies would be out of place here. The end result is the construction of what is known as a cline map, which shows the frequency with which certain mutant alleles appear in a given geographic area. The maps, then, become the relevant observation. Three such maps accompany this article; I shall return to them when I discuss some feline phenotypes.

Underlying any interpretation to be made from the cline maps and the data they reflect must be an appreciation that what is being studied is the complex of adaptations of an organism shifting from one ecological niche to another. The cat has moved, or is moving, from a wild and predatory life-style to a domesticated and subsidized one. It is evolving to a new niche, which is essentially the urban habitat. In the process it is experiencing a new set of interspecies and intraspecies relations.

What does this experience have to do with coat colors? In mammals there is a definite (but only rudimentarily understood) relation between pigmentation and endocrine chemistry. For example, the pigment melanin and the hormone adrenalin share a metabolic pathway, a common precursor being required for the synthesis of each. Studies of several kinds of animal have revealed that basic

THREE MUTANT CATS are portrayed in the illustration on the opposite page, together with the "wild," or nonmutant, type (*a*). The mutants, which embody traits controlled by certain alleles, or variable genes, are nonagouti (*b*), which is most commonly represented by the black cat; blotched tabby (*c*), and sex-linked orange (*d*). The color, pattern and texture of the fur provide a ready means of ascertaining the presence of the mutant alleles.

a



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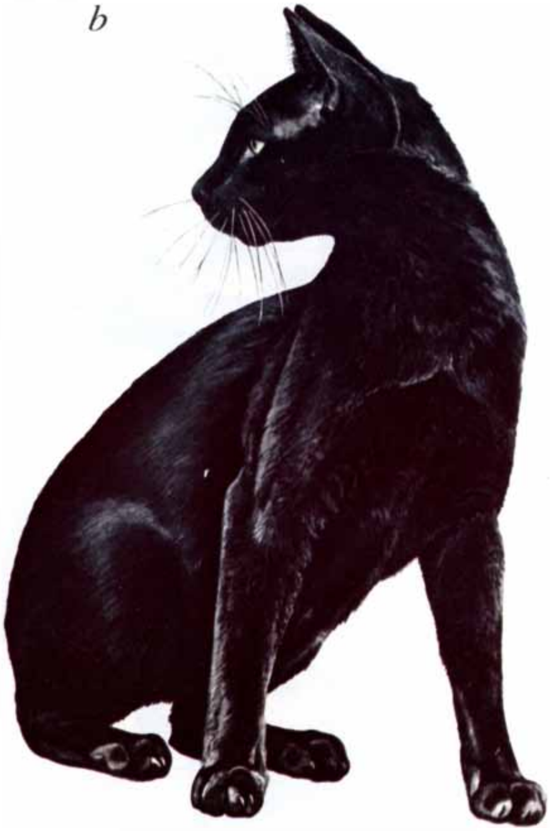

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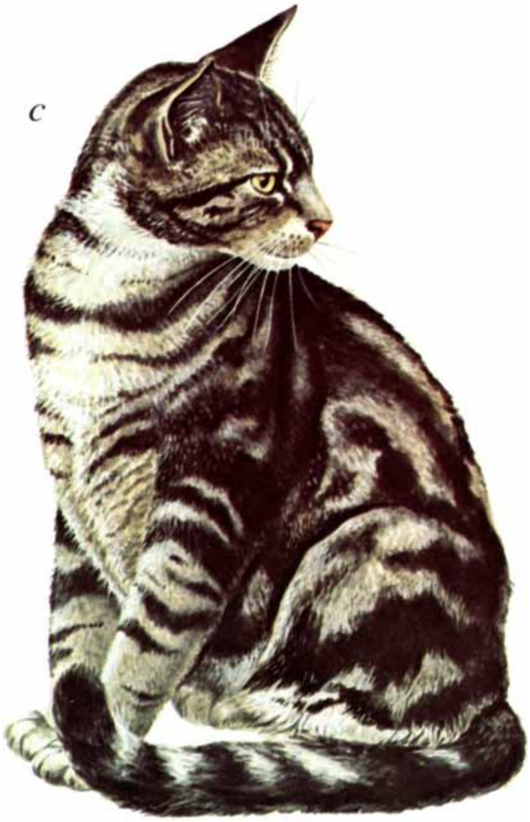

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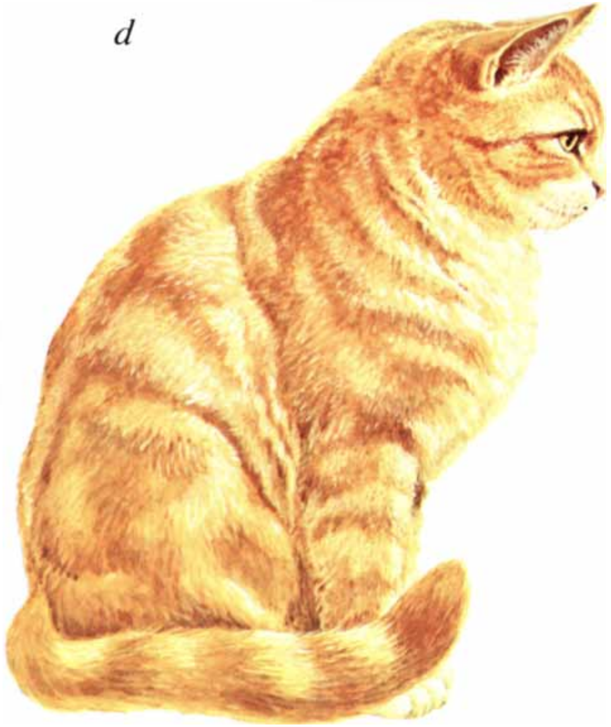


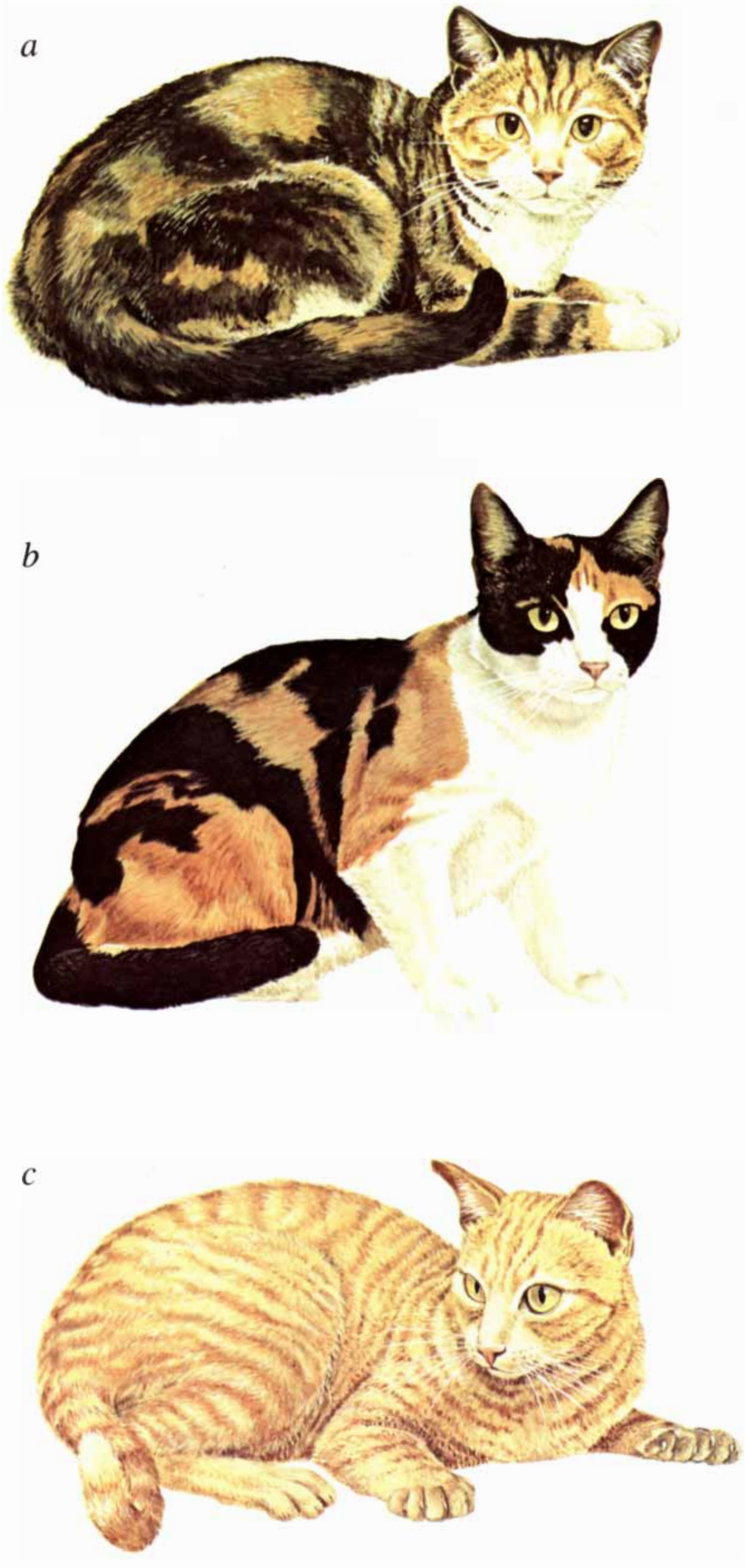
behavioral traits such as fear and aggression can be manipulated by simply crossing different coat-color mutants. Such effects have been documented for rats, mice, mink and foxes; if the effort were made, the same effect would almost certainly be revealed in cats and probably in all other mammals.

A piece of evidence here is that virtually every mutation in the cat shows a differential selective sensitivity to some feature or features along an urban-rural axis. For example, the genetic profiles of the cats of London and Paris show more similarities to each other than either profile does to that of the rural cats of Brittany. The selective forces responsible for these distinctions seem to be powerful; in one study the cats of urban and suburban Glasgow could be distinguished from one another. In a number of ways this spectrum of habitats is a spatial representation of the most important changes that have taken place in the living conditions of cats over the centuries. Recall that only the small towns and rural communities of today retain ecological features that were almost universal until a few hundred years ago. In ancient times a community of 10,000 inhabitants constituted a major urban complex. Only a few cities, such as Alexandria and Carthage, had populations of more than 100,000.

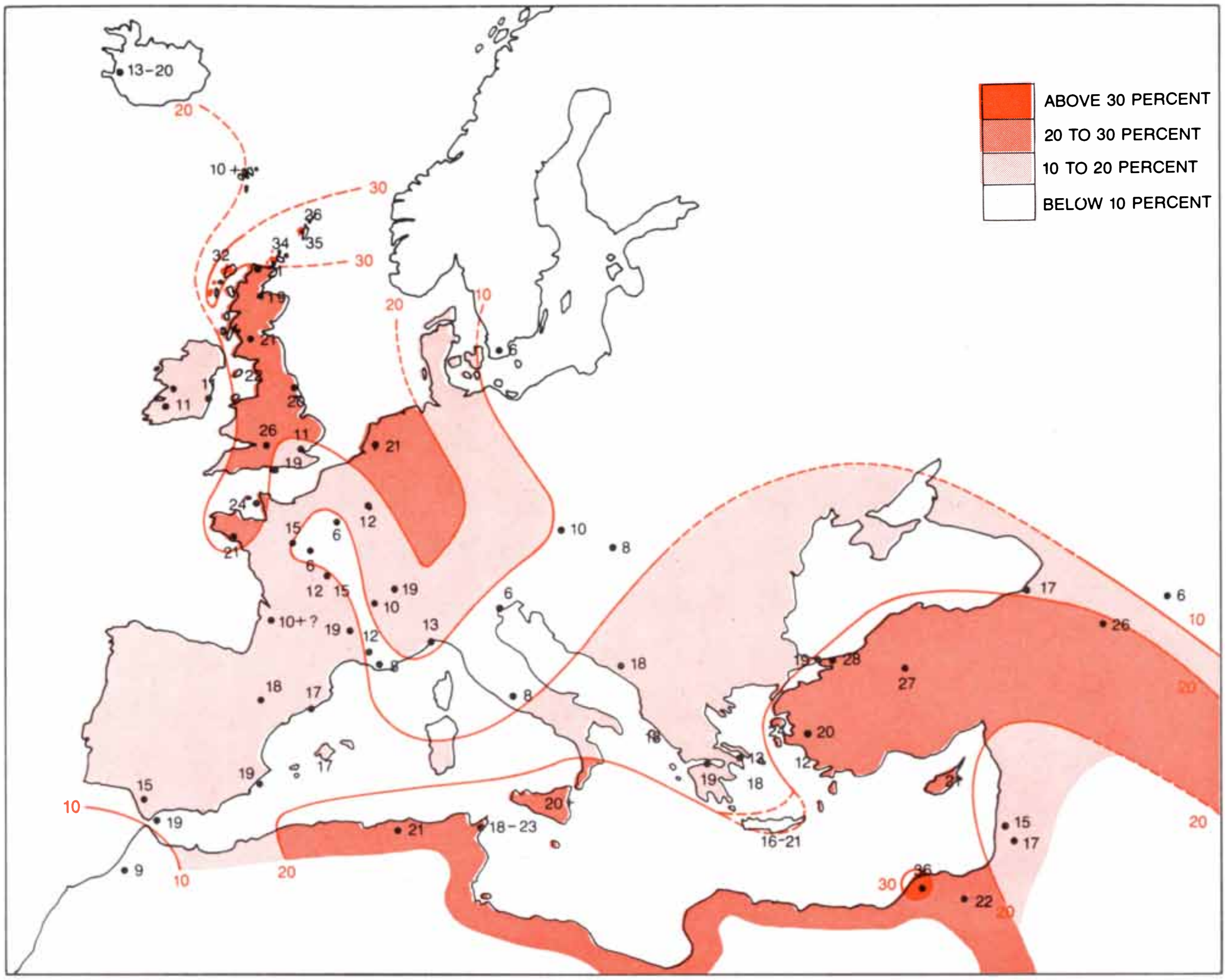
Since people and cats are inextricably associated in the process of domestication, it is necessary to look at some of the ways in which they do and do not interact. I have already noted that intentional human direction in modifying the gene frequencies of cats is largely negligible. There are, however, certain exceptions.

One of them might be termed novelty selection. This phenomenon derives from the human penchant for the odd and the curious or for the esteem of rarity. It may have had far-reaching ramifications in the history and development of all domesticated animals, but it seems most conspicuous today in the cat.

As background one should bear in mind that a new mutation, whatever its intrinsic adaptive value may be, is at a high risk of loss through the vagaries of chance. Geneticists refer to the process as genetic drift. In populations of cats one can observe that several mutant alleles stand at values that give their respective phenotypes a frequency of about 10 percent over large geographic areas or a maximum of 10 percent in scattered localities. The figure holds for mutant alleles that are inherited as dominant (controlling traits such as whiteness and polydactyly, referring to an excess of toes over the normal number), recessive (long hair and the Siamese pattern) or lethal (Manx taillessness), even though some of the traits are not beneficial to the animal.



VARIANTS CONTROLLED BY THE SEX-LINKED-ORANGE ALLELE are represented by the tortoiseshell (*a*), calico (*b*) and marmalade (*c*) cats. Tortoiseshell and calico cats are usually female, since the orange mutation is located on the *X*, or female, chromosome. A female has two *X* chromosomes and so can simultaneously express both orange and nonorange traits.



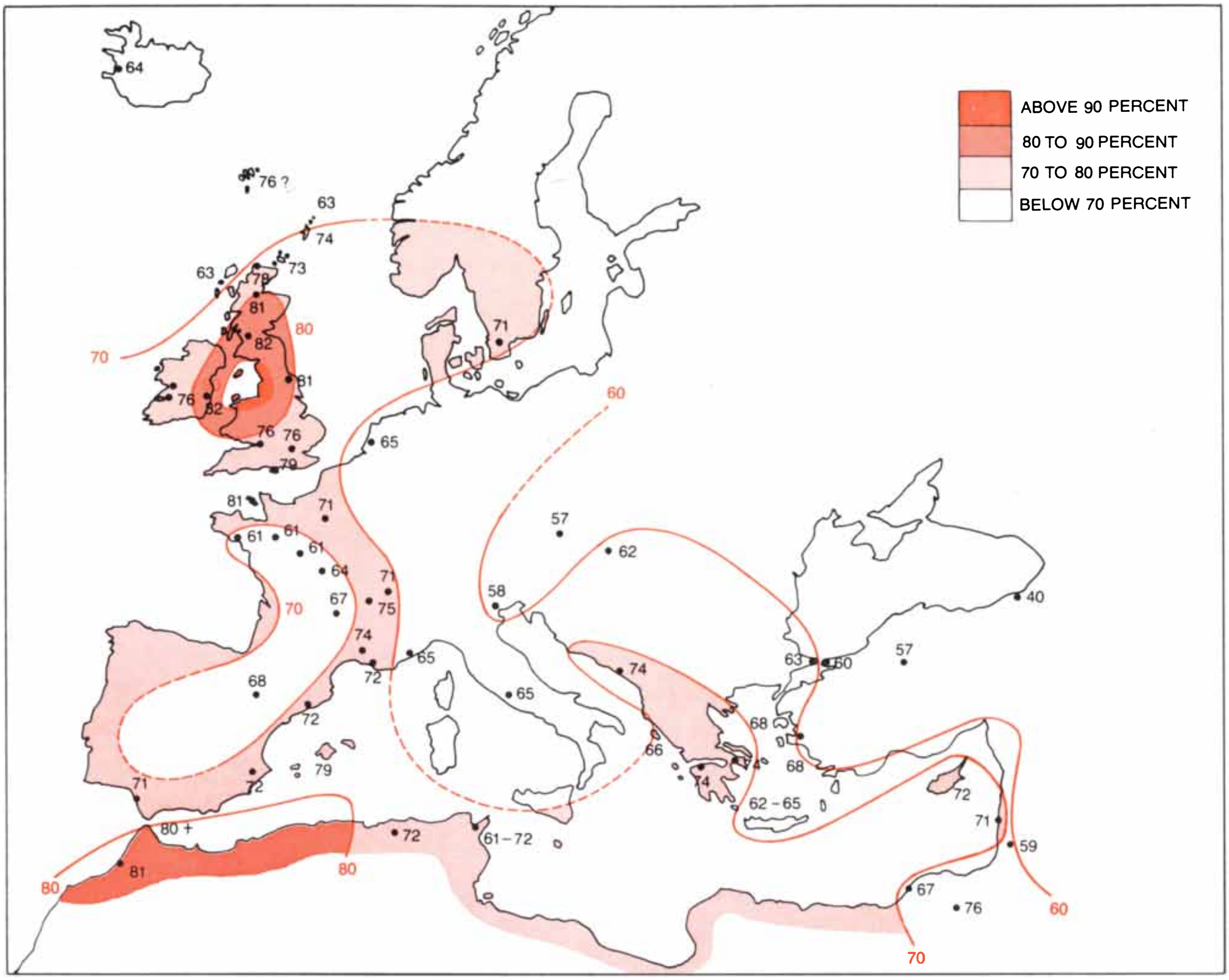
CLINE MAP indicates the distribution of the sex-linked-orange allele in terms of percents. Such a map is made by sampling the cat population in a number of places and mathematically translating the observable traits of the sampled animals into mutant-allele frequencies. The contour lines give percents in increments of 10, and more precise percentage figures are given for a number of cities. The clinal data suggest that the focus of the sex-linked-orange allele, that is, the location where the mutant first obtained a foothold, was in Asia Minor.

The explanation seems to be that when a phenotype reaches 10 percent, it is no longer perceived as being novel and is therefore regarded with indifference. If the phenotype's incidence begins to fall, however, it may be favored again. Hence a noteworthy type of selection, which could be called frequency-dependent selection, operates to facilitate the introduction and maintenance of genetic variation in populations. Presumably at the other end of the scale a highly advantageous mutation will be prevented from entirely displacing its alternative (going to fixation) by the same force. This unusual system may underlie the richness of genetic variability seen in domesticated animals, although in the more exploited species the variations are rapidly partitioned into breeds tailored for some particular human requirement. In cats, since the animals do not rank high in economic or social affairs, such variations simply become dispersed throughout populations.

A second exception results from what can be called selective migration. Paradoxically, what are water barriers to most animals become veritable highways to cats. Most domestic animals have been transported over water, of course, but usually they go under strict control. Cats actually take up residence on ships and come and go at will (at the risk of being left in port). Apparently as soon as men had mastered the art of commercial navigation, cats became habitual members of the ship's company.

The choice of feline shipmates may do little more than extend novelty selection. On the other hand, it may promote further genetic change owing to circumstances that enable basic aesthetic (or other) preferences to become effective agents of selection. Whatever the reasons for the choice of cats, the effect in maritime migrations may be particularly strong. The animals involved are often removed from the inertia implicit in being part of a large population and are transported to a smaller community. A human preference that would be swamped in a settled cat population can become quite evident in a migratory population.

Inevitably some mutations confer special advantages in certain circumstances. A familiar example involves the allele for darkness in moths; in normal circumstances it is deleterious, making the moth too conspicuous to birds, but in sooty industrial areas it makes the insect less conspicuous. When the normal background rate of mutation is coupled with novelty selection and migratory selection, the generation of variability is accelerated and the process of adaptation is facilitated. The mutant, preserved and secured, as it were, by special selection, now comes under the influ-



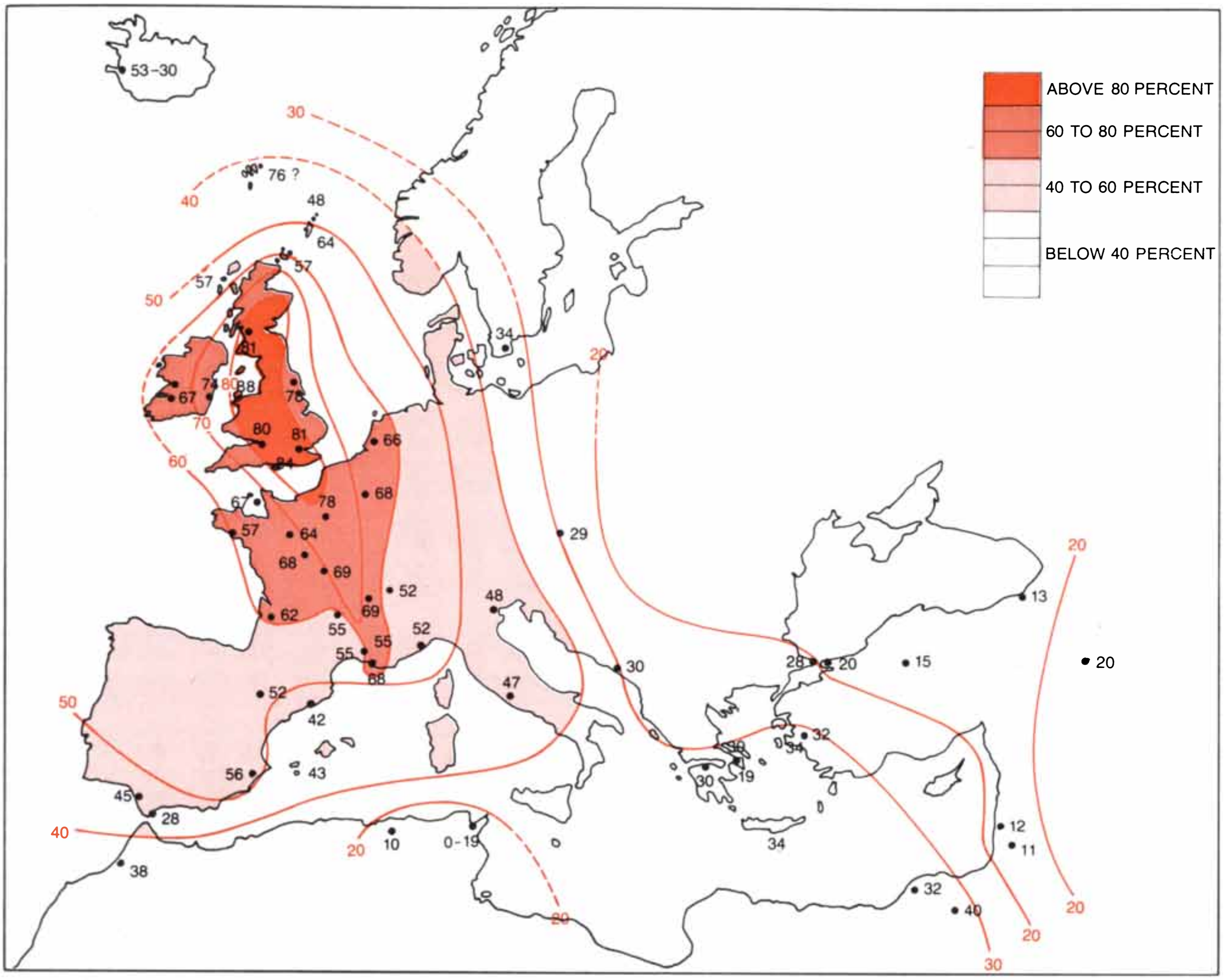
NONAGOUTI ALLELE is distributed as depicted in this cline map. Agouti, named for the South American rodent that exemplifies the condition, is a salt-and-pepper appearance caused by the fact that each hair of the fur has a band of reduced pigmentation below the tip. The nonagouti mutation eliminates the band and brings about a more uniform pigmentation, which is most commonly black. The distribution suggests that a major focus of the mutation (some 2,500 years ago) was in the eastern Mediterranean, probably Greece or Phoenicia.

ence of natural selection, in the sense that its fate is no longer linked directly to the idiosyncrasies of man. The mutation may impart some intrinsic superiority, such as resistance to disease or a broader tolerance in nutritional requirements, or it may modulate behavior in such a way as to reduce friction between species and within the species. Whatever the contribution, new forces come into play according to the nature of the genetic difference.

In some cases mutants are most successful in the heterozygous state. (An organism receives half of its genes from the mother and half from the father. If both of the two gametes, or sex cells, that fuse during fertilization carry the same gene for a certain trait, such as coat color, the offspring is homozygous. If they carry different genes for the trait, the offspring is heterozygous.) Heterozygosity may impart a "hybrid vigor," in which case the mutants will reach an equilibrium according to the relative fitness of the two homozygous alternatives. Other factors may be most advantageous only in one of the homozygous combinations. Then the mutants rise toward fixation at a rate that depends on the relative adaptive values of the alternative genotypes. Finally, a mutation may confer no inherent advantage, although because of its novelty it is preserved and dispersed at low levels.

Among the four cat genotypes I shall discuss below, the evidence suggests that one, sex-linked orange, imparts a heterozygous advantage; that another, nonagouti (usually black), manifests features of heterozygous and homozygous advantage, depending on the circumstances; that a third, blotched tabby, is so powerfully favored in the homozygous state that it is driving inexorably to displace its alternative allele, the wild type, and that the fourth, polydactyly, persists as a curiosity. My assumptions about selective forces are based partly on the clinal distributions and partly on other evidence and theoretical considerations. No unequivocal proofs have yet been produced; the following discussion therefore serves mainly to describe some of the hypotheses that are being put forward as guidelines for further study.

It is worth noting explicitly the underlying assumption that the present heterogeneous patterns of the four mutants (as well as of other mutants) have arisen from an ancestral population that was relatively uniform and homogeneous. Thus a fundamental influence in the distribution of any mutant is the time and place of "origin," by which is meant the time and the site in which the mutant initially secured a foothold. Such a point becomes the focus for further dispersal, whatever the mutant's precise geographic point of origin may have been. I therefore employ the term focus to cover the situation, with the understanding that the literal place of origin may or may not be coincidental.



BLOTCHED-TABBY ALLELE exhibits this distribution. The map can be read to suggest two foci for the allele, one (the more prominent) in Britain and one in northeastern Iran. The westward flow of the mutant from the focus in Iran seems to be merging in Asia Minor with the eastward flow from the focus in Europe. The hypothesis of Britain as a focus of the allele is supported by the numbers of cats bearing the allele in New England, Canada, Australia and New Zealand, all of which were colonized over some 300 years from Britain.

Sex-linked orange is a mutant responsible for a variety of well-known phenotypes, depending on the sex and the genotype of the individual carrying the gene and on certain interactions with other mutants. The most familiar examples are the cats commonly called marmalade, tortoiseshell and calico. Tortoiseshell and calico cats are almost always female, since the phenotype depends on heterozygosity. (The orange mutation is located on the female, or *X*, chromosome. Since a female has two such chromosomes, she can carry and simultaneously express both orange and nonorange. Males normally have only one *X* chromosome, the other one being *Y*, and so a male can express orange or nonorange but not both at once.) This is a fascinating story in itself, but in the present context the relevant point is that the frequency of the sex-linked-orange allele is not known to rise above 36 percent anywhere in the world; 25 percent is closer to the usual level. This observation leads to the tentative conclusion that the basic equilibrium is at about 25 percent, which is a likely level to obtain in cases of heterozygous advantage. Hence the most parsimonious interpretation of the clinal distribution of the sex-linked-orange allele is that where the percentage is lower than 25 an equilibrium has not yet been struck, and where it is higher the equilibrium has been disturbed.

The cline map showing the distribution of the sex-linked-orange allele presents an extraordinary pattern: an irregular central area with frequencies distinctly lower than those found outside the core. The full explanation for this pattern is elusive, but one of the geographic features—the corridor through France, linking London and the Mediterranean—is explainable. The valleys of the Seine and the Rhône, augmented in recent times by an elaborate barge-canal system, have long been a highly developed maritime route employed as an alternative to the transport of goods by way of the Strait of Gibraltar.

This inland conduit is a constant feature in the distribution of three of the four mutants under consideration. It has clearly served to promote the dispersal of nonagouti, blotched-tabby and other mutants but seems to have had an opposite influence on sex-linked orange. The low values of the mutant in parts of the core, Rome and Marseilles in particular and perhaps London too, are attributable to the long, continuous presence of large populations of cats. When sex-linked orange reached those areas, it would have represented only a small fraction of all the alleles present. Hence the low frequency of the mutant in the corridor reflects little more than the reduced opportunity for the recruitment of sex-linked-orange cats as migrants. The long stability of the cat population in turn probably reflects the centuries of Roman hegemony in the region.

Can the focus of the mutant be deduced from the clinal distribution? The relatively high frequency of sex-linked orange along the northern coast of Africa, in the Balearic Islands and along the Mediterranean coast of Spain suggests a migration from the east over water. Asia Minor therefore emerges as a potential focus, since the frequencies there are comparatively uniform and presumably at an equilibrium over a large area. With certain exceptions the levels drop off in every direction.

What, then, would account for the high frequency of the mutant in the islands off the northern and western coasts of Scotland and to a lesser extent in rural Iceland, the Faroe Islands and the Isle of Man? The frequency of dominant white is also higher there than almost anywhere else. Could it be that 1,000 years after they were introduced to these last outposts of European civilization cats still reflect what may have been aesthetic preferences of the Vikings?

The only other place where this combination of orange and dominant-white frequencies is known to occur is the remote district of Van in eastern Turkey. It is noteworthy that dominant-white cats, although they may be pleasing to the eye, are basically a disadvantaged genotype. They suffer from reduced viability, and the ones that survive are often afflicted with defects of sight and hearing and are susceptible to certain kinds of skin cancer. Wherever their numbers are high, the hand of man can be inferred. The evidence suggests that the Vikings selectively transported this profile of sex-linked orange and dominant white from their contacts on the Black Sea and planted it in the North Atlantic.

Turning to the mutant nonagouti, the most common manifestation of which is the black cat, certain broad features are worth mentioning. Agouti (so named because the agouti, a South American rodent, exemplifies the suite of characteristics well) is a basic mammalian condition. The agouti phenotype is due primarily to the distribution of melanin in the hair shaft in such a way as to produce a band of reduced pigmentation below the tip of the hair. The result is a salt-and-pepper, or brindle, pattern. A simple recessive mutation, nonagouti, eliminates this band and so gives rise to a hair that is more or less uniformly pigmented along its length.

Most mammals are agouti, but most domesticated mammals are nonagouti. The cat is something of an exception in that everywhere it shows a sharp dimorphism for the two alternative states. Some 150 surveys have revealed that nonagouti stands at above 50 percent. The finding is strong circumstantial evidence that a basic equilibrium exists at this level and that it is probably determined by heterozygous advantage.

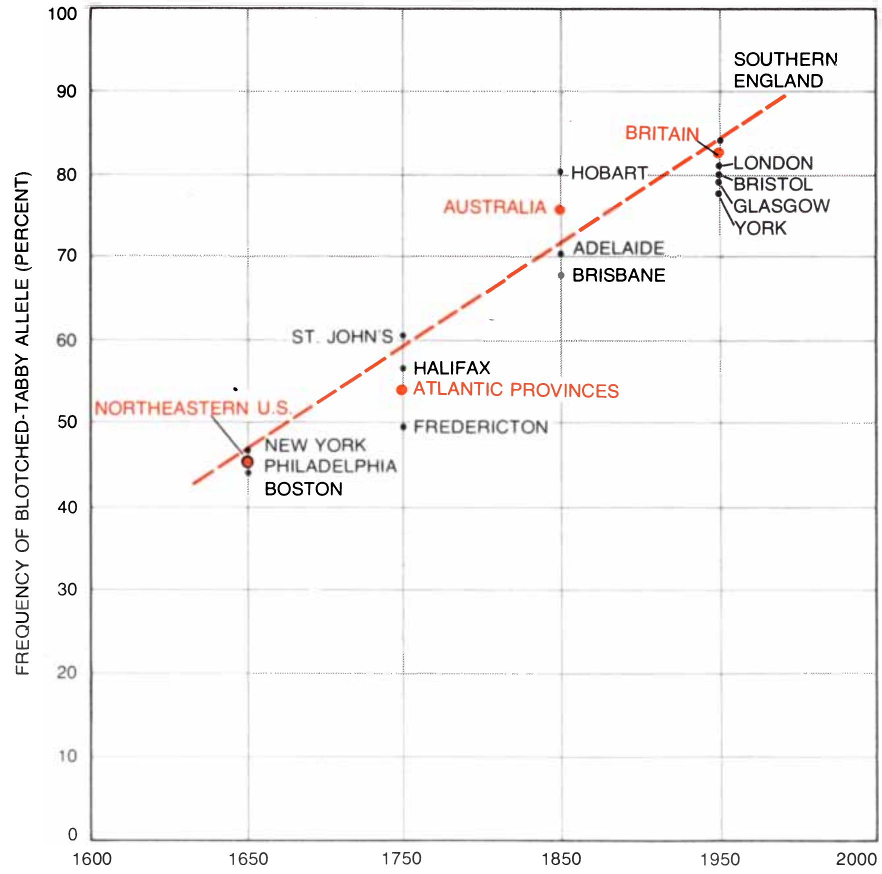
Can the hand of man be seen in the distribution of nonagouti cats? The highest frequencies of the mutant are found in Britain and in parts of northwest Africa. Slightly lower frequencies predominate along the narrow corridor through central France and throughout most of the Mediterranean; Rome and Venice are conspicuous exceptions.

The evidence is strong that the nonagouti mutant is favored by the urban habitat. If the evidence is construed to mean that the mutant is instrumental in fostering the cat-human affiliation, some sensible interpretations can be made. The high values in Britain stem from the high degree of affiliation implicit in selective migration, reinforced by intensive urbanization. The significance of the corridor through France is again that it had a principal role in the movement of commerce.

Although the British and northwest African areas are undoubtedly serving now as major foci, the high frequencies of the mutant there were created initially by the sequential intensification of frequencies through selective migration. In other words, each time people embarked to expand their sphere of civilized activity they took along an increasingly concentrated sample of nonagouti cats. Was the first step in this process, at least in the classical Mediterranean, taken by Greeks and Phoenicians in their colonization of Massilia and Carthage? Was a second step taken by Carthaginians when they founded communities in the Balearics, Algeciras, Tangier and Rabat?

Blotched tabby displays a close approach to the ideal dissemination of a mutant. The pattern, taken at face value, suggests a British focus (and in this instance probably a British origin), penetration through France and a rapid spread eastward across the Mediterranean. An eastern focus has recently been identified in or adjacent to northeast Iran. The westward flow from this focus seems to be merging on the Anatolian plateau of Asia Minor with the eastward flow from Europe.

The selective advantage shown by the blotched-tabby mutant is a mystery. The type is clearly spreading like an epidemic that will apparently engulf all cat populations. Even among the feral cats of Tasmania the mutant demonstrates



TIME AND FREQUENCY of blotched-tabby allele are plotted according to a system in which the date assigned to each community (*black dots*) and region (*colored dots*) is the approximate year in which the place was colonized from Britain and the present frequency of the allele in each place approximates the frequency it had in the British cat population at the time of colonization. The line representing the average predicts closely the present frequency of the allele in Britain (*upper right*), supporting the inference from the cline map pertaining to blotched tabby that the allele has been rising rapidly in Britain and diffusing steadily into surrounding areas.

superiority to the alternative (the wild type) in the face of a selection pressure that is rapidly reducing most of the other mutants to low levels.

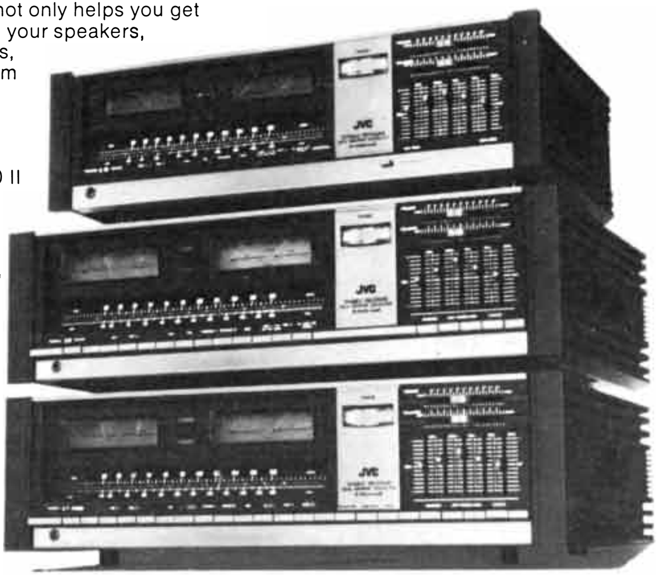
Since the blotched-tabby allele presumably arose rather recently, and since it shows such a powerful impetus to spread, few clues for tracing its history can be found in the Old World clines. Data from the New World, Australia and elsewhere supplement the picture of Britain as a focus.

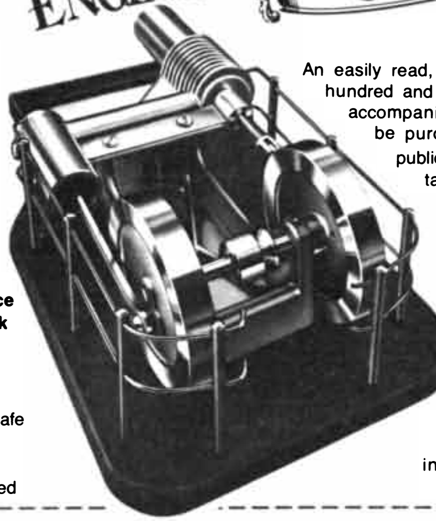
Beginning in the 17th century British cats were exported to lands that had no indigenous cats. New England, Canada, Australia and New Zealand were all recipients, at different times, of British propagules. If the premise is accepted that each of these populations was based on a representative sample of British cats drawn off over a period of 300 years, an interesting relation appears between the frequency of certain alleles and the time of sampling. Blotched tabby is the key to this analysis, since it shows a dramatic correlation.

Suppose various places are assigned dates according to the time of initial settlement, and the present genetic profiles of cats in those areas are taken to approximate those of the original cat population; it is then possible to plot time against frequency. This exercise reveals a trend, established in the first 200 years, that predicts the present frequency of blotched tabby in Britain with remarkable accuracy. The finding reinforces the appraisal, based on the cline map of the Old World, that the blotched-tabby allele has been rising rapidly in Britain and diffusing into surrounding populations. Comparable analyses of the exploration and colonization by the Dutch, the French, the Portuguese and the Spanish would probably yield similar pictures.

My final example concerns a mutation resulting in extra digits. (Polydactyly, meaning many digits, is not really an accurate term.) Cats with this condition are common in New England, New Brunswick and Nova Scotia, where they may constitute more than 10 percent of all individuals. Elsewhere, however, except for isolated pockets, they are rare.

The evidence suggests a New England origin, or at least a New England focus, for the dispersal of such cats, doubtless on the basis of novelty. The strong likelihood that the cats must have been present in, say, Boston by the middle of the 18th century is supported by their equal abundance today in Halifax. That city was not founded until the middle of the 18th century, and then it was at first a center of commercial activity involving New England and later a refuge for thousands of Loyalists fleeing the American rebellion. It would seem that the people who traveled to Halifax transported more than goods, services and political persuasions. They also took their polydactyl cats.





The Functions of Paleolithic Flint Tools

The microscopic examination of the working edges of certain stone implements used by ancient hunters makes it possible to distinguish among such uses as scraping hide, cutting meat and sawing wood

by Lawrence H. Keeley

Almost the only evidence of man's presence on the earth for a period of more than half a million years is vast numbers of stone tools. Some are made of basalt, some of quartzite or quartz and some of the volcanic glass obsidian. In many places the majority are made of flint. As soon as these objects were recognized as man's handiwork they were assigned names based on guesses about their probable function. The French began the process with *coup-de-poing,* which in English became "hand axe." A multitude of other functional names followed: "end scraper," "side scraper," "blade," "point," "burin" and the like. Although generations of prehistorians have used such names, there has been scarcely any tangible evidence on what purposes the stone tools actually served.

Over the past 15 years students of early man have grown sufficiently dissatisfied with this state of affairs to do something about it. The result has been the development of a methodology known as microwear analysis, which reveals the functions of many early flint implements. The evidence is almost indelibly recorded in the form of microscopic traces of wear on the working edges of the flint.

One reason for the current lively interest in the function of stone tools is that progress in the methods of absolute dating, such as carbon-14 analysis, has freed many prehistorians from two former preoccupations. The first was, in the absence of absolute dating, the construction of relative chronologies. The second was closely related to the first: it was the search for "cultural" similarities between assemblages of stone tools from different areas. Such similarities aid in the construction of interlocking regional chronologies. Early in the 1960's a new school of prehistorians began to offer fresh hypotheses to explain the variations between and within regional assemblages of tools.

In this view the variations were attributable less to chronological and cultural differences and more to differences in function. For example, the new school sought to explain the differences between the kinds of tools present in two roughly contemporaneous assemblages in terms of the different kinds of activity the tools' users could have pursued in the two places. Proponents of this school argued that in attributing such differences to "cultural" distinctions between two unrelated groups the older school was misreading the evidence.

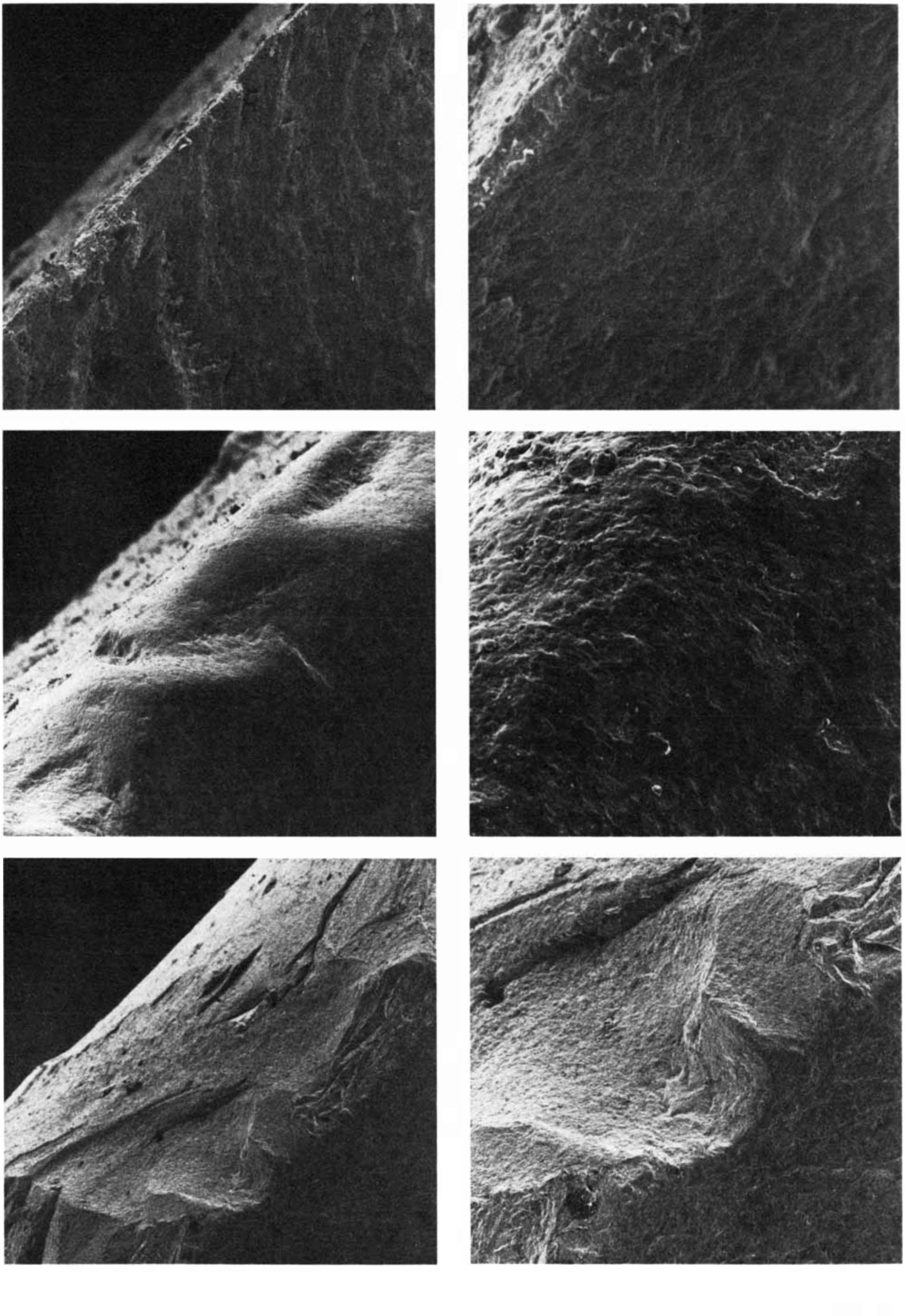
A vital prerequisite to the testing of the functional hypotheses was a detailed knowledge of what the artifacts were used for and how. In 1964 *Prehistoric Technology,* a summary of the studies of tool function conducted by the Russian prehistorian S. A. Semenov, was published in an English translation. Semenov and his colleagues at the Leningrad Academy of Sciences had established the fact that tools of even the hardest stone retained actual traces of their use in the form of polishes, striations and other alterations of the tools' working edges. More often than not the traces of wear were visible only at quite high magnifications. It seemed to scholars in Britain and America that at last the means were in hand for pursuing just the kind of information about tool function that the new hypotheses required.

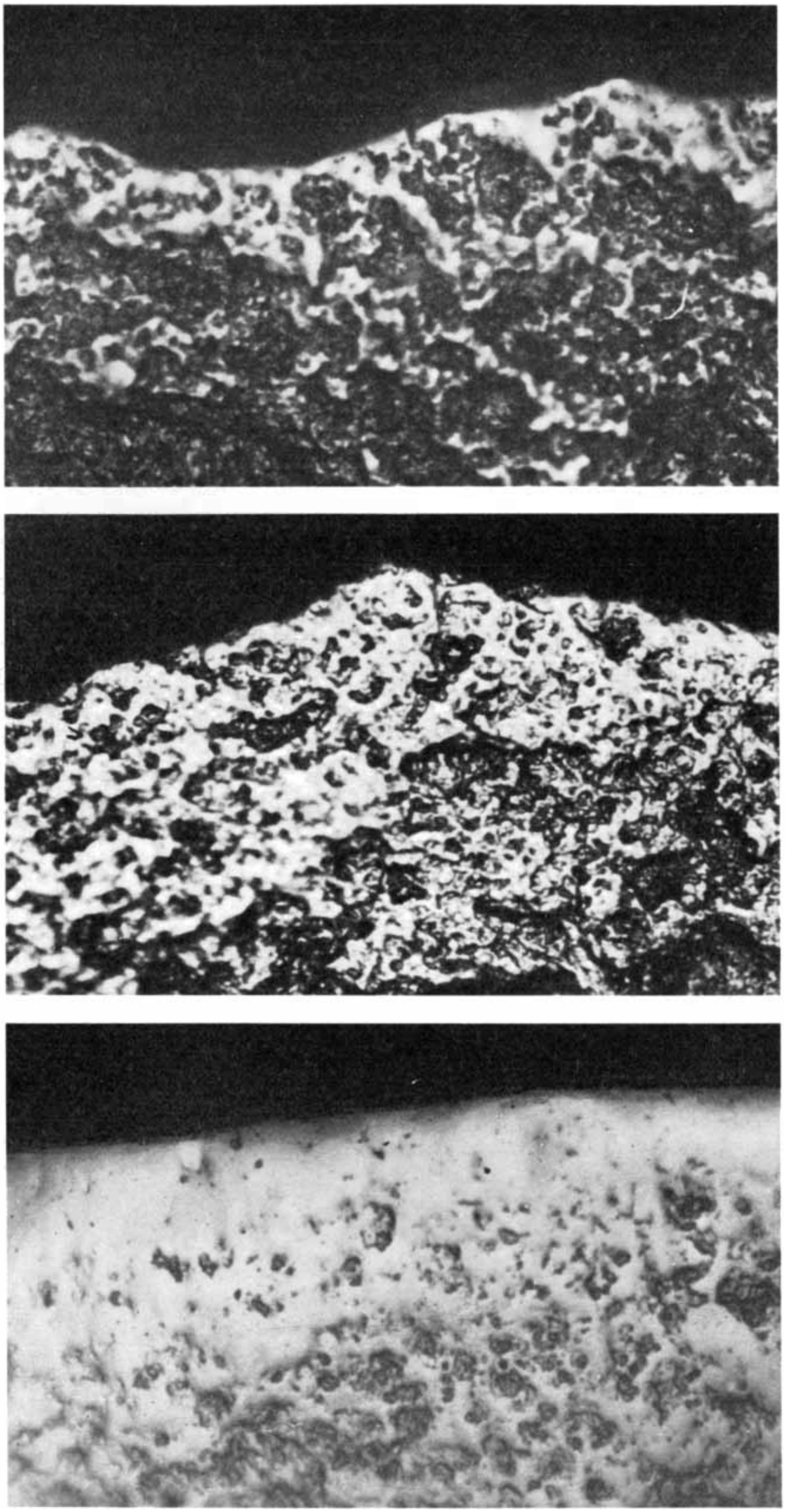
Semenov's functional interpretations of the uses of Paleolithic and later stone implements unearthed in the U.S.S.R. were fascinating but also tantalizing. He had not included a detailed account of the methodology that formed the basis for his interpretations. To make matters worse, the particular kinds of microscopic equipment employed by Semenov were then available only in the U.S.S.R., and so the translator had omitted most of the few technical details Semenov had included in his original.

As a result a number of prehistorians outside the U.S.S.R. proceeded to do microwear analysis armed only with the translation of Semenov's book and stereoscopic microscopes that often had a maximum magnification of 80 diameters. In addition to this technical handicap the implements these workers selected for study were made from stone materials quite unlike those found in the U.S.S.R. Disappointment and disillusionment followed as one investigator after another found Semenov's results impossible to substantiate.

This situation, however, was scarcely surprising. For one thing, in most cases the investigators could not even see microwear features such as the polishes and striations Semenov had observed because the magnifications they were working with were far too low. For another, the low-magnification wear features they could see (primarily edge damage, the small breaks and flake scars on the working edge of the tool) did not allow precise and unambiguous interpretations of tool function. Many investigators came to the conclusion that Semenov's interpretations were suspect

ALTERED MICROTOPOGRAPHY of the working surfaces of flint tools is seen in the scanning electron micrographs on the opposite page. At the top left is the edge of an unused flint; it is magnified 300 diameters. At the top right is a closer view of an unused flint surface, magnified 1,700 diameters. The author used the flint edge and surface in the middle (magnified 140 and 1,700 diameters respectively) to scrape dry hide. The tool edge is markedly rounded, and the topography of the tool surface has been altered by contact with the hide so as to acquire an extreme matte texture. The author used the edge and surface seen at the bottom (magnified 70 and 130 diameters respectively) to scrape bone. Both edge and surface show the uneven topography produced by such work; characteristic small pits have developed on the flint surface.





WOOD POLISHES produced on the working edge of three modern replicas of flint tools are visible in these micrographs; all enlarge the surface 300 diameters. The author scraped yew wood with the tool at the top. A characteristically bright wood polish has begun to appear on the elevated parts of the flint. He whittled birch wood with the tool in the middle; the extent of the polish is attributable in part to the wider contact between tool and workpiece. He scraped yew extensively with the tool at the bottom; the depressions on its edge are almost obliterated.

and that microwear analysis simply did not work. Nevertheless, the demand for information about the functions of stone tools ensured that the research would continue.

As a result of this chain of events investigators outside the U.S.S.R. concentrated on studies of the edge damage that could be observed with low-powered stereomicroscopes and ignored the polishes and striations that only begin to be visible at a magnification of 200 diameters. Many edge-wear studies sensibly relied on experiments. Modern replicas of Paleolithic implements were made and were used in various ways to work on a wide range of materials in order to determine whether the resulting traces of wear differed from material to material. Most of these programs, however, involved too few experiments, controlled too few variables and were too limited in scope to achieve anything useful.

The one adequate program employing the low-magnification approach to the analysis of edge damage was conducted at Harvard University by Ruth Tringham and her students. When the results of the work were published in 1974, the chief demonstrable distinction proved to be one between work on "hard" materials (such as bone, antler and wood) and work on "soft" materials (such as meat, hides and nonwoody plant materials). No reliable criteria were found for distinguishing between different methods of working, such as scraping, whittling, sawing, cutting and the like. It was also impossible to distinguish between on the one hand edge-damage scars resulting from the actual use of an implement and on the other hand small scars created in the course of manufacture or by the implement's rubbing against other hard materials during millenniums of burial.

I first undertook research in microwear in 1972 after a review of the literature in the field and some preliminary studies. These preliminaries convinced me that I should employ a wider range of microscope magnifications and techniques than others had. I began with a program of experiments designed to provide a framework for analysis of the functions served by particular sets of flint implements from English sites of the Lower Paleolithic: 500,000 to 100,000 years ago.

I had three microscopes at my disposal: a light stereomicroscope with a range of magnifications between six and 50 diameters, a light microscope with a range between 50 and 1,000 diameters, and my principal research instrument, a microscope with an incident-light attachment and a range between 24 and 400 diameters. I also made occasional use of a scanning electron microscope, mainly for magnifications above 500 diameters.

After making replicas of Paleolithic stone implements I conducted a series of nearly 200 tests, processing a variety of foodstuffs and other materials in many different ways. I also subjected certain implements to the kinds of natural wear that are likely either to make microscopic scars similar to those made by human use or to erase such scars. Along this same line I was able, thanks to the availability of large numbers of Paleolithic implements that had been subjected to wear by soil movements, chemical weathering and abrasion by waterborne and wind-borne sediments, to compare this natural kind of wear with my experimental results.

The key finding that emerged from those tests was that microwear polishes on the working edges of modern replicas become visible at magnifications between 100 and 400 diameters under illumination striking the sample at an angle of 90 degrees to the optical axis of the microscope. The different kinds of polish can readily be distinguished from one another. Whether the activity was cutting or whittling wood, cutting bone, cutting meat or scraping skins, I found that each produced a characteristic kind of work polish.

The work polishes proved to be durable; they could not be removed from my replica implements even with chemical cleaning. I applied caustics that ran the full pH spectrum from an extreme base (sodium hydroxide) to an extreme acid (hydrochloric) without effect. The same was true with various organic solvents. I concluded that the work polishes represent real and permanent alterations in the microtopography of the flint. Accordingly similar polishes seemed likely to have survived unaltered on flint artifacts of great age. This being the case, it should be possible to infer from the traces of microwear observable on a Paleolithic tool just what use that particular tool had served.

The distinctive microwear polishes can be described as follows.

Wood polish: The tool edge shows a polish that is consistent in appearance regardless of whether the wood being worked is hard, soft, fresh or seasoned. The polish is also the same regardless of the manner of tool use. It is very "bright," reflecting a considerable percentage of the incident illumination, and very smooth in texture. Because the polish first develops on the elevated parts of the microtopographic surface of the flint its gross appearance is affected by that topography up to the point where the contact area becomes completely polished. Thus if the original topography of the flint is coarse, the polish in its initial stages will be distributed in a netlike pattern. If the flint is fine-grained,

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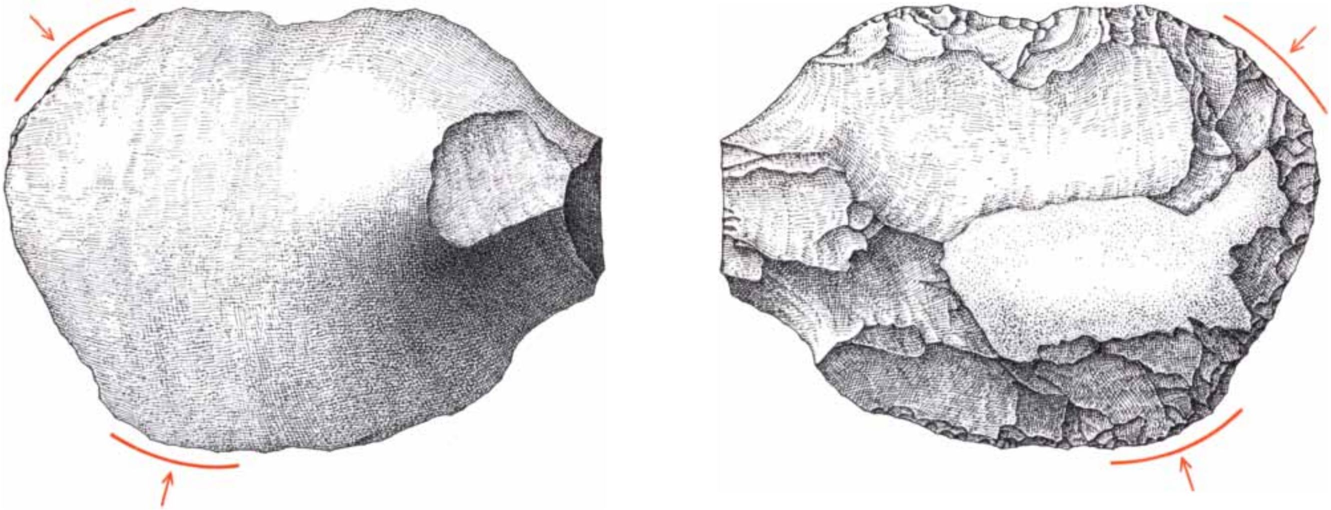
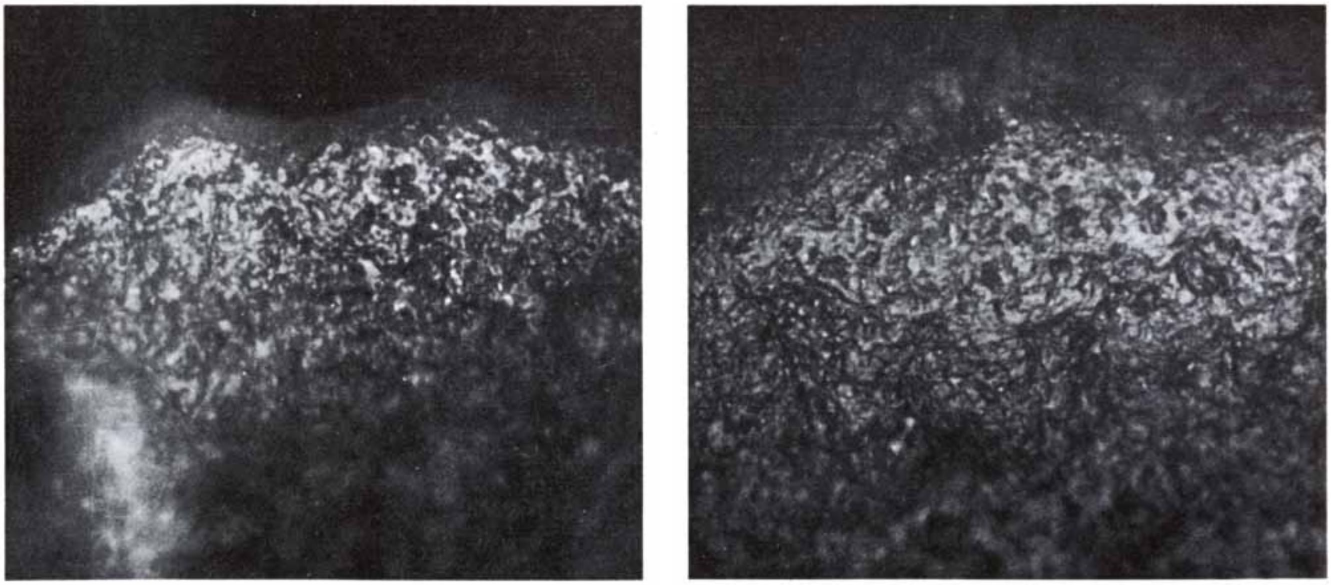
The New Telescope That's Popularizing Astronomy the polish is soon evenly spread. Regardless of the distribution, the polish has a constant bright, smooth character.

Bone polish: The tool edge is bright, but the polish has a rough, uneven texture that lacks the smoothness characteristic of wood polish. One distinctive feature of the rough texture of bone polish is the presence of numerous pits on the otherwise bright surface. Bone polish develops more slowly than wood polish. On a modern replica, even after prolonged use, the polish is seldom very extensively developed. My experiments revealed no consistent differences between the polishes on tools used to work cooked bone and those on tools for working uncooked bone, or between the polishes on tools used to work bone belonging to different species of animals.

Hide polishes: Here the tool edges do not develop a single distinctive kind of polish. The hide polishes differ depending on the material being worked. They range from a relatively bright polish with a greasy appearance (produced by working fresh wet hide) to a dull matte polish (produced by working dry hide or leather). The differences are attributable to variations in the quantity of lubricants present in the animal skin at different stages. A fresh hide gradually creates a polish not unlike that created by the cutting of meat. As the hide becomes progressively drier it contains progressively less lubricant, and the tool polish not only develops faster but also is duller and less greasy in appearance. If the hide is fully dried or tanned, the polish is quite dull and shows an extreme matte texture. Regardless of these differences in polish all hide-working tools show two characteristic kinds of microwear. One is relatively severe attrition of the working edge of the implement, that is, removal of flint by means other than breakage or scratching. This attrition gives the stone implement a markedly



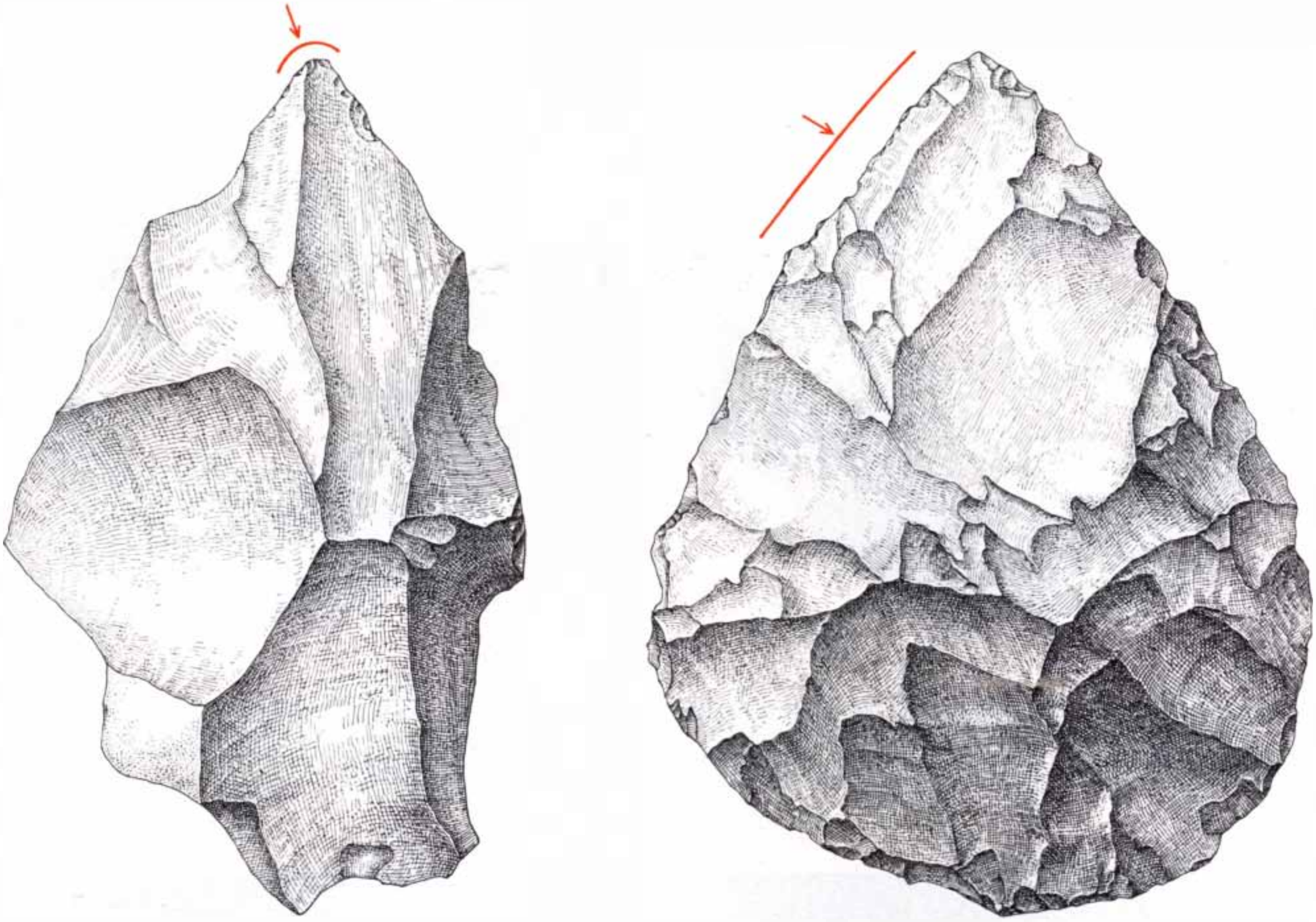
PALEOLITHIC FLAKE TOOL, a "side scraper" from Hoxne, an Acheulean site in England, was among some 800 flint implements examined for evidences of microwear by the author. The top of the flake (*right*) still shows some of the outer surface (*lighter area*) of the nodule of flint the flake was struck from. Lines and arrows (*color*) indicate the working edges of the tool. Prehistorians have assumed that scrapers were used to process animal hides. Microwear traces found on the flake lend support to such an assumption (*see illustration below*).



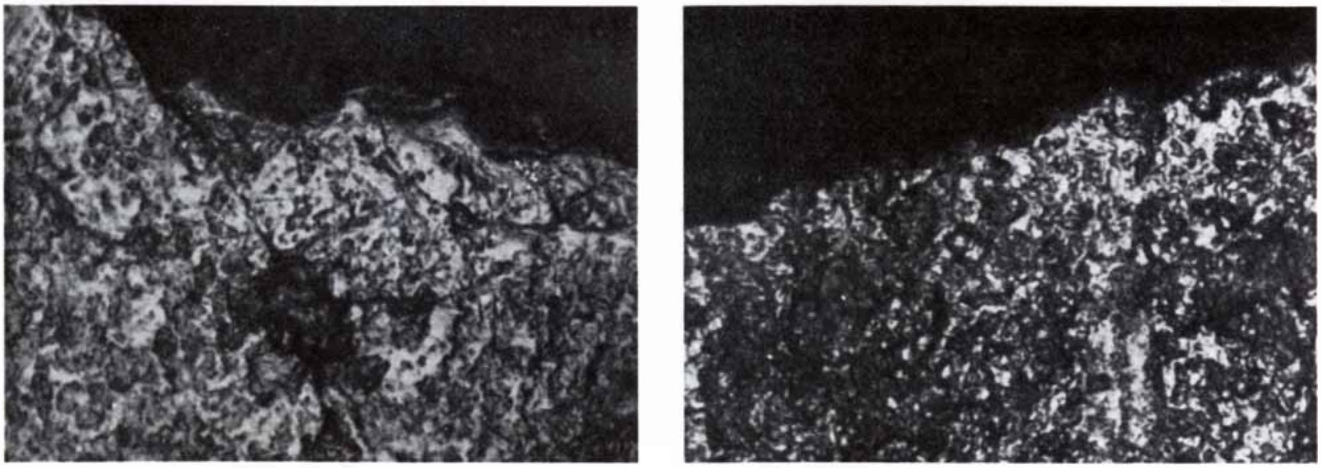
REPLICA AND ORIGINAL are compared in these micrographs. The tool edge at the left was used by the author to scrape dry pigskin for an hour. The edge, seen here magnified 300 diameters, developed a dull matte work polish and had become rounded by wear. The edge of Hoxne scraper (*right*) is seen magnified 300 diameters. It shows the same dull matte polish and wear-rounding the replica tool does.

rounded edge. The other characteristic is the development of shallow and diffuse linear surface features that run parallel to the direction in which the tool is moved. These diffuse linear marks are similar to the striations caused by other kinds of materials, but they cannot be mistaken for such striations, which are much more prominent.

Meat polish: The tool edge that is used to slice meat and other soft animal tissue develops a microwear polish rather like the polish produced by working fresh hide. This polish is easily distinguished, however, from the polishes created by the working of dry hide, bone, antler, wood and nonwoody plant materials. Pronouncedly greasy, it is at the same time dull rather than bright. Thus with respect to brightness the contrast between meat polish and an unaltered flint surface is slight. For this reason meat polish does not show up well in photomicrography. The distinction is nonetheless clear to the eye. The grainy texture characteristic of raw flint is replaced by a matte texture that, although it seems to preserve the original surface microtopography, has actually transformed the elevations and depressions



BIFACIAL TOOLS from two Lower Paleolithic sites in England are a "chopper" from Clacton-on-Sea (*left*) and a "hand axe" from the Acheulean site Hoxne. Lines and arrows (*color*) locate their working edges. The microwear analysis shows they served different functions.



TWO WORKING EDGES are magnified 300 diameters. At the left is one edge of the "bit" of the Clacton biface. The presence of wood polish indicates that the supposed "chopper" was used for woodworking; damage to the bit point, not visible here, indicates that the tool was used to bore holes. The edge of the Hoxne "axe" at right shows dull, greasy work polish characteristic of meat-cutting implements.

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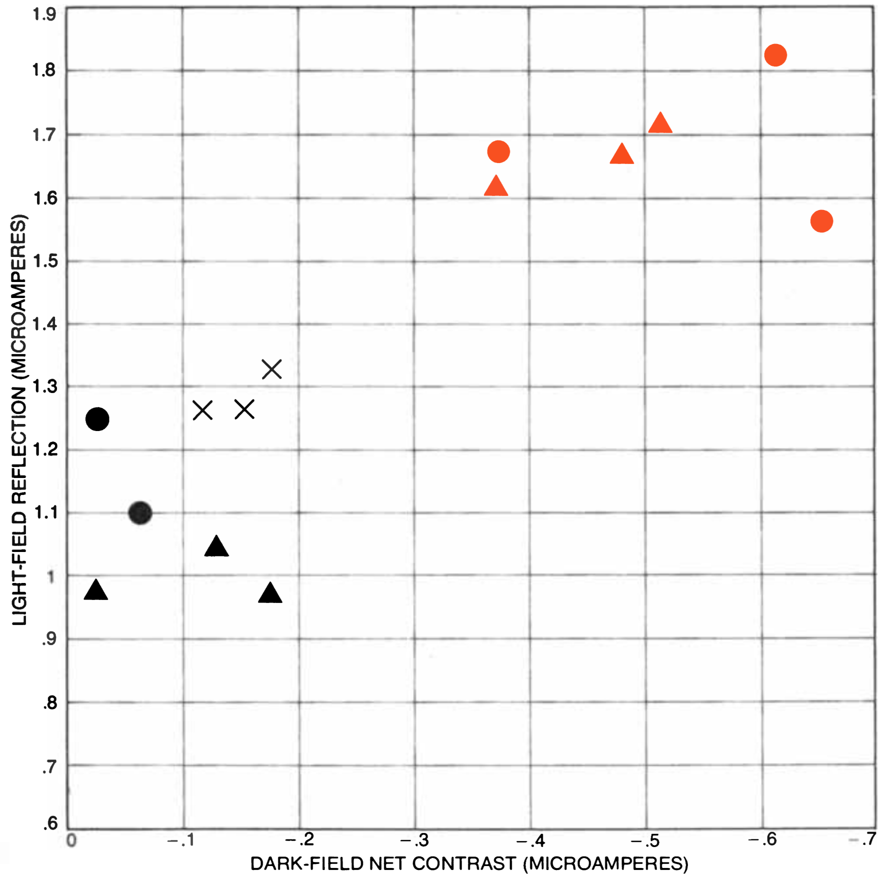
into a semicontinuous surface. Tools that show meat polish also frequently bear short, narrow striations.

Antler polishes: The edges of tools used to work antler exhibit one or another of two distinctive polishes. The difference depends on how the tool was used. Scraping, planing or graving antler leaves a very bright and smooth polish. Sawing antler, however, leaves a polish like bone polish: it is bright but pitted. In its early stages of development smooth antler polish is sometimes virtually indistinguishable from wood polish. When it is further developed, the polished surface displays small scattered depressions, giving it a pockmarked appearance that is quite different both from a wood polish and from the stronger surface pitting characteristic of the rougher antler polish. My experiments with antler were conducted almost entirely with samples that had been soaked for a day or two in water. Dry antler is so hard that stone tools used to work it are dulled by edge damage before anything has been accomplished. Water-soaked antler, however, is quite easy to work.

Nonwoody plant polishes: The edges of tools used to cut nonwoody plant stems, such as grasses or bracken, acquire a "corn gloss." The characteristic feature is a very smooth, highly reflective surface with a "fluid" appearance. If any striations are present, they often appear to be "filled in." At the same time the polished surfaces of the working edge develop curious comet-shaped pits. As the term implies, corn gloss is most commonly found on the flint sickles used by Neolithic farmers to harvest domesticated species of the grass family. As I was to discover, however, some nonwoody plants were cut in Lower Paleolithic times, and the cutting tools developed the same kind of gloss.

Work polishes alone enable the investigator to infer what materials were processed with various flint implements. If one is to determine how the implements were used, however, one must rely on several other kinds of microwear evidence. Perhaps most important are the distribution and orientation of such linear wear features as striations. Other kinds of evidence include the location and nature of edge damage and the location and extent of the polished working portions. All such evidence must be considered in relation to the general size and shape of the tool. In the broadest terms, once an inventory of the various kinds of microwear evident on a particular implement has been made, one then asks how the tool must have been handled to acquire the observed features. For example, microwear traces on both sides of a working edge, combined with striations that run parallel to the edge, are the strongest kind of evidence that the implement was used for sawing or cutting. Analysis of the work polish should then indicate what material was sawed or cut.



RELATIVE BRIGHTNESS of various work polishes is shown in this reflectivity graph as a function of two measurements. The ordinate values indicate the amount of light reflected from a standard area of polished surface under normal light-field illumination, as registered in microamperes on a photometer. The abscissa values indicate differences between the reflectivity of polished and unpolished surfaces of an implement under dark-field illumination: the smaller the difference, the rougher the texture of the polished surface. The brightest and smoothest of the work polishes were the "corn glosses" produced by cutting nonwoody plant stems rich in plant opal. Colored dots indicate the readings on Neolithic flint sickle blades from Syria; the triangles, the readings on Neolithic blades from Bavaria. Among the dullest and roughest of the work polishes were the ones formed on modern replicas by work on greasy hide (*black triangles*); the polishes produced by work on dry hides (*black dots*) were rougher but brighter. Polishes produced by working wood (*black crosses*) were smoother and brighter.

Having established six broad categories of polishes, I was prepared to apply my experimental results to selected Paleolithic artifacts. A skeptical colleague suggested, however, that I first submit my analytical technique to a blind test. The colleague, Mark H. Newcomer of the University of London, had strong doubts about the validity of microwear analysis. We agreed that he would make several replicas of flint tools and then work on various materials with them. After recording what he had done with the tools and then cleaning them, he would send them to me for analysis. Thereafter we would meet and compare my inferences with his records of the actual uses. Newcomer made 15 replicas of ancient flint tools and did various kinds of work with a total of 16 tool edges.

The results of the blind test were instructive. To be sure, the number of implements was small. Nevertheless, I identified the working portions of the tool edge in 14 edges of the 16. For 12 of the edges I was able to reconstruct the mode of tool use and for 10 of them to infer the kind of material worked.

Some of the inferences were remarkably close to the mark. For example, Newcomer had skinned a hare with a double-edged tool, using one of the edges for the actual skinning and the opposite edge to sever those parts of the limbs that remained with the skin during hide preparation. I identified the wear on the skinning edge as meat-cutting polish. (I had no way of knowing that in this instance the meat was less than a millimeter below the skin.) The microwear on the opposite edge I interpreted as the result of breaking a joint.

With another implement Newcomer had cut fresh meat resting on a wood cutting board. I was able to distinguish

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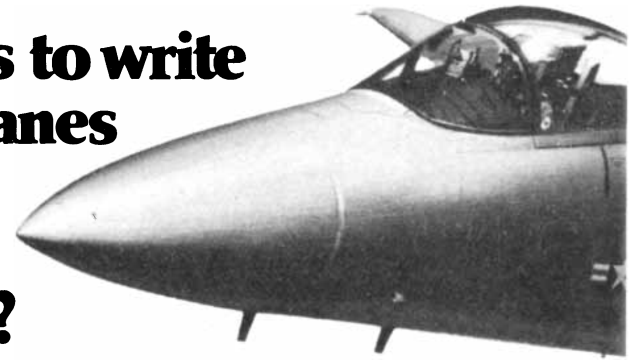

In aerospace, one often wonders what wonders will come along next. A current wonder is the F-15 Eagle, the best fighter aircraft in the world.

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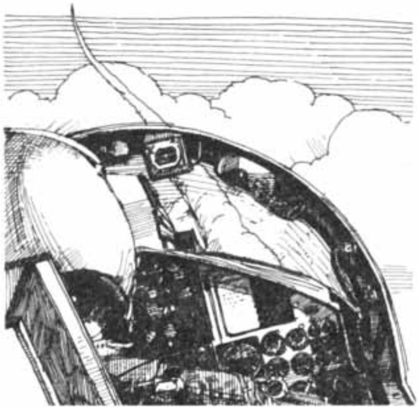

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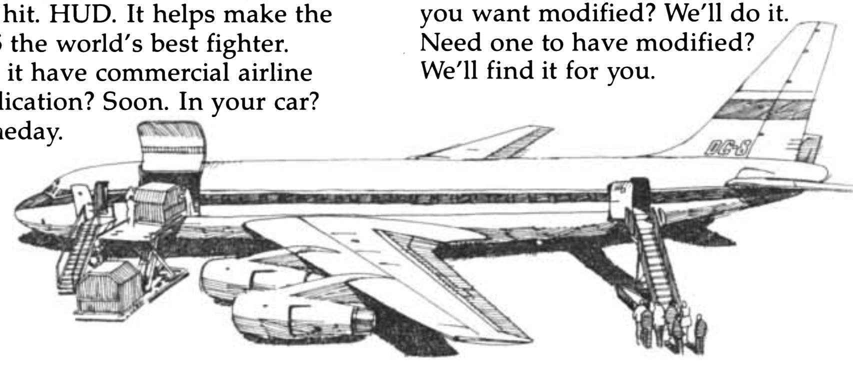
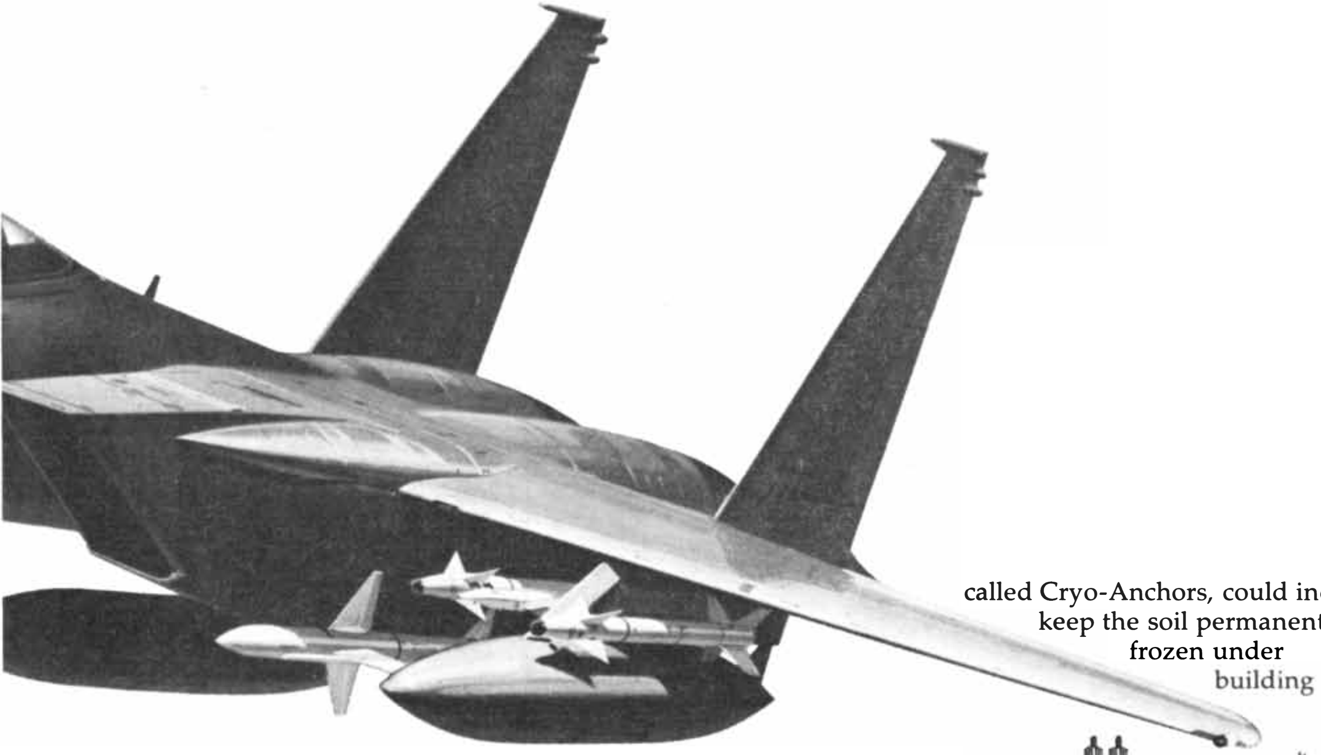
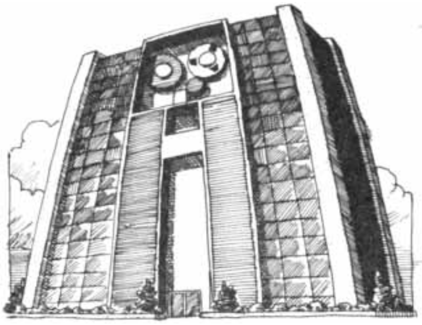
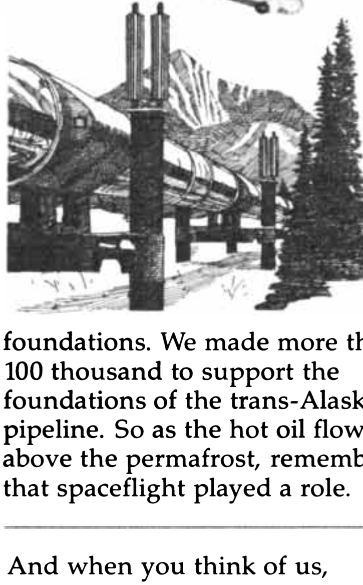








between the microwear caused by the cutting of the meat and the incidental wear caused by the contact between the flint and the cutting board.

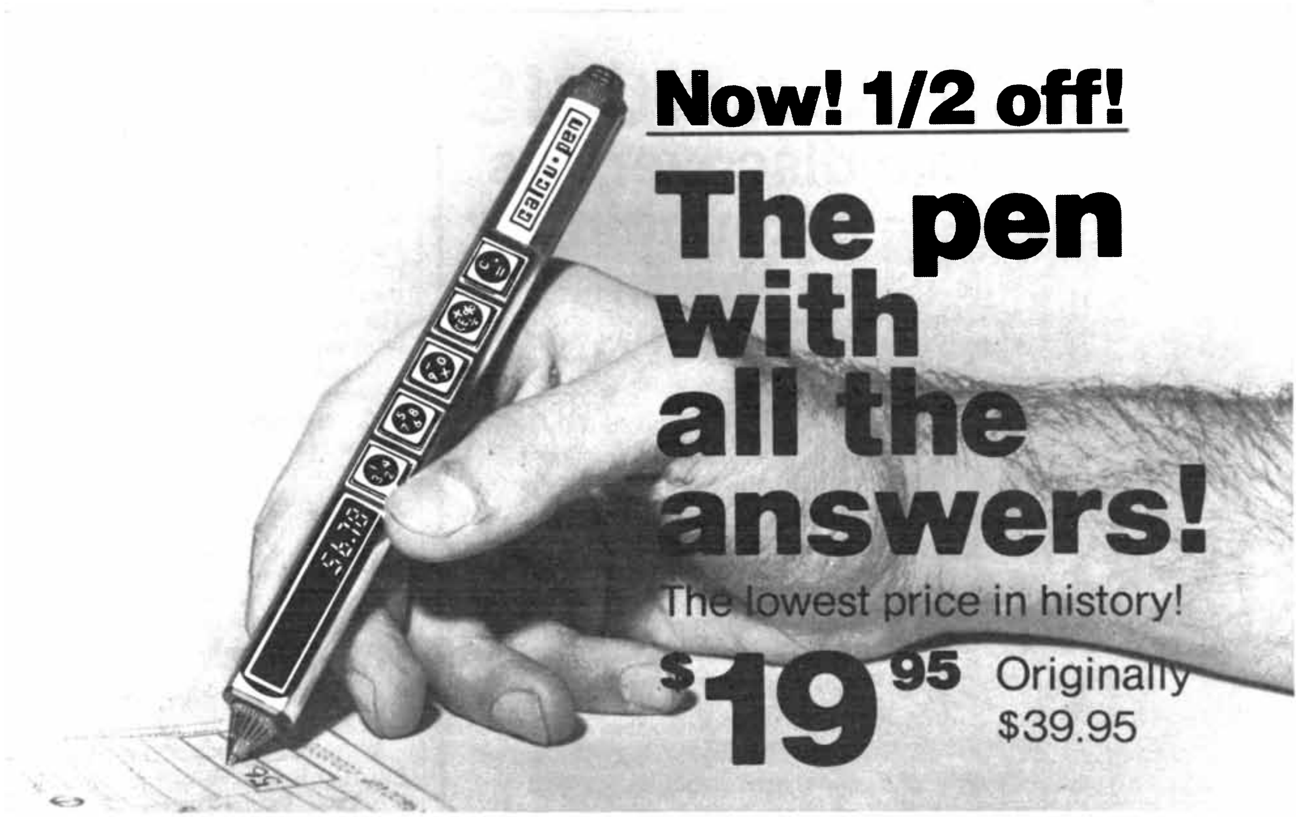
Even some of my misinterpretations were not unreasonable. For example, Newcomer had used the edge of one flint tool to cut frozen meat, which leaves few traces of wear. He had cut the meat on a wood board, however, and contact with the board did leave discernible traces. I interpreted the resulting microwear as characteristic of an implement used very delicately on wood. Since Newcomer's tests were the first check on the validity of high-resolution microwear analysis, I found the results quite encouraging.

It was now time to apply the technique to selected Paleolithic artifacts. Three classic British sites of the Lower Paleolithic period met the desired criteria. First, flint implements from all three sites are well preserved; they have not accumulated the surface patina that would conceal or destroy the evidence of microwear, and they have usually escaped damaging natural abrasion. Second, all the artifacts had been recently excavated, ensuring that their stratigraphic position in the ground had been recorded under strict controls and that they had been carefully handled and stored to eliminate the danger of post-excavation damage. The sites were at Clacton-on-Sea in Essex (the "Golf Course site"), at Swanscombe in Kent (the "Lower Loam") and at Hoxne in Suffolk (mainly the "Lower Industry").

The Clacton site has given the name Clactonian to an entire Lower Paleolithic flint-tool industry that flourished some 250,000 years ago during the early stages of the Mindel-Riss interglacial period. The distinctive flake tools of the Clactonian industry were made by striking rather coarse flakes off nodules of flint and trimming a few of the flakes into the desired shape. Some of the left-over "cores" of flint were also employed as tools.

The Lower Loam at Swanscombe is a somewhat later Clactonian site, occupied during the same Mindel-Riss interglacial period. The stone artifacts from the Lower Loam include tools made on flakes. Hoxne, a still later site, has yielded refined tools worked on both sides. These "bifacial" implements are typologically assigned to the Acheulean, a Lower Paleolithic industry named after Saint-Acheul, the site in France where such implements were first found. The Hoxne strata also contain an abundance of flint flakes, many of them the waste left over from production of the bifacial tools.

The total number of artifacts in suitable condition for microwear analysis was not large. The Clacton group included 144 tools from a layer of gravel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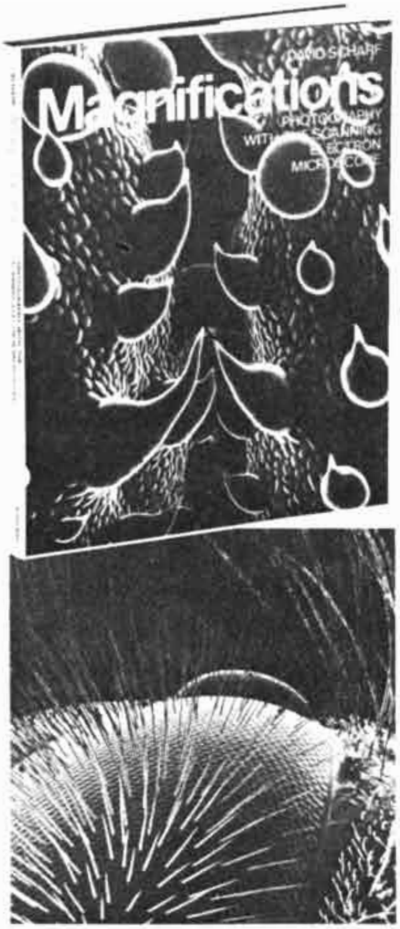

at the Golf Course site and 102 from a layer of marl. Some of the flakes could be fitted into the original core from which they had been struck, indicating that they had been made on the spot. Taken together with microwear evidence that the flake tools had been used for butchering, woodworking, hide-working and some work on bone, this suggests that the Golf Course site was probably occupied for some time rather than being a transient hunters' camp. The predominant activities at the site were woodworking and butchering.

Of the artifacts from Clacton that I examined 22 were the coarse bifacial tools that are traditionally classified as choppers. Microwear indicates that only two of the 22 had actually been used as tools. This is a utilization rate of 10 percent, about half the rate for the flakes found at the site. Of the flakes from the gravel 22 percent showed traces of use; of those from the marl 16 percent did. The relative ratios suggest that the Clacton toolmakers were primarily interested in using their flint cores to turn out flakes, as opposed to bifaces.

Sixty-six flake tools from the Lower Loam at Swanscombe were in suitable condition for microwear analysis. Of these only four actually showed traces of use. The microwear characteristics shown by the four flakes were much like those visible on flake tools from Clacton. The Swanscombe sample is too small, however, to allow any conclusion from this coincidence.

The artifacts from Hoxne included one group of tools (Lower Industry, Layer 3 West) with little or no abrasion damage. I studied the entire assemblage from that layer, numbering 408 implements. I also analyzed a random sample of artifacts from other Lower Industry and Upper Industry strata. The Acheulean industry at Hoxne, with its emphasis on the manufacture of bifacial tools, is marked by large quantities of flakes that must be counted as potential implements even though most of them are surely the debris of toolmaking, too thin-edged and fragile to be made into flake tools. Indeed, microwear analysis reveals that only 9 percent of the flakes from all the Lower Industry levels actually show evidence of wear.

The makers of the Hoxne tools used them for butchering, woodworking, hide-working and for boring wood and bone. Interestingly enough, some were also used to slice or cut plant material other than wood. These hunters may have gathered reeds or bracken for bedding. The butchering was not done exclusively with flake tools: two of the Lower Industry "hand axes" showed the polish characteristic of butchering implements.

Among the Upper Industry tools at

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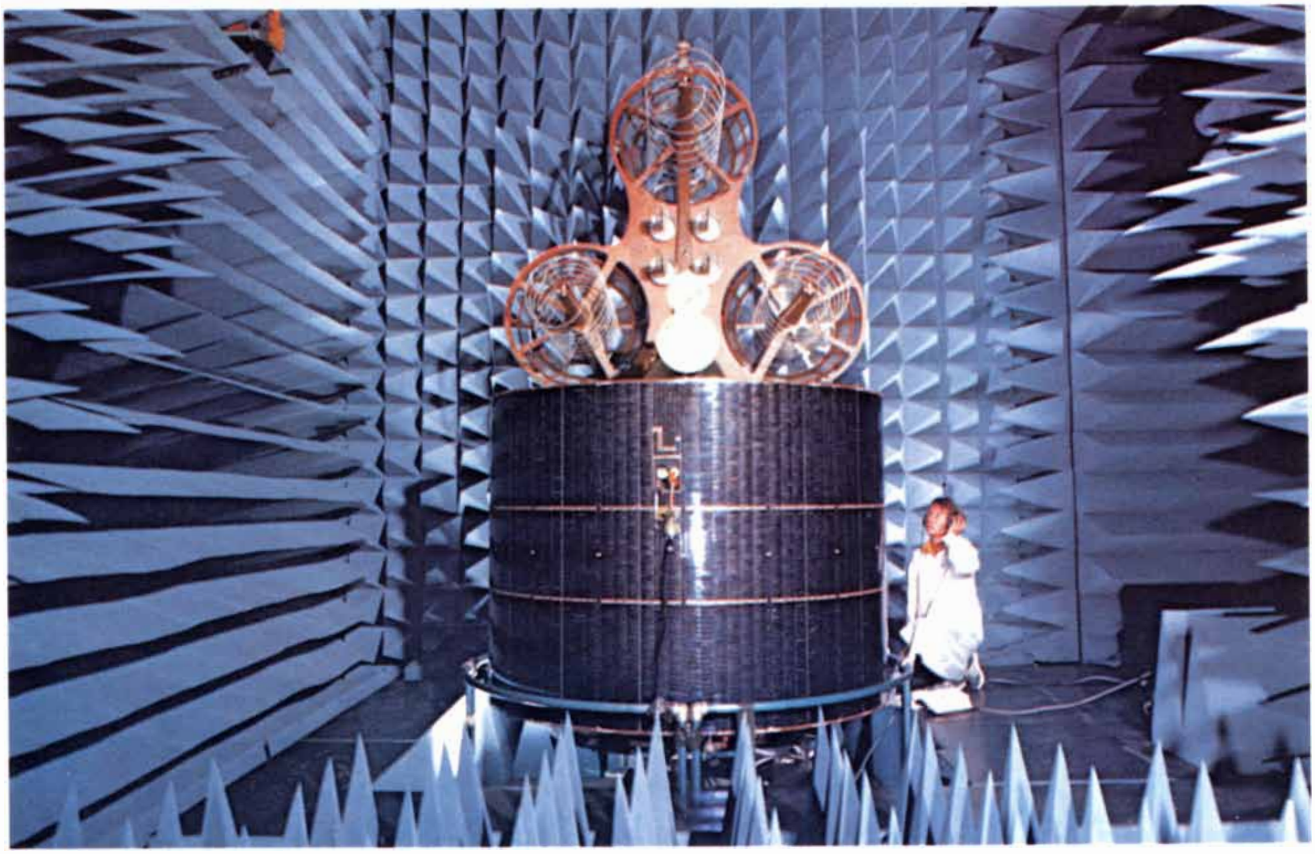
DP Dialogue

Notes and observations from IBM that may prove of interest to the engineering community



Marisat is a communications satellite made by Hughes to serve U.S. Naval and commercial maritime users. Here the satellite is placed in an anechoic chamber that isolates it from environmental electromagnetic and sound energy.

APL Brings the Computer to Hughes Engineers

Engineers at Hughes Aircraft Company communicate with an IBM computer through nearby terminals in a programming language called APL. A powerful language that can specify extensive computation with a few symbols, APL requires little experience or training in computer programming.

Says Robert Vuilleumier, a technical staff manager in Hughes' Los Angeles-based Space and Communications Group: "APL is a particular timesaver on problems which generate big data tables. For example, to tabulate the gain of a microwave antenna against temperature typically requires a listing of 17 columns by 30 lines. Preparing this table manually can take two days; the computer takes a few minutes.

"Quite often," Vuilleumier notes, "I need to recompute a table for a slightly different parameter value. Repeating the antenna analysis at a higher frequency would be an example. It takes only a moment to type in the new parameter and re-execute the program from the terminal."

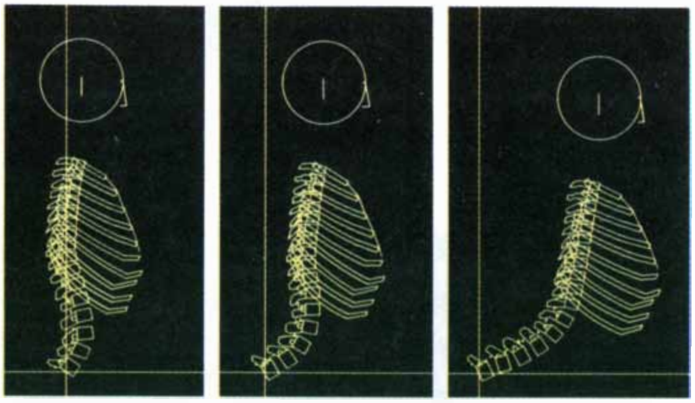
Adds George Williams, an engineering project manager who was instrumental in APL development at the group: "APL is very effective for small jobs with their own data bases, and for spur-of-the-moment programming. I have seen users arrive at the terminal and depart so quickly I thought they'd changed their minds, but they had actually finished writing and executing their programs.

"I recently watched someone define a plane on the basis of three points in space for a geometric calculation," he continues, "using only three lines of APL code. Conventional programming would have required three pages."

"In addition to engineers, managers use APL for manpower and budget planning, cost estimating for proposals, and facilities management," says Conrad Stensgaard, Jr.

Stensgaard, a senior staff engineer, helped install APL in the System/370 Model 158 in the Hughes Computation Center. "APL has brought the computer much closer to our users," he says, "lowering the 'threshold' of entrée to the machine for small tasks and making interactive computing directly available to the end user."

Simulated Spine Hastens Injury Research



The effect of a 30-mph automobile crash on the human trunk is shown by these drawings derived from a computer. A normal spine is at left; the center and right views show its position 20 and 40 milliseconds after impact.

This insight into the complex mechanics of the backbone was made possible by a mathematical model of the spine, developed on an IBM System/370 Model 158 at the Chicago Circle campus of the University of Illinois, sponsored in part by the Aerospace Medical Research Laboratory. Engineers at the university are studying the effects of injuries and disease on the back.

The potential benefit is far-reaching, since eight million people in the U.S. suffer from back problems, and half a million currently wear braces.

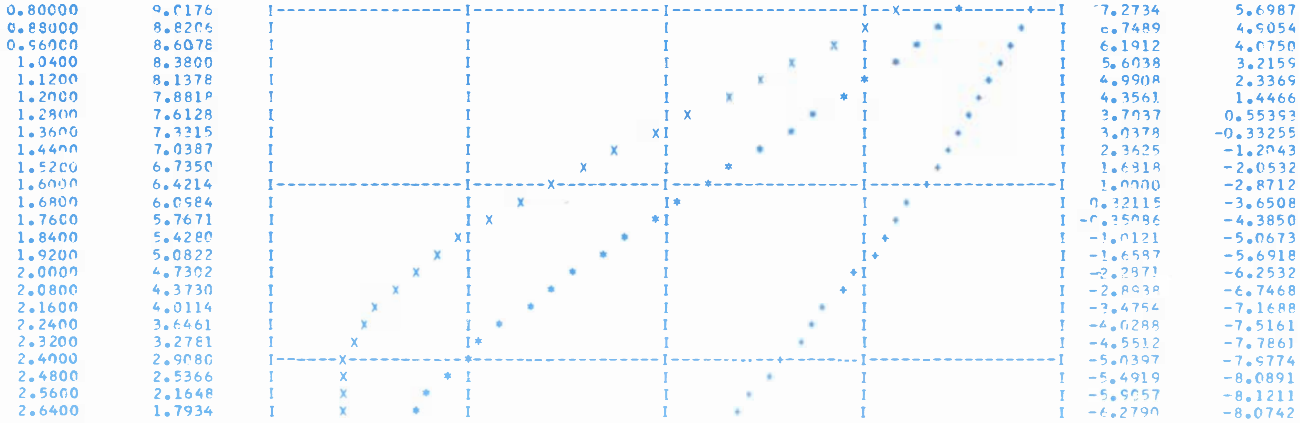
"We don't know much about that sophisticated structure we call the spine," says Dr. Albert B. Schultz, professor of mechanical engineering. "We're working with orthopedic surgeons to learn more, in the hope of preventing and treating back problems."

"Because we can apply engineering principles to the skeletal system," adds Dr. Ted B. Belytschko, professor of structural engineering, "we can sometimes determine in a few days responses to treatment which would take years to find by observing results of therapy."

In one experiment, the computer simulates the force applied to the spine by a therapeutic brace. "This helps show us the effectiveness of different modes of treatment," Dr. Schultz notes. "In treating lateral curvature of the spine, or scoliosis, the model has told us that applying pressure from the side will often be more effective than a stretching force."

By means of the computer model, engineers in the university group have predicted the effect of a hip-to-neck brace in a number of patients. The actual results of treatment supported the predictions in 80 percent of the cases.

Each year an additional 400,000 American workers incur back injuries; Dr. Schultz and his colleagues expect the computer model to help analyze their causes. The results will be available as guidance to therapists, orthopedists and industrial safety programs.



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 2.0800   4.3730  -2.8938   -6.7468
 2.1600   4.0114  -3.4754   -7.1688
 2.2400   3.6461  -4.0288   -7.5161
 2.3200   3.2781  -4.5512   -7.7861
 2.4000   2.9080  -5.0397   -7.9774
 2.4800   2.5366  -5.4919   -8.0891
 2.5600   2.1648  -5.9057   -8.1211
 2.6400   1.7934  -6.2790   -8.0742
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Models Aid Study of Continuous Systems

Simulation as a means of investigating the behavior of a complex physical system is often far simpler and less time-consuming than seeking an analytical solution.

Engineers or designers can create computer models of almost any complex mechanical, electrical or other physical system—aerodynamic components, control systems or industrial processes, for example—by means of IBM's Continuous System Modeling Program III (CSMP III). It can also be used in the analysis of systems with discrete components such as digital filters, control elements or logic.

An engineer can readily describe a system to the computer in the CSMP language, which includes 42 powerful functions for performing integration, differentiation, signal and function generation, Laplace transformation, and switching and logic.

Additionally, since Fortran IV is also a subset of the language, the user can build large functions and submodels specifically suited to his application. The CSMP III Library stores these functions, as well as arbitrary or experimental data, tables and complete models—any of which can be executed alone or in combination with other simulation elements.

The system to be modeled may be entered as a set of differential equations, or as interconnected blocks, each characterized as a mathematical function. CSMP III simulates with time as the independent variable and stores the successive values of as many as 220 dependent variables. Up to 55 of these may be printed during the run, and as many as five may be print-plotted simultaneously. Trial runs quickly show which simplifications of the real system can be made with no significant loss in accuracy.

With its Graphics Feature, CSMP III can display up to four co-ordinate grids on an IBM 2250 Graphic Display Terminal, with up to four variables plotted on each grid. Experimental data can be displayed graphically and edited interactively before it is incorporated into a simulation model.

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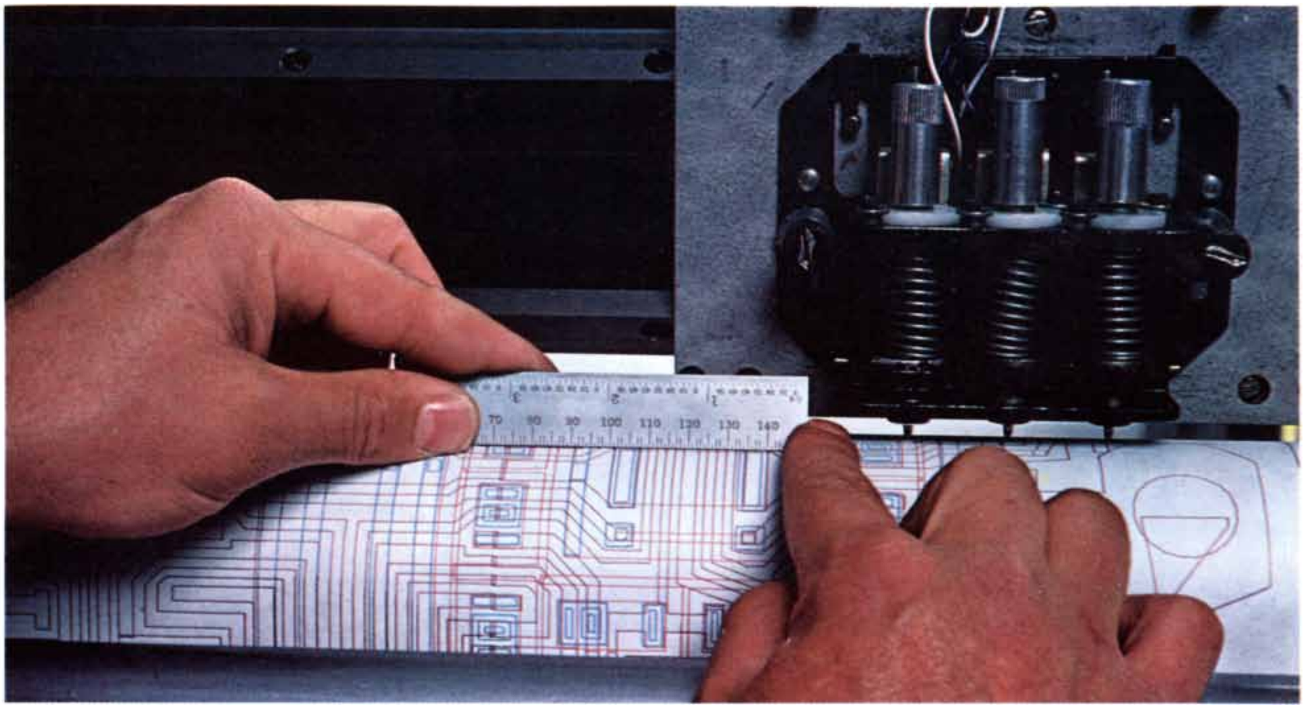

When computer-aided design of the integrated circuit chip is complete, a computer-driven plotter draws a three-color layout of the circuit in large scale.

Computer Designs and Fabricates Computer Circuits

Today's high-speed, high-capacity computer systems depend on advanced electronic devices using Large Scale Integration technology. This microminiaturized circuitry puts thousands of memory or logic circuits into a space a quarter-inch square or less, making possible speeds of billionths of a second.

At IBM's General Technology Division facility in Burlington, Vermont, the computer itself is instrumental in the design and production of these advanced semiconductor devices. Engineers there are using a System/370 Model 168 and IBM 2250 Graphic Display Terminals to design and produce the high-precision photo-masks that are critical to the fabrication of integrated circuit "chips." Intricate patterns are successively overlaid using a lithographic process to build a finished chip containing thousands of individual memory cells.

To create a tentative design for a mask, an engineer draws lines with a light pen directly on the face of a graphic display terminal connected to the Model 168. The system automatically resolves the sketch into a precise pattern of straight lines and geometric shapes.

"It's easy to move elements around on the screen, trying alternative layouts until we find the optimum use of the space available on a chip," says Paul Serednicky, manager of computer-aided graphics. "We can rapidly try so many alternatives that we are finding much more efficient layouts than we ever could manually on a drafting board.

"Since the finished device usually consists of one memory cell pattern repeated many times," Serednicky adds, "the engineer can develop it once in detail. The system then replicates it the required thousands of times, automatically rotating it, generating mirror images and adding interconnections.

"Perhaps most significant, though, is that the computer generates a tape that guides automatic production of the mask itself in the final size. Previously, we had to draft the design by hand, and then use it as a guide in the preparation—also manual—of an oversized mask.

"Any change forced us to start over again from the beginning and repeat the manual process. Now we can go back at any time and make a change or improvement in the mask design. We can accommodate an engineering change in minutes instead of weeks."

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Hoxne were a small number of the flake implements that are traditionally called "side scrapers" and are presumed to have played a role in the dressing of hides. The microwear on these tools lends support to the guess of the traditionalists; most of the side scrapers show the polish characteristic of hide-working tools.

To cite one further example of microwear analysis, a bifacial tool from Clacton was found to show wood polish on its working surface. Further examination revealed utilization damage that could only have come from a rotary motion such as boring; the tool had been turned in a clockwise direction at the same time that downward pressure was being applied. Similar wear patterns also appear on flake tools that were used for boring. The patterns suggest that the Clacton woodworkers of perhaps 200,000 years ago were consistently right-handed.

The seeming wastefulness represented by the 9 percent rate of flake utilization at Hoxne may be more apparent than real; most of the flakes were biface-manufacture waste and unsuitable for use as tools. The prodigal use of flint at Clacton cannot be similarly explained away as the debris of bifacial-tool production. Perhaps at both sites much of the waste is better explained by the fact that chalk flint, an excellent raw material for the making of stone tools, can be found easily almost anywhere in southeastern England: in river gravels, on beaches and other superficial deposits and of course in exposures of the chalk itself.

The microwear analysis of work polishes on this group of Lower Paleolithic implements provides the first direct and unequivocal evidence of the kinds of human activity that took place at English campsites roughly 250,000 years ago. Such findings make it clear that a new and rewarding method of archaeological research has finally come of age. It is now possible, assuming that the tools have been suitably preserved, to determine in most instances not only how ancient flint tools were used but also what they were used on.

It seems very likely, although it remains to be proved, that microwear that can be interpreted in similar ways is present on tools made from stone materials other than flint, such as obsidian, chert and even fine-grained basalts and quartzites. I have found this to be true of one fine-grained chert from southern Africa; experiments show that the material retains microwear polishes that are directly comparable to those found on chalk flint. The information derived from future microwear studies should enable prehistorians to discuss with increasing confidence the technology and economy of early man.

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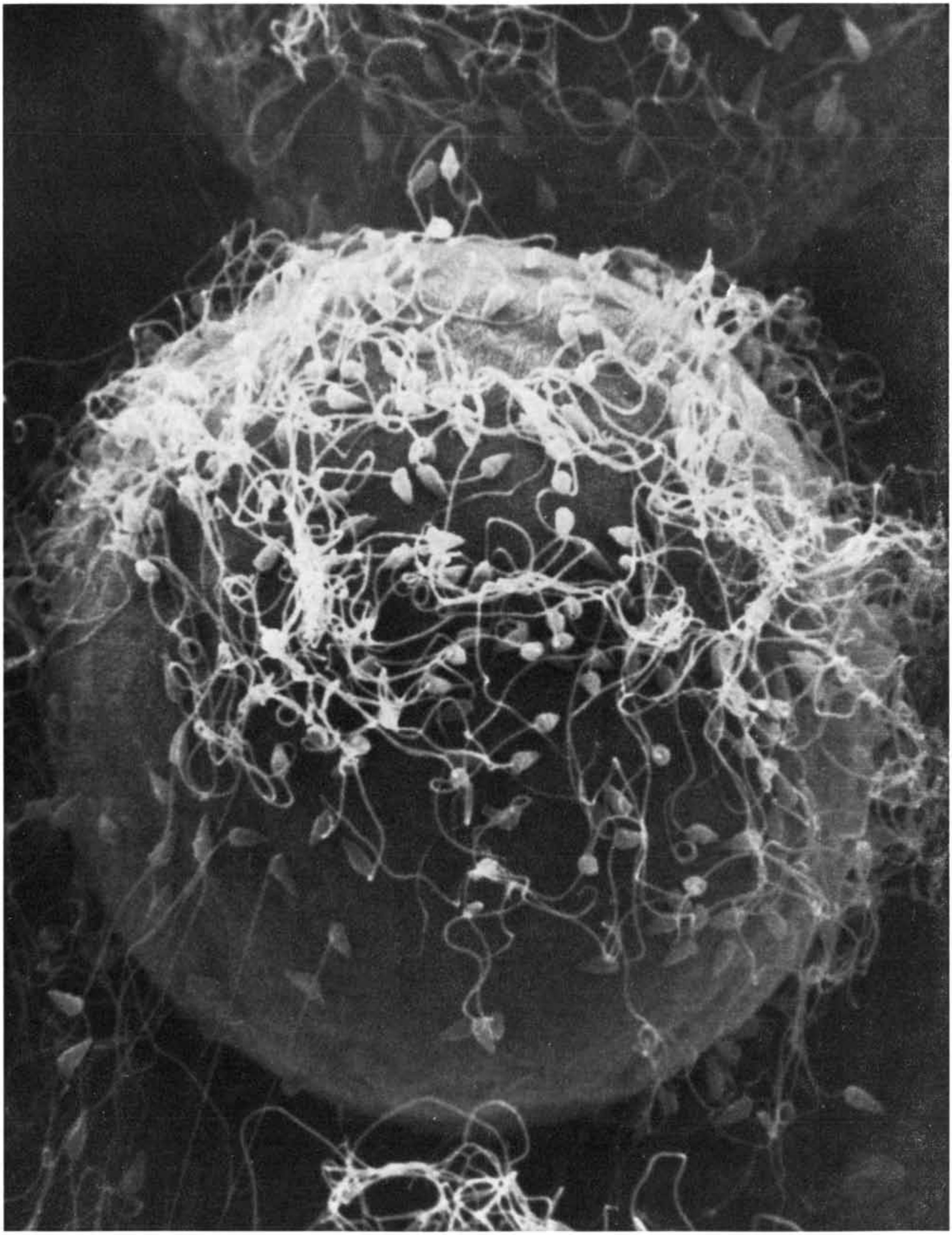


THOUSANDS OF SPERM bind to the surface of a sea-urchin egg in this scanning electron micrograph made by Mia Tegner in the author's laboratory. The egg surface seen here is not the plasma membrane, the outer membrane of the egg cell proper, but a coat known as the vitelline layer, which contains receptor sites for the sperm. In spite of the vast numbers of sperm only one sperm is allowed to fertilize the egg. If more than one gets through (the condition called polyspermy), there will be an excess of paternal chromosomes and embryo will abort in embryogenesis. Animal eggs have evolved mechanisms to prevent polyspermy. The magnification is 2,880 diameters.

The Program of Fertilization

The fusion of a sperm and an egg triggers a series of transient changes in the concentration of ions that prevents the fusion of additional sperm and initiates development of the embryo

by David Epel

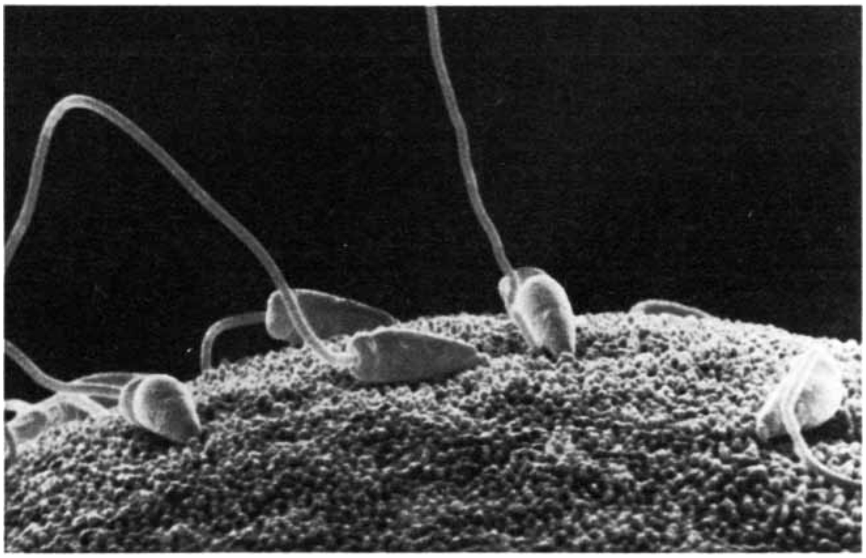
The interaction of a sperm and an egg marks a dividing line between life and death. If the two cells interact successfully and fertilization occurs, their nuclei (each containing half of the full complement of chromosomes) will combine, and the development of a new individual will begin. If successful interaction does not occur, the two cells will die within hours or at the most a few days. Living organisms therefore expend much physiological and behavioral energy ensuring that these two cells will meet and that fertilization will take place.

The process of fertilization can be divided into three major steps: the recognition of the egg by the sperm, the regulation of the entry of the sperm by the egg so that the genetic material of only one sperm will combine with that of the egg, and the activation of the dormant metabolism of the egg so that cell division and embryonic development can begin. Over the past few years intensive biochemical investigation has begun to provide a description of these events at the molecular level. The concepts derived from these studies may help us to comprehend other cellular transformations, such as those that occur in cancer, and may also provide new approaches to the control of human fertility.

The eggs of marine invertebrates, particularly echinoderms (such as sea urchins, sand dollars and starfishes), are the classical preparation for the study of fertilization. These animals release vast numbers of gametes (egg or sperm cells), only a few of which successfully interact in seawater to give rise to viable offspring. Sea urchins, for example, have a breeding season that lasts from three to eight months, during which a female can release up to 400 million eggs and a male as many as 100 billion sperm. Notably valuable to the investigator is the fact that the eggs and sperm can be easily removed from these organisms and allowed to combine in laboratory glassware. One merely suspends the eggs in seawater and adds a small amount of sperm while stirring. Within seconds the eggs are synchronously fertilized, and one can then study the events that occur not in one fertilized egg but in an entire population of them.

In 1877 centuries of speculation about the role of semen in procreation came to an end when the Swiss zoologist Hermann Fol watched through his microscope as a starfish sperm cell attached itself to and fertilized a starfish egg. Only recently, however, have many of the fundamental questions about the mechanism of fertilization begun to be answered. One problem that long confronted biologists is how the sperm specifically recognizes the egg. Although the sperm appear to reach the egg by virtue of their numbers and by chance, some mechanism must prevent the sperm from fusing with any other kind of cell it may encounter along the way.

The specific recognition of the egg by the sperm is believed to occur when the sperm makes contact with the jelly coat that surrounds the egg. Substances in the jelly coat interact with the plasma membrane, the outer membrane of the sperm cell, at the tip of the sperm. This region on the sperm cell, known as the acrosome (from the Greek for sharp body), is altered by the interaction and releases digestive enzymes that enable the sperm to dissolve a hole in the layers surrounding the egg, so that the sperm can reach the surface of the egg proper. In invertebrates such as the sea urchin the acrosome simultaneously undergoes a remarkable structural change: it exudes a thin filament called the acrosomal process that attaches itself to the vitelline layer of the egg, a thin membrane underlying the jelly coat. The attachment site is apparently a receptor protein associated with the vitelline layer that recognizes and binds to a complementary protein on the acrosomal process. Indeed, Kenji Aketa and his colleagues at Nagoya University and Victor D. Vacquier and his colleagues at the University of California at Davis have independently isolated the complementary pro-

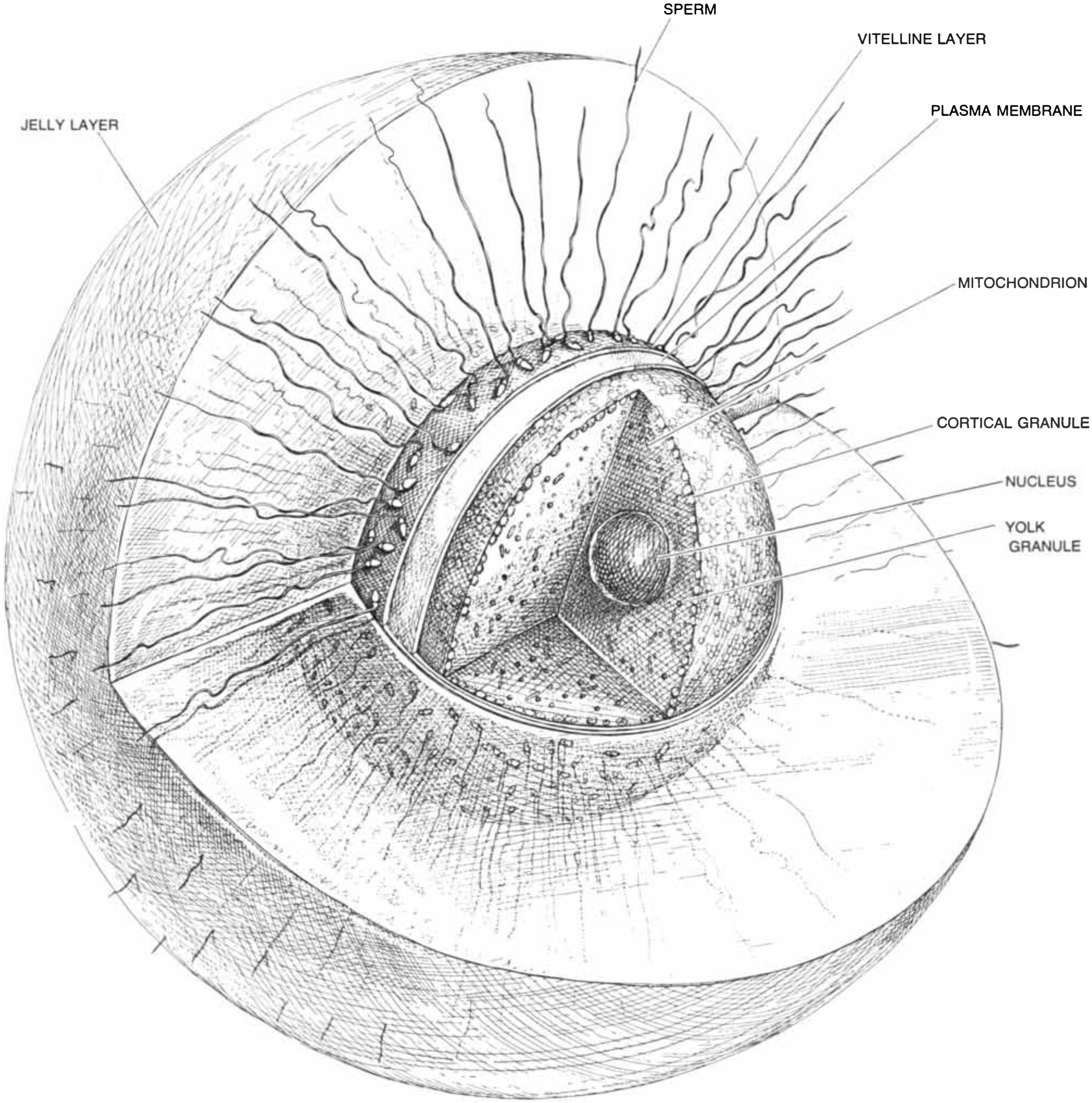


CLOSE-UP OF THE SURFACE of a fertilized sea-urchin egg shows several sperm bound to the vitelline layer. The egg surface is covered with tiny projections of the plasma membrane called microvilli. The micrograph was made by E. William Byrd in the author's laboratory.

teins. These workers found that if antibodies to the receptor proteins are prepared and are added to the suspension of eggs before the addition of sperm, fertilization cannot occur.

Once the tip of the acrosomal process has interacted with the receptor site, it perforates the vitelline layer and fuses with the underlying plasma membrane of the egg. The plasma membranes of the two cells then become continuous, forming a bridge that progressively enlarges until the entire sperm is surrounded by the egg plasma membrane and is incorporated into the egg.

Although only one sperm normally fuses with the egg plasma membrane and enters the egg, many supernumerary sperm also attach themselves to the surface of the egg during insemination. Scanning electron micrographs made by Mia Tegner in my laboratory at the Scripps Institution of Oceanography have revealed that under saturating con-



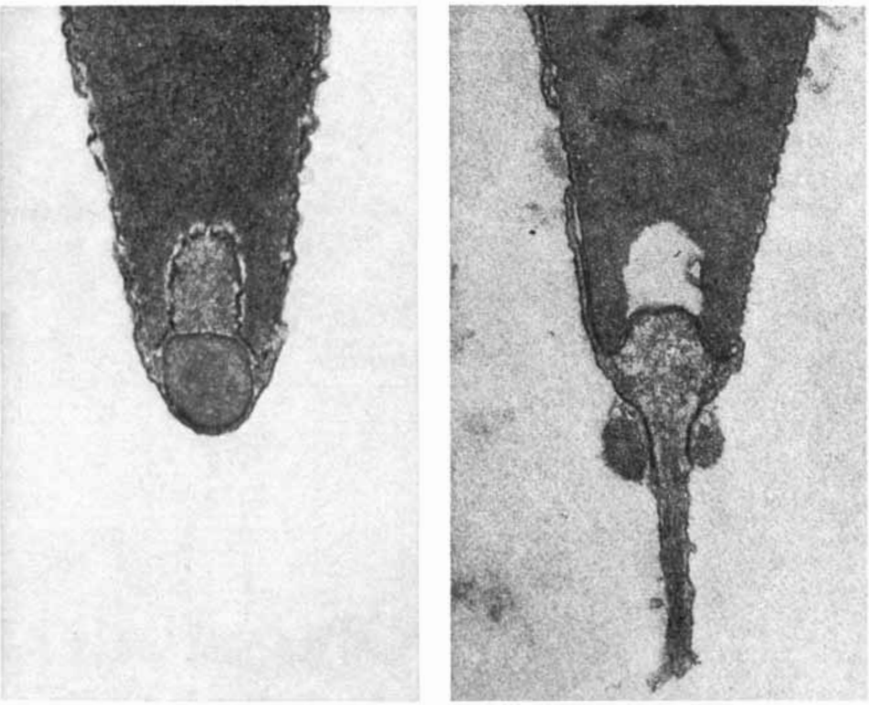
SEA-URCHIN EGG is diagrammed in section at the moment of fertilization. The egg is 75 micrometers in diameter and is entirely surrounded by a thick jelly layer, through which the sperm penetrate, probably by dissolving holes in it with digestive enzymes. The sperm then bind to receptor sites on the vitelline layer. Just below the plasma membrane are thousands of one-micrometer cortical granules, which fuse with the plasma membrane seconds after fertilization and release their contents into the space between the membrane and the vitelline layer. The protoplasm of the egg contains numerous yolk granules and mitochondria (which respectively provide food and chemical energy) and a single nucleus containing half of the normal complement of chromosomes. The halving of chromosome number in the unfertilized egg is the result of the reductive cell division called meiosis, which takes place at a late stage of egg maturation. The fusion of a single sperm with the egg provides the other half of the normal chromosome complement and activates the egg to begin embryonic development.

ditions as many as 1,500 sperm can attach themselves to a single egg. Although this redundancy is necessary to ensure that at least one sperm will fertilize the egg, it is potentially troublesome: if more than one sperm enters the egg, a condition known as polyspermy, the number of chromosomes will be larger than the normal full complement and development will be aborted early in embryogenesis. Animal species have therefore had to evolve mechanisms for preventing more than one sperm from entering the egg.

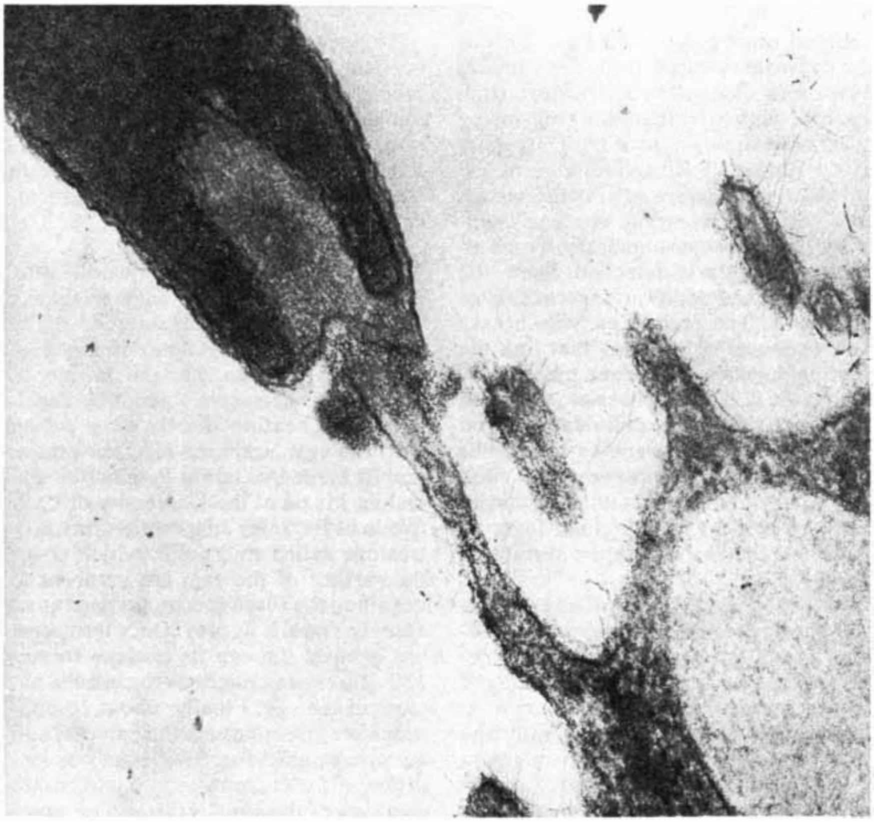
Work on the sea-urchin egg in the 1950's by Lord Rothschild and Michael M. Swann in England suggested that there are two separate barriers to polyspermy: a fast and incomplete block occurring within the first few seconds of sperm-egg contact, followed by a slower and more complete block. The nature of the early block has recently been revealed by the Ph.D. research of Laurinda Jaffe at the University of California at Los Angeles. She inserted microelectrodes into a sea-urchin egg and measured the changes induced by fertilization in the voltage between the inside and the outside of the cell. She found that about a second after the attachment of the sperm there is a flow of sodium ions into the cell, causing a brief voltage shift resembling that of a nerve impulse. The voltage change is apparently responsible for keeping the supernumerary sperm from entering the egg. In support of this hypothesis Jaffe found that when she artificially increased the voltage across the membrane of unfertilized eggs to the level normally observed after fertilization (with the aid of a "voltage clamp" system) and then added sperm to the eggs, fertilization did not occur.

Investigations of the slower block to polyspermy have focused on the cortical reaction: a massive structural change in the egg that occurs shortly after fertilization. As we have seen, the plasma membrane of the unfertilized egg is surrounded by the thin membrane of the vitelline layer. Directly below the plasma membrane is the cortical layer, which contains some 15,000 tiny vesicles called cortical granules, each one about a micrometer (10^{-3} millimeter) in diameter. Some 25 to 35 seconds after the acrosomal process of the fertilizing sperm penetrates the vitelline layer, the cortical granules fuse with the plasma membrane and discharge their contents into the space between the plasma membrane and the overlying vitelline layer. The reaction begins at the site of sperm-egg fusion, rapidly propagates over the entire surface of the egg and is complete within an additional 20 seconds.

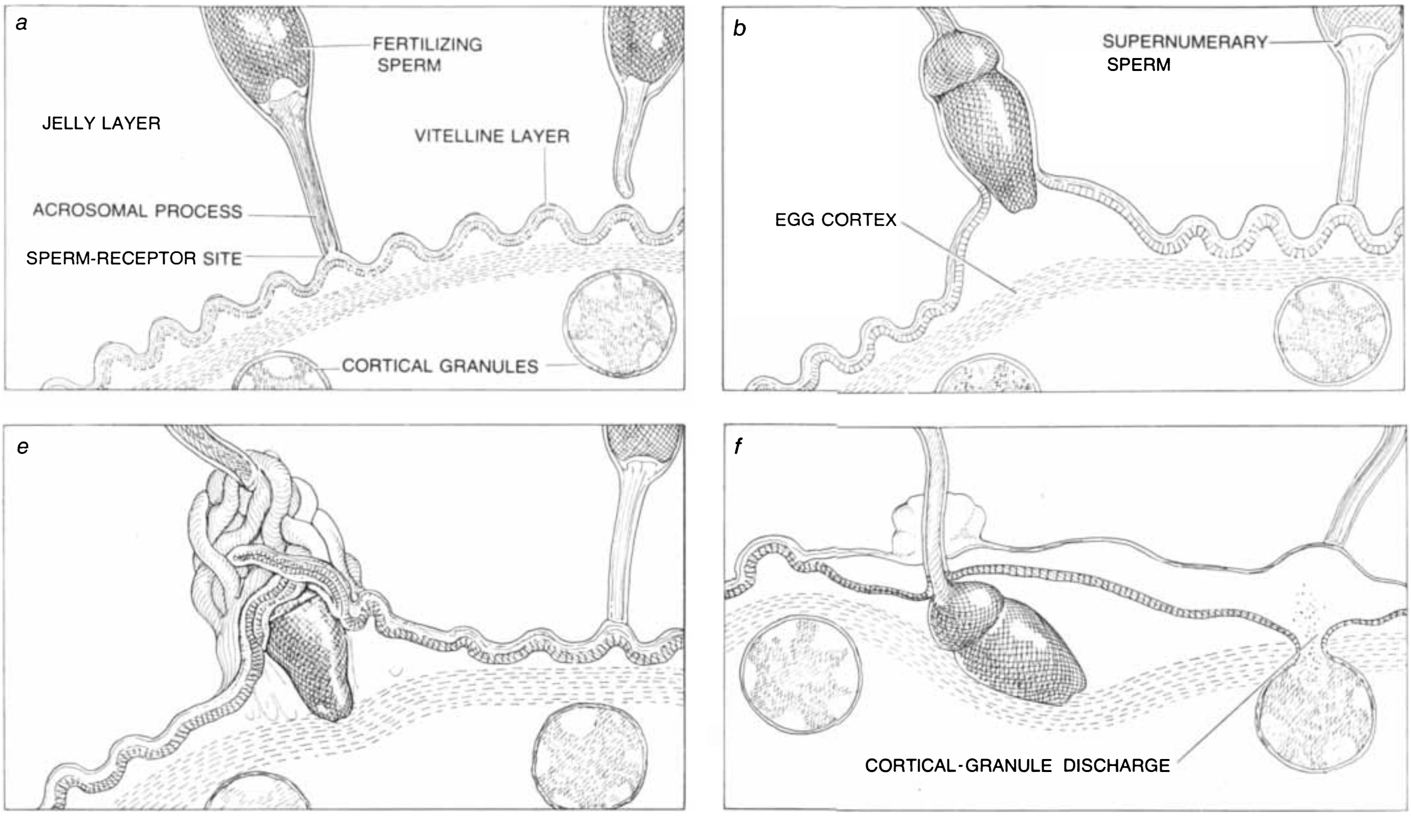
Analysis of the contents of the cortical granules has revealed that they contain a mixture of enzymes, structural proteins and colloidal materials called



DRAMATIC STRUCTURAL CHANGE occurs in the sperm of sea urchins and other invertebrates following the initial sperm-egg interaction. The tip of the sperm head exudes a thin filament known as the acrosomal process; this filament then penetrates the vitelline layer of the egg and fuses with the egg plasma membrane. The pair of transmission electron micrographs shown here, made by Frank Collins of Stanford University, show a sperm of the sea urchin *Lytechinus pictus* before and after formation of process. Magnification is 45,500 diameters.



MOMENT OF FUSION between the tip of the sperm acrosomal process (*left*) and an egg microvillus is captured in this transmission electron micrograph, also made by Collins. The fusion results in the formation of a cytoplasmic bridge through which the sperm cell enters the egg.



CORTICAL REACTION is induced by the fusion of the fertilizing sperm with the egg. In this sequence the acrosomal process of the sperm penetrates the vitelline layer and fuses with the egg plasma membrane (*a, b*). The microvilli in the vicinity of the sperm elongate and then interdigitate over the sperm head, drawing it into the egg (*c–e*). Entry of the sperm is accompanied by the fusion of 15,000 cortical granules with the egg plasma membrane and the release of their contents into the space below the vitelline layer (*f*). The reaction spreads

sulfated mucopolysaccharides. Two of the enzymes released from the granules have been characterized by Edward J. Carroll, who was then working in my laboratory and is now at the University of California at Riverside. One of the enzymes specifically alters the sperm-receptor proteins on the vitelline membrane, so that supernumerary sperm already bound are detached from the membrane and additional sperm cannot bind to it. The second enzyme breaks down connective proteins that link the vitelline layer to the plasma membrane, so that the two membranes are detached from each other. The colloidal material released from the granules then pulls water into the space between the vitelline layer and the plasma membrane by osmosis, causing the vitelline layer to swell and lift away from the surface of the egg.

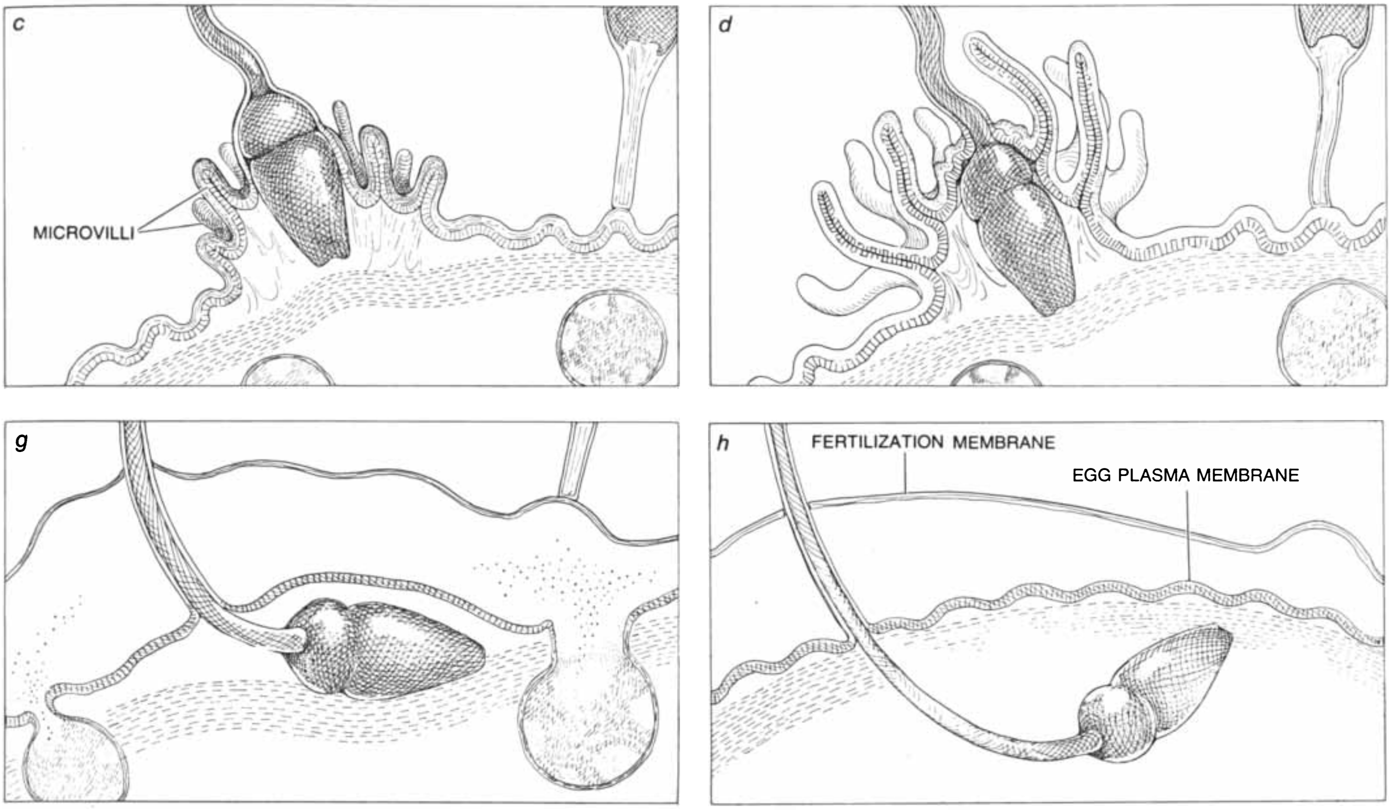
Within a minute of sperm-egg contact structural proteins derived from the cortical granules associate with the detached vitelline layer, transforming it into a protective envelope known as the fertilization membrane. Meanwhile other colloidal material derived from the granules covers the surface of the egg to form a transparent membrane called the hyaline layer, which later plays an important role in holding together the cells formed by the cleavage of the egg.

This sequence of events following the cortical reaction provides a formidable block to polyspermy. The destruction of the sperm-binding sites and the formation of the fertilization membrane effectively prevent supernumerary sperm from approaching the plasma membrane and fusing with it.

If all goes well, during and following the cortical reaction a single fertilizing sperm enters the egg. The mechanism by which this occurs is still not understood, but it does not depend on the motility of the sperm; the sperm's whiplike flagellum stops beating shortly after fusion with the egg. Scanning electron micrographs made by Gerald P. Schatten and Daniel Mazia at the University of California at Berkeley suggest that tiny protrusions called microvilli, which cover the surface of the egg, are involved in engulfing the fused sperm, perhaps as an amoeba engulfs its prey. Once the sperm has entered the egg its nucleus rotates 180 degrees and migrates toward the nucleus of the egg. Finally, about 20 minutes after insemination, the paternal and maternal nuclei fuse. With the condensation of the chromosomes and the first cleavage of the egg, fertilization is completed and embryonic development has begun.

Before the egg is fertilized it exists in a metabolically repressed state. The exact extent of this repression is unclear, but respiration, the transport of substances into and out of the cell and the synthesis of protein and RNA are considerably reduced, and DNA synthesis is completely shut off. At fertilization there is a general activation of the cell's dormant metabolism and an initiation of embryonic development. This activation and initiation does not result from the provision of some factor missing from the sperm, because eggs can be experimentally induced to develop simply by pricking them with a pin or exposing them to salt or acid solutions. Although the resulting embryos usually do not survive because they possess only half of the full number of chromosomes characteristic of the species, allowing lethal recessive genes to be expressed, the fact that the egg can be activated in this way means the sperm merely triggers a genetic program that has already been laid down in the egg.

When I first began 13 years ago to study the biochemical events underlying egg activation, I was fascinated but bewildered by the large number of changes that are evoked in the sea-urchin egg by fusion with the sperm. My initial research showed that the activation process can be broken down into two distinct phases: a constellation of "early" changes occurring during the first 60 seconds after sperm-egg contact and a series of



over the entire egg surface in 20 seconds. One enzyme released from granules destroys the sperm-receptor sites on the vitelline layer; a second enzyme causes vitelline layer to elevate from the egg surface, carrying away the supernumerary sperm (*g*). Structural proteins released from granules then transform detached layer into a protective envelope termed the fertilization membrane (*h*). Sperm nucleus later rotates 180 degrees within the egg and fuses with egg nucleus. Drawing is based on one made by Gerald P. Schatten of Florida State University.

"late" changes beginning five minutes after contact.

The current view of the program of fertilization changes indicates that the early changes begin with an influx of sodium ions about three seconds after the addition of sperm, which, as we have seen, constitutes an early block to polyspermy. A second change, beginning at about 20 seconds, is a sudden increase in the concentration of calcium ions inside the cell. A few seconds later sperm entry and the cortical reaction begin. Almost simultaneously there begin a massive influx of sodium ions from the seawater into the egg and a discharge of acid (hydrogen ions, or protons) from the egg into the seawater. The acid release, as we shall see, results in a large decrease in the acidity of the egg's cytoplasm.

Three seconds after the start of the cortical reaction an enzyme is activated that converts about half of the cell's supply of the coenzyme NAD into its phosphorylated form, NADP. Both of these substances are forms of the *B* vitamin niacin; the conversion from one to the other shifts the metabolism of the cell to a more reducing and hence more synthesizing state. Then, some 10 to 20 seconds after the start of the cortical reaction, or about 35 to 45 seconds after the addition of sperm, there is a large rise in the oxygen consumption of the egg. At about the same time glucose-6-phosphate dehydrogenase, one of the enzymes required for the metabolism of sugars, is released into the cytoplasm from storage depots inside the cell.

The late changes, beginning five minutes after insemination, include biosynthetic events that are of paramount importance to embryonic development. At this time the rate of protein synthesis begins to rise, and there is an increased exchange of potassium ions across the cell membrane. Also at five minutes transport systems are activated that bring into the cell amino acids, phosphate and nucleosides: the various building blocks from which protein and DNA are made. At 20 to 25 minutes the first cycle of DNA synthesis begins.

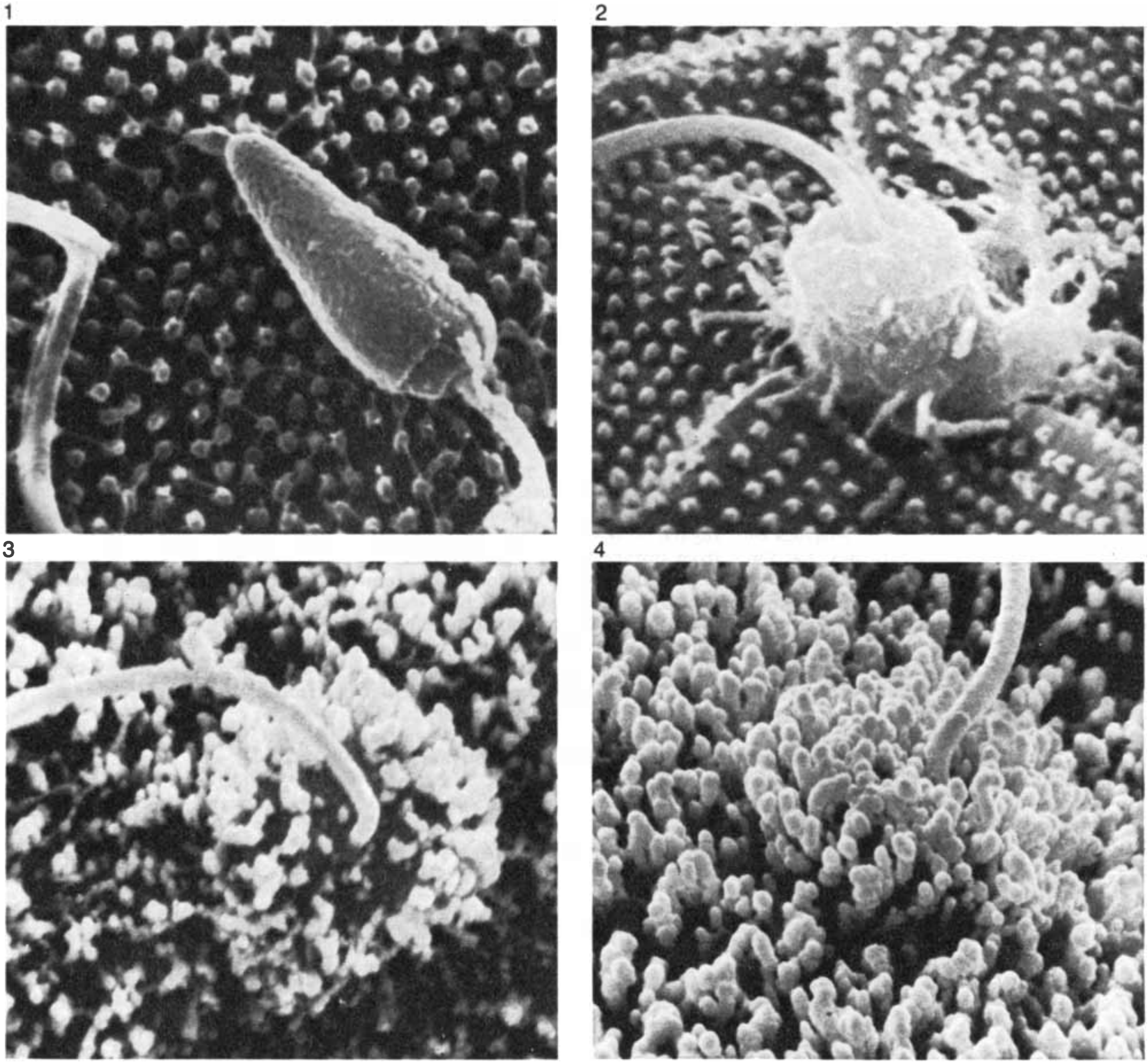
How can the fusion of a sperm with only .0002 percent of the egg surface be sufficient to trigger all these changes? One explanation is that the tiny perturbation caused by the sperm is amplified at or near the egg surface and that the amplified signal is then relayed to the biochemical machinery in the cytoplasm. In other systems intracellular messengers such as cyclic AMP and small ions such as calcium do indeed function in this way. The events of activation, however, have not been correlated with an increase in the level of cyclic AMP.

In 1937 my former professor Mazia, who was then working in the laboratory of L. V. Heilbrunn at the University of Pennsylvania, first observed that the concentration of calcium ions inside the egg increases after fertilization. Today Mazia's findings would be considered suspect because the increase in calcium levels had been detected in homogenates of eggs prepared at various times after fertilization. Perhaps, it could be argued, the observed increase is simply an artifact of the disruption of the cells.

The validity of Mazia's observations were verified, however, in an experiment performed recently by Ellis B. Ridgway of the Medical College of Virginia in collaboration with John C. Gilkey and Lionel Jaffe of Purdue University. They made use of the luminescent protein aequorin, which is extracted from a jellyfish. Aequorin glows only in the presence of calcium ions, so that it is a useful probe for detecting changes in the amount of free calcium inside cells. When Ridgway and his collaborators injected aequorin into the large unfertilized eggs of a fish, the Japanese medaka (*Oryzias latipes*), they observed a low level of luminescence. Within a minute after fertilization, however, the luminescence increased ten-thousandfold, indicating that large amounts of calcium had been liberated inside the egg. The luminescence remained high during the period of the cortical reaction, and then it decreased back to the original low level. If the investigators first sat in a darkened room to adapt their eyes and then fertilized a single egg, they could actually see the glow of the egg with the unaided eye.

Mazia had originally suggested that the increase in free calcium induced by fertilization was related to egg activation, but he was not sure whether the increase was a primary cause of activation or simply a result of it. Several years ago Richard A. Steinhardt of the University of California at Berkeley and I, and independently Edward L. Chambers, Berton C. Pressman and Birgit L. Rose of the University of Miami School of Medicine, realized that we could distinguish between these two alternatives with the aid of the recently discovered antibiotic ionophore A23187. Ionophores in general are drugs that make the cell membrane selectively permeable to certain ions. A23187 in particular makes the membrane permeable to doubly charged positive ions such as magnesium or calcium. If increased calcium alone caused the activation of the egg, we reasoned, then the presence of this ionophore should trigger development parthenogenetically (in the absence of sperm).

We both found that the ionophore was indeed an exceptional parthenogenetic agent. It activated sea-urchin eggs faster than sperm and with a sequence of events identical with that accompanying normal fertilization. In collaboration with Carroll in my laboratory and with Ryuzo Yanagimachi of the University of Hawaii School of Medicine, Steinhardt and I found that the ionophore



INCORPORATION OF THE FERTILIZING SPERM into the egg is shown in this series of scanning electron micrographs. First the sperm attaches to the vitelline layer by its acrosomal process (*1*); then it fuses with the egg plasma membrane. The egg responds with a localized elongation of its microvilli, which begin to surround the fused sperm (*2*). Next the cortical reaction takes place, resulting in the elevation of the vitelline layer and its transformation into the fertilization membrane. The final two views were obtained by removing the fertilization membrane from the egg. Three minutes after fertilization the sperm is about half-incorporated into the egg and is covered by the egg plasma membrane (*3*); one minute later only the sperm's tail is visible (*4*). Views *1*, *3* and *4* were made by Tegner; view *2* was made by Schatten and Daniel Mazia at the University of California at Berkeley. Micrographs are magnified 15,000 diameters.

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activated eggs from a wide variety of animal phyla, including the tunicates; the mollusks, the amphibians and the mammals. To our surprise activation occurred in the absence of calcium or magnesium in the seawater, suggesting that the mechanism of action of the drug was to free ions from stores bound to membranes within the cell. The ions that were liberated were presumably calcium because the bulk of the magnesium ions in the unfertilized sea-urchin egg are in the free state, whereas calcium ions are in a bound form from which they can be released.

What exactly is the calcium doing? An elegant experiment performed by Vacquier indicates that calcium directly induces the fusion of the cortical granules with the plasma membrane of the egg. Vacquier attached unfertilized sea-urchin eggs to a glass microscope slide that had been coated with a positively charged "sticky" protein such as protamine. He then subjected the attached cells to a jet of calcium-free water, causing the cells to burst and leave behind their plasma membrane together with its associated cortical granules. Vacquier then found that the cortical granules of these "inside out" cells could be made to discharge their contents when calcium was added to them.

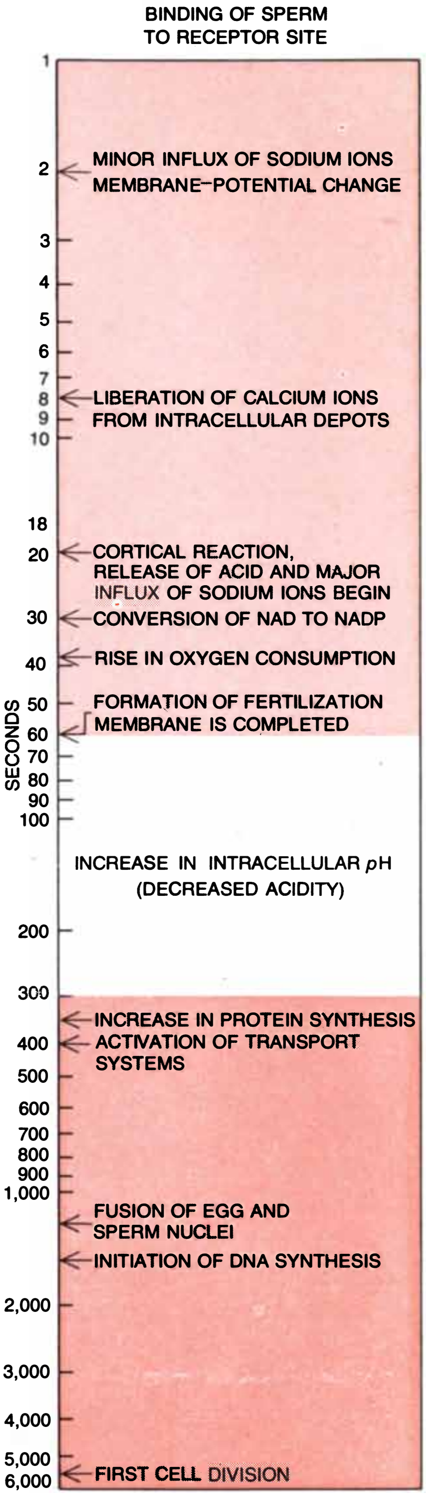
Does the calcium-induced cortical reaction trigger the late events such as protein and DNA synthesis? Several important observations indicate that this is not the case. For example, a number of drugs that block the cortical reaction do not prevent the activation of embryonic development. Moreover, in 1972 Steinhardt and Mazia found that by incubating unfertilized eggs in low concentrations of ammonia they could activate several of the late changes such as protein synthesis, DNA synthesis and even chromosome condensation without activating early changes such as the cortical reaction. Subsequent experiments by Carroll in my laboratory and by Vacquier showed that the incubation of eggs in a variety of compounds having an amine group (NH_2), for example the anesthetic procaine, also activated the late changes in the absence of the early changes. All these findings suggested that the early changes were not a necessary precondition for the late ones.

The first clue to the mechanism of activation of the late changes came from our investigation of the discharge of acid from the egg, which begins at the start of the cortical reaction and continues for the next four minutes of development. An acid is defined as a molecule that readily donates a proton to another molecule; it can also be a free proton (a hydrogen atom minus its single electron). Thus the egg was secreting either acidic molecules or protons into the surrounding seawater. At first we thought acidic molecules were being released, because it was known that the sulfated mucopolysaccharides discharged from the cortical granules were acidic. A problem with this hypothesis arose, however, when Miles R. Paul, who was then a graduate student in my laboratory, discovered that the eggs of the echiuroid worm *Urechis caupo,* which do not undergo a cortical reaction, nonetheless release acid when they are fertilized. A second problem with the acid originating in the cortical granules arose from our calculations of the amount of acid released by sea-urchin eggs: if the acid were contained solely in the granules, it would have to be at a concentration of .1 mole of acid per liter, which seemed too high for the normal functioning of the cell.

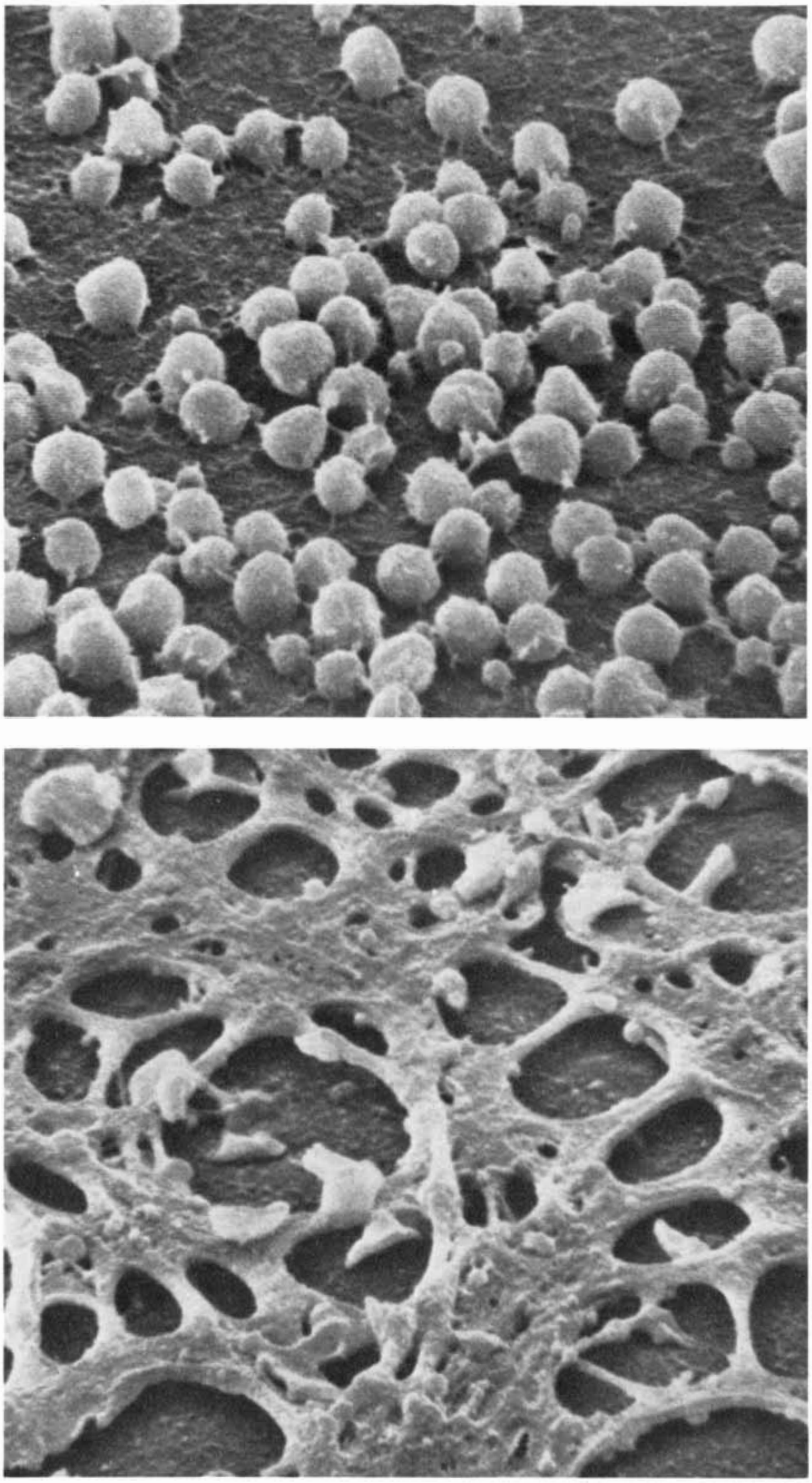
The definitive proof that the release of acid from the egg was not related to the cortical reaction came from our analysis of the activation of the late changes by ammonia and other amines. James D. Johnson and I at the Scripps Institution and Paul, working at the University of Victoria in Canada, found that acid was released when the late changes were triggered by placing eggs in a solution of ammonia or procaine, even though the eggs did not undergo the cortical reaction. When we then added sperm to the eggs to induce a cortical reaction, we observed to our surprise that no additional acid was released. We therefore concluded that acid release is related to the activation of synthesis and not to cortical-granule secretion.

Our next clue to the nature of activation came from Chambers' discovery that sodium ions are required for the continuation of development after the cortical reaction. When he fertilized eggs in normal seawater and just after the cortical reaction transferred them to sodium-free seawater, the nuclei of the sperm and the egg failed to fuse and development stopped. It was as if the eggs had been placed in a kind of suspended animation. When Chambers added sodium ions to the solution, development resumed where it had left off. The sodium requirement lasted for only a few minutes after the cortical reaction. If the eggs were fertilized in regular seawater and transferred to sodium-free seawater 10 minutes later, development was not arrested.

This finding suggested that sodium was involved in biosynthetic activation. Was it related to the release of acid from the egg? To find out we first arrested the development of eggs by placing them in sodium-free seawater 60 seconds after fertilization and then measured the acidity of the suspension. As we expected, no acid was being released. When sodium ions were added to the suspension, however, acid appeared in the seawater



TIMETABLE OF EVENTS following the fertilization of the egg of the sea urchin *Strongylocentrotus purpuratus* is graphed on semilogarithmic scale. The events can be divided into an early phase, occurring within the first 60 seconds after fertilization (*light color*), and a late phase, beginning about 300 seconds after fertilization (*dark color*). The early changes mostly involve small molecules such as ions and coenzymes; late changes involve synthesis of large molecules such as proteins and DNA and the activation of transport systems for amino acids and nucleosides.



ISOLATED CORTICAL GRANULES can be made to discharge their contents by adding calcium ions to them. Victor D. Vacquier of the University of California at Davis isolated the cortical granules by affixing unfertilized sea-urchin eggs to a glass slide and disrupting the eggs with a jet of calcium-free water. The jet carried away the cell cytoplasm, leaving behind an "inside out" plasma membrane with some cortical granules still attached to it, as is shown in the scanning electron micrograph at the top. When calcium ions were added to this preparation, the granules fused with one another in an explosive reaction (*bottom*). This experiment suggests that the normal process of fusion of the cortical granules with the egg plasma membrane results from the increase in free calcium ions inside the egg. Magnification is 10,000 diameters.

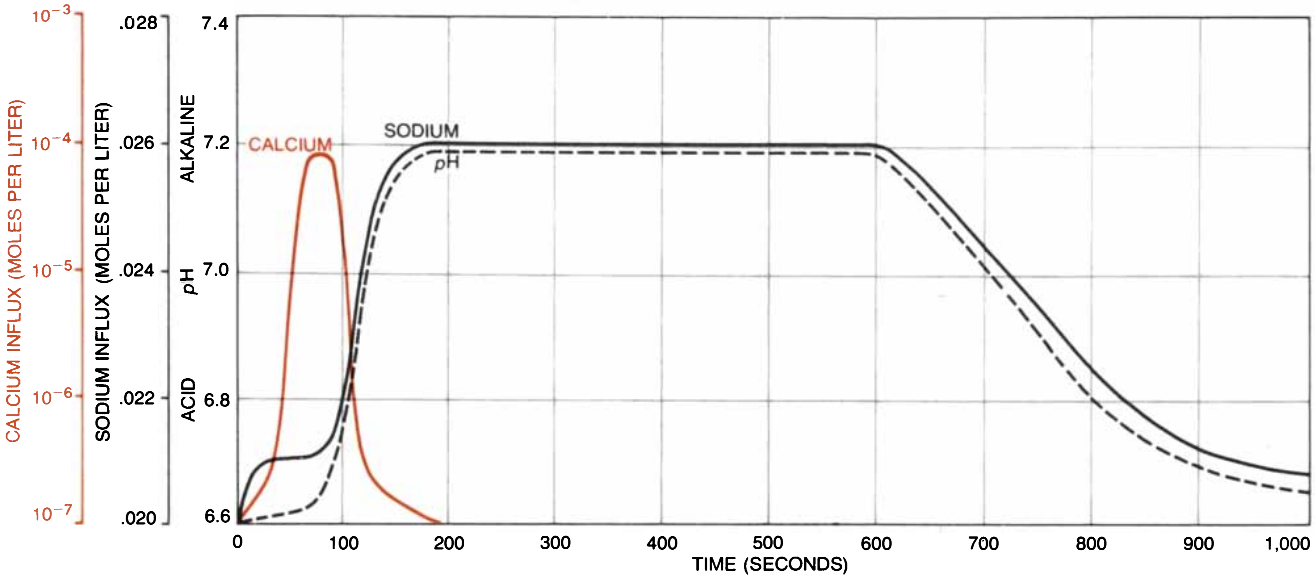
and the eggs began to develop. We tested several ions normally found in seawater and discovered that only sodium initiated acid release and promoted development.

This observation suggested that sodium ions are involved in a sodium-proton exchange, in which a sodium ion is taken into the cell for each proton discharged from the cell. Our hypothesis was supported by the finding that when we measured the uptake of sodium into the egg with the radioactive isotope sodium 22, the uptake temporally and quantitatively paralleled acid release. We also found that when sodium uptake was blocked with the aid of the diuretic drug amiloride, activation of development did not take place. Thus sodium uptake and acid release appeared to be essential for triggering embryogenesis.

We next wondered which of these two processes was the essential one for triggering development. An experiment suggested by Chambers' work provided the answer. He had found that when he arrested egg development at 60 seconds after fertilization by placing the egg in sodium-free seawater, development could be restarted simply by adding ammonia to the seawater. We discovered that under these conditions acid was released, indicating that it is the efflux of protons and not the influx of sodium ions that is the crucial event for triggering development.

What is the effect of the acid efflux on the egg? The most reasonable hypothesis is that the loss of acid makes the cytoplasm of the egg more alkaline. We tested this hypothesis by the unorthodox but expedient method of homogenizing eggs at various times after fertilization and directly measuring the acidity of the homogenate with a *p*H electrode. Assuming that these measurements can be directly extrapolated to the living cell, they reveal that the *p*H increases (becomes less acidic) by .4 *p*H unit during the first five minutes after fertilization. This *p*H shift has recently been confirmed in Steinhardt's laboratory by Sheldon Shen, who worked with microelectrodes inserted directly into the egg. All the available evidence indicates that it is the *p*H shift that turns on the synthetic machinery of the egg after fertilization.

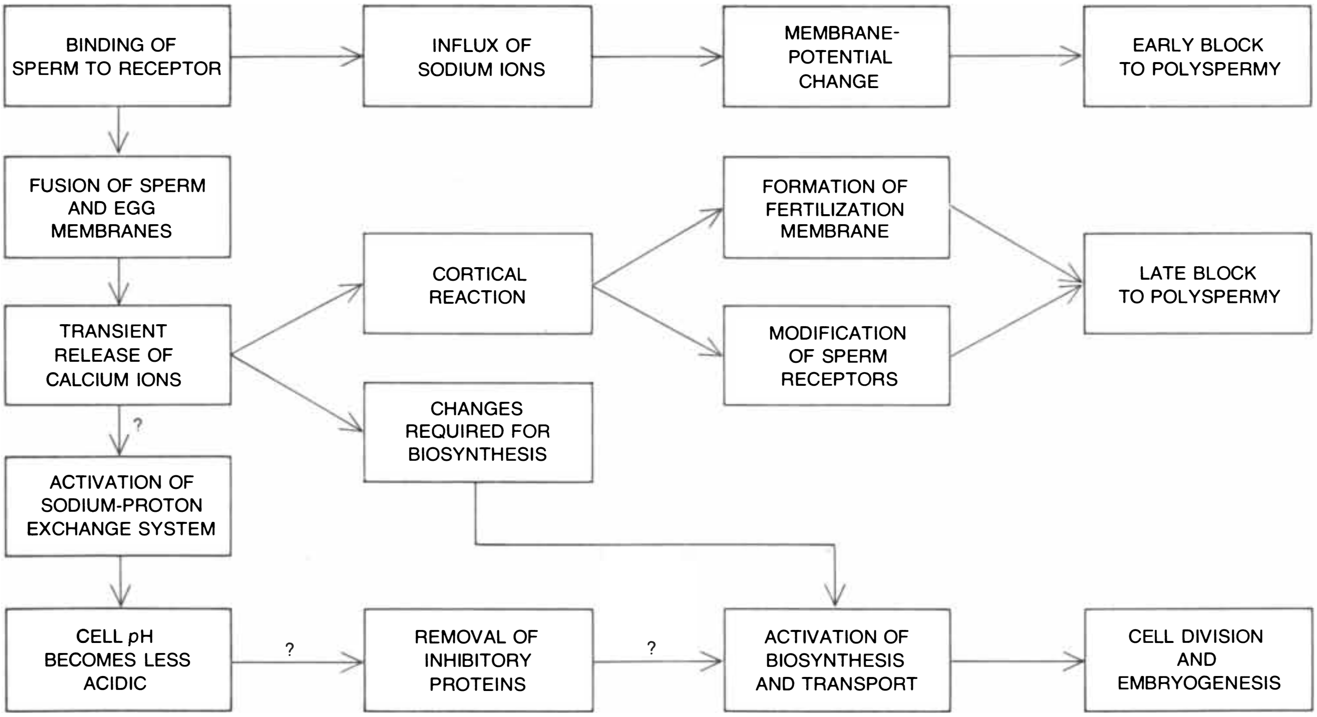
This discovery has raised two major questions. One is: What is the early, calcium-dependent change that results in the activation of the sodium-proton exchange system? The resolution of this question requires an understanding of how the early changes modify the structure of the egg surface. One possibility is that the calcium-induced cortical reaction alters the surface of the egg in such a way that the sodium-proton exchange system is exposed or activated. A second possibility is that the increased concen-



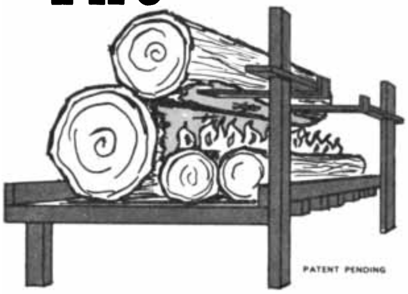
CHANGING CONCENTRATIONS of sodium ions, calcium ions and hydrogen ions (protons) inside the egg appear to be involved in many of the changes induced by fertilization. A few seconds after fertilization there is a small influx of sodium ions into the egg associated with a transient electrical depolarization of the cell membrane. At about 20 seconds calcium ions are released from intracellular stores, apparently triggering the cortical reaction and other early changes. At about 60 seconds the sodium content of the egg begins to increase, accompanied by an efflux of protons and a rise in *p*H, which somehow triggers synthetic activity and cell division. At 180 seconds calcium concentration has decreased to original level, and between 10 and 20 minutes sodium and *p*H have returned to their original levels.

tration of calcium inside the egg directly alters the permeability of the egg plasma membrane. This hypothesis is suggested by the experiments of Michael Berridge and Robert Meech of the University of Cambridge, who found that an increased concentration of calcium ions inside the cell increases the permeability of cells in the salivary gland of insects and of nerve cells in snails. A third possibility is that the release of calcium affects contractile proteins such as actin in such a way as to place the sodium-proton exchange system in the proper configuration for activity. Future experiments should enable us to determine which of these possibilities is correct.

The other question is: How does the increased *p*H of the fertilized egg turn on metabolic processes such as the synthesis of protein and the replication of


BINDING OF SPERM TO RECEPTOR
INFLUX OF SODIUM IONS
MEMBRANE-POTENTIAL CHANGE
EARLY BLOCK TO POLYSPERMY
FUSION OF SPERM AND EGG MEMBRANES
FORMATION OF FERTILIZATION MEMBRANE
CORTICAL REACTION
LATE BLOCK TO POLYSPERMY
TRANSIENT RELEASE OF CALCIUM IONS
MODIFICATION OF SPERM RECEPTORS
CHANGES REQUIRED FOR BIOSYNTHESIS
?
ACTIVATION OF SODIUM-PROTON EXCHANGE SYSTEM
CELL pH BECOMES LESS ACIDIC
?
REMOVAL OF INHIBITORY PROTEINS
?
ACTIVATION OF BIOSYNTHESIS AND TRANSPORT
CELL DIVISION AND EMBRYOGENESIS

FLOW CHART outlines the largely hypothetical relations among the early calcium-dependent changes (such as the cortical reaction) and the late *p*H-dependent changes (such as DNA synthesis). The mechanism by which calcium turns on the sodium-proton exchange system to result in a reduction of the acidity of the egg cytoplasm (an increase in *p*H) is not yet understood. How this *p*H shift initiates protein and DNA synthesis is also not known, but it may involve the removal of inhibitory proteins from functional proteins such as those of ribosomes or from structural proteins such as actin or tubulin subunits. In the latter case removal of an inhibitory protein might enable the subunits to polymerize into filaments, resulting in major changes in cell structure that could initiate a variety of biochemical events.



DNA? Recent work by David Nishioka, a postdoctoral investigator in my laboratory, and by Shen and Steinhardt has shown that the *p*H shift induced by fertilization is transient and rapidly decreases back to the level found in the unfertilized egg. Nishioka has made the important discovery that the *p*H need be raised for only a 10-minute period to initiate development. This finding implies that the *p*H change does not act directly to increase the rate of synthetic processes, since most of the synthetic changes occur after the transient *p*H rise is over. Rather, the transient *p*H rise initiates a change in the cell, which in turn results in the activation of the egg.

What might this *p*H-sensitive change be? Since so many different events are initiated during activation, there might be many *p*H-sensitive processes or alternatively a generalized or pervasive effect of increased *p*H on the cell. An attractive hypothesis, which could account for the pervasive effects of the *p*H shift, is that an inhibitor molecule is bound to critical proteins such as enzymes or the proteins of ribosomes and that the transient increase in *p*H causes the inhibitor to dissociate from these proteins, enabling them to function in synthetic reactions. Once this inhibitor molecule has been destroyed the egg is irreversibly committed to development.

An interesting example of this type of regulation, and one that might well apply to egg activation, has been described by Lewis G. Tilney of the University of Pennsylvania. Tilney has focused on the formation of the acrosomal process during the initial phase of fertilization, and he has discovered that the acrosomal process is created by the explosive polymerization of actin, a contractile protein that can exist in two states: as individual subunits or as a filamentous chain. Until the sperm is triggered to form the acrosomal process the actin in the head of the sperm is kept in the unpolymerized state, apparently through the association of the actin subunits with an inhibitory protein. When the sperm is triggered by interaction with the jelly coat of the egg, the inhibitory protein dissociates and the actin subunits spontaneously polymerize. Tilney and his colleagues have recently shown that the dissociation of the inhibitory protein is caused by an increase in intracellular *p*H! Applying this concept to the activation of the egg, one might speculate that inhibitory proteins are similarly bound to major structural proteins of the egg, such as actin or perhaps tubulin. The *p*H shift would then cause the inhibitory protein to dissociate from the actin or tubulin subunits, causing them to polymerize. This event would result in a major reorganization of cell structure and initiate a variety of seemingly unrelated changes.

A major question raised by these discoveries is whether the ionic mechanisms that regulate cellular activity at the beginning of life also do so during later stages of the organism's existence. Nerve and muscle are well-known examples of tissues whose function is closely related to small ions such as those of sodium, potassium and calcium, and there are recent indications that ions may also participate in the regulation of more complex processes such as cell division and cell differentiation. A number of investigators have found that increasing the intracellular levels of calcium or magnesium ions, either by means of drug ionophores or simply by adding ions to the medium of the cells, will transform previously quiescent cells in tissue culture into actively dividing cells. Most striking is the recent demonstration by Clarence D. and Charlotte Cone of the Veterans Administration Hospital in Hampton, Va., that one can induce nerve cells (which normally never divide) to begin division by increasing the concentration of sodium ions inside them.

Developmental changes also appear to involve changes in ions. For example, Lester G. and Lucena J. Barth, working at the Marine Biological Laboratory in Woods Hole, Mass., have found that simple variations in the concentration of sodium ions can switch the differentiation of embryonic amphibian skin cells so that they become nerve cells. A second example is the induction of developmental programs in plants by light. The effector is the plant pigment phytochrome, and the work of Ian A. Newman and Winslow R. Briggs of the Carnegie Institution of Washington's Department of Plant Biology has shown that the first change induced by light is one in the permeability of the cell membrane to ions.

It is not clear how small ions can yield such diverse effects, and indeed the difficulty of imagining possible mechanisms has led many workers to disregard or discount hypotheses that modulation of ion content may be an important factor in regulating cell function or an initiator of changes in cell differentiation. The discovery that transient changes in intracellular calcium and intracellular *p*H trigger the development of sea-urchin eggs now provides a paradigm for visualizing how ions can switch on completely new cellular activities. We do not yet know whether intracellular *p*H is an important regulator of development in eggs other than those of the sea urchin or whether it is involved in other cell functions. It seems likely, however, that regulation through the transient or permanent modulation of ionic content is widespread in the living world and that the mechanisms for regulating cellular activity at fertilization are utilized throughout the life of the organism.

Eleven questions to ask yourself before buying a 35mm SLR.

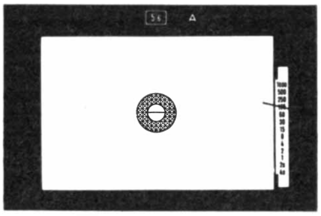
Knowing what to look for now in a 35mm SLR can save you money and prevent problems later on.

1. How much camera do I need? Most manufacturers, including Minolta, offer a tempting array of features. Like interchangeable finders and focusing screens, motorized film winding, self-timers and multiple-exposure capability. If you'll be using them, fine. If not, save yourself some money by cutting out the frills.

2. Is match-needle or electronic auto-exposure control best? Minolta offers both, so our only concern is that you get what's best for you.

Generally a match-needle camera costs less. To set exposure, you line up two needles in the viewfinder. It's easy, fast and accurate, but you do the work. Minolta SR-T match-needle cameras offer a wide variety of features and prices.

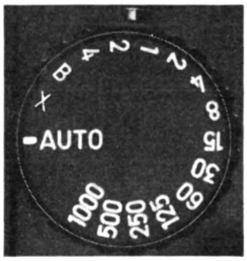
Minolta's newest 35mm SLR's have electronically controlled shutter speeds. So even if the light changes the instant before you shoot, the camera will set itself for correct exposure. Among Minolta's electronic SLR's, you'll find features like interchangeable viewfinders and screens, shutter speeds to 1/2000th of a second and multiple-exposure capability.



3. What should I look for in the viewfinder? First of all, a bright image. So you can see clearly and focus easily. Judge this by comparing several brands under the same light conditions.

Then, exposure information. The more the viewfinder shows, the more you know about how the camera is taking the picture. If this means a lot to you, pay the extra cost. If not, save on a simpler camera.

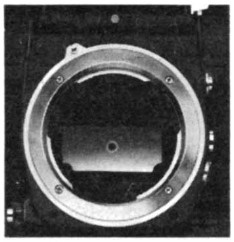
The important thing about Minolta SLR's is that in every single one, you can compose, focus, set exposure and shoot without ever looking away from the viewfinder. So you won't miss shots of even the fastest-moving subjects.



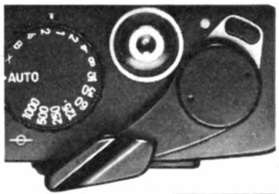
4. What range of shutter speeds do I need? Most picture taking is done at speeds between 1/60th and 1/500th of a second. But to stop very fast action, higher speeds are handy to have. And slower speeds are useful for available-light shooting and spectacular night shots. Depending on the Minolta model, you can get speeds as fast as 1/2000th of a second and as slow as 16 seconds.

5. What is a "fast" lens, and do I need one? The more light a lens lets in, the "faster" it is. Faster lenses like an f/1.2 or f/1.4 are more expensive, but nice to have if you do a lot of shooting in dim light.

6. Why is the lens system important? Interchangeable lenses let your camera grow with you. Minolta offers almost 40, from a 7.5mm "fisheye" to a 1600mm super-telephoto. Minolta makes all their own lenses to insure compatibility with Minolta cameras.



7. How fast can I change lenses? You shouldn't have to miss shots. So Minolta developed and patented a bayonet mount that lets you change lenses with less than a quarter turn. And unlike other bayonet mounts, Minolta's doesn't require you to realign f/stops afterwards.



8. How should the camera feel? Solid. Comfortable. Not too big, not too small. Your fingers should fall naturally into place on the controls. Advance the film wind lever. If it feels gritty or rough now, how will it feel after a couple of thousand shots?

9. How should it sound? Press the shutter button. Noisiness means either vibration or inadequate damping of moving parts. Or both. The newest Minolta shutters are a joy to hear because you almost can't hear them at all.

10. How do I judge craftsmanship? Compare. Everything should be tucked in neatly. Finishes should be even and unmarred. No machining marks should be visible, even inside the camera.

11. What is the camera's reputation? Be sure to ask friends about Minolta. Since it's the best-selling imported camera brand in the U.S., chances are someone you know owns one.

And if you'd like literature on Minolta 35mm SLR's, write to Minolta Corp., 101 Williams Drive, Ramsey, N.J. 07446. In Canada: Minolta Camera (Canada), Inc., Ont.

Minolta

The more you know about cameras, the more you'll want a Minolta.

An Early Energy Crisis and Its Consequences

In the 16th century Britain ran out of wood and resorted to coal. The adoption of the new fuel set in motion a chain of events that culminated some two centuries later in the Industrial Revolution

by John U. Nef

In medieval Europe wood was utilized not only in many types of construction but also in most domestic and industrial heating. Then in Britain in the second half of the 16th century coal came into widespread use as a substitute for wood as fuel. The earliest coal-burning economy the world has known was established first in England and then in Scotland between about 1550 and 1700. This transition from woodcutting to coal mining as the main source of heat was part of an early British economic revolution. The first energy crisis, which has much to do with the crisis we now face, was a crisis of deforestation. The adoption of coal changed the economic history of Britain, then of the rest of Europe and finally of the world. It led to the Industrial Revolution, which got under way in Britain in the last two decades of the 18th century. The substitution of coal for wood between 1550 and 1700 led to new methods of manufacturing, to the expansion of existing industries and to the exploitation of untapped natural resources.

To make these assertions is not to belittle the role of other changes during the Middle Ages and the Renaissance in the coming of our industrialized world. The century before Britain's wood crisis—the 100 years from about 1450 to 1550—was characterized by a new spirit of expansion. Voyages of discovery were launched, carrying explorers to the ends of the earth. The art of printing with movable type spread across Europe, and the production of paper expanded; millions of books were printed and put in circulation. In central Europe, where the major centers of mining and metallurgy were to be found, the output of ores, particularly silver-bearing copper ores, multiplied severalfold. The years between 1494 and 1529 have been described as bringing about a "revolution in the art of war." With the help of the new firearms Spain conquered Mexico and Peru.

These and other innovations increased, directly or indirectly, the need for all existing kinds of energy: the heat provided by wood and the power provided by wind, animals and running water. The need for larger amounts of wood for construction and for heating, particularly for the smelting and refining of ores, called for a substantial increase in the felling of trees.

All Europe felt these pressures, and yet the first large area to experience an acute shortage of wood was Britain. Why did the fuel revolution that led to new uses of heat energy begin in that particular place? Was wood particularly scarce there? It seems to be true that the most populous parts of Scotland (the areas surrounding the Firth of Forth) were barren of trees; a wit from England is said to have observed in the reign of James I that if Judas had repented in the king's native land (Scotland), he would have been hard put to find a tree on which to hang himself! Such an explanation does not fit England. The wood crisis there has to be attributed to the requirements of expanding agriculture, industry and commerce, all stimulated by a growing, shifting population.

It appears that Sweden and the Netherlands were the only other European countries to experience anything comparable to the growth and resettlement of the British population in the period from 1550 to 1700. The population of England and Wales, about three million in the early 1530's, had nearly doubled by the 1690's. The resulting demand for wood for various purposes was further increased by changes in the distribution of the population. In this period the inhabitants of London multiplied at least eightfold, from some 60,000 in 1534 to some 530,000 in 1696.

According to Gregory King's estimate for the latter year, the British capital had by then become the largest city in Europe and perhaps the world. King estimates that England's other "cities and... market towns" had a total population of about 870,000. This means that although only one person in 10 was a "townsman" in the 1530's, one person in four was a townsman in the 1690's. Larger towns meant heavier demands on nearby wood supplies. Moreover, outside the towns there was much migration of the unemployed across the country in search of work. Wherever they found employment, shelter had to be provided, putting still another strain on the forests.

During the reigns of Elizabeth I (1558–1603) and James I (1603–25) this pressure on the supply of trees was reflected in the soaring cost of firewood and lumber for construction. The period from 1550 to 1640 was a time of inflation throughout Europe, but the price of wood in England rose very much faster than that of any other commodity in general use anywhere. Complaints of deforestation came from all parts of the kingdom.

Wherever coal seams outcropped in Europe, coal had been burned in small quantities since the 12th century. (It had been more extensively burned in China earlier than that and also to some degree in Roman Britain.) In Europe during the later Middle Ages peasants had occasionally warmed their homes or stoked their lime kilns and smithies with these "black stones." Why then was coal not widely adopted as a fuel on the Continent and in Britain before the forests were seriously depleted?

In societies earlier than the one that arose in western Europe in medieval times mining was looked on with disfavor. It was often regarded as robbery, even as a kind of rape. Unlike the plow, which made the earth fertile, the pick and shovel removed what seemed to be irreplaceable soil and subsoil.

By the early 16th century a different attitude toward the exploitation of the more valuable underground resources found expression in two books. In *De re metallica* (1556) Georgius Agricola (1494–1555) ranked the miner's calling higher than "that of the merchant trading for lucre." And in *Pirotechnia* (1540) Vannoccio Biringuccio (1480–1539) advocated an all-out assault on these underground riches. He advised "whoever mines ores... to bore into the center of the mountains... as if by the work of necromancy or giants. They should not only crack the mountains asunder but also turn their very marrow upside down in order that what is inside may be seen and the sweetness of the fruit despoiled as soon as possible."

The new dignity attached to mining was reserved for metallic ores. It did not extend to coal. The medieval craftsmen who needed fuel wanted their work to be beautiful, whether it was for their church or for rich laymen. The unpleasant smoke and fumes of coal therefore limited the market for it. There was little incentive before the mid-16th century to dig deep into the soil in search of this dirty fuel as long as wood was available, and there seemed to be an abundance of that. Biringuccio himself believed the forests of Europe could fill all conceivable future demands for fuel. In *Pirotechnia* he wrote: "Miners are more likely to exhaust the supply of ores than foresters the supply of the wood needed to smelt them. Very great forests are found everywhere, which makes one think that the ages of man would never consume them... especially since Nature, so very liberal, produces new ones every day." Coal is mentioned only once in his long treatise and then just to dismiss it: "Besides trees, black stones, that occur in many places, have the nature of true charcoal, [but] the abundance of trees makes [it] unnecessary... to think of that faraway fuel."

Less than a generation later the English turned to coal under pressure from the high price of wood. By the early 17th century efforts by the government to stop deforestation were felt to be imperative because the shortage of lumber for shipbuilding seemed to threaten Britain's existence. A royal proclamation of 1615 laments the former wealth of "Wood and Timber," the kind of wood that is "not only great and large in height and bulk, but hath also that toughness and heart, as it is not subject to rive or cleave, and thereby of excellent use for shipping, as if God Almightie, which had ordained this Nation to be mighty by Sea and navigation, had in his providence indued the same with the principall materiall conducing thereunto." By the middle of the 17th century coal had proved so useful and was already so widely burned that the British had come to make necessity a virtue. They reconciled themselves to the disappointing failure of their explorers to locate sources of precious metal and of their miners to find much of it in Britain itself. In spite of the smoke and fumes of coal and in spite of a widespread distaste for it, by the time of the civil war in the 1640's Londoners were dependent on the coastwise shipment of coal to keep warm. In 1651 the anonymous author of *News from Newcastle* wrote verses in praise of the new fuel. "England's a perfect World! Has Indies too! / Correct your Maps; New-castle is Peru!... / Let th' naughty Spaniard triumph, 'til 'tis told / Our sooty mineral purifies his gold."

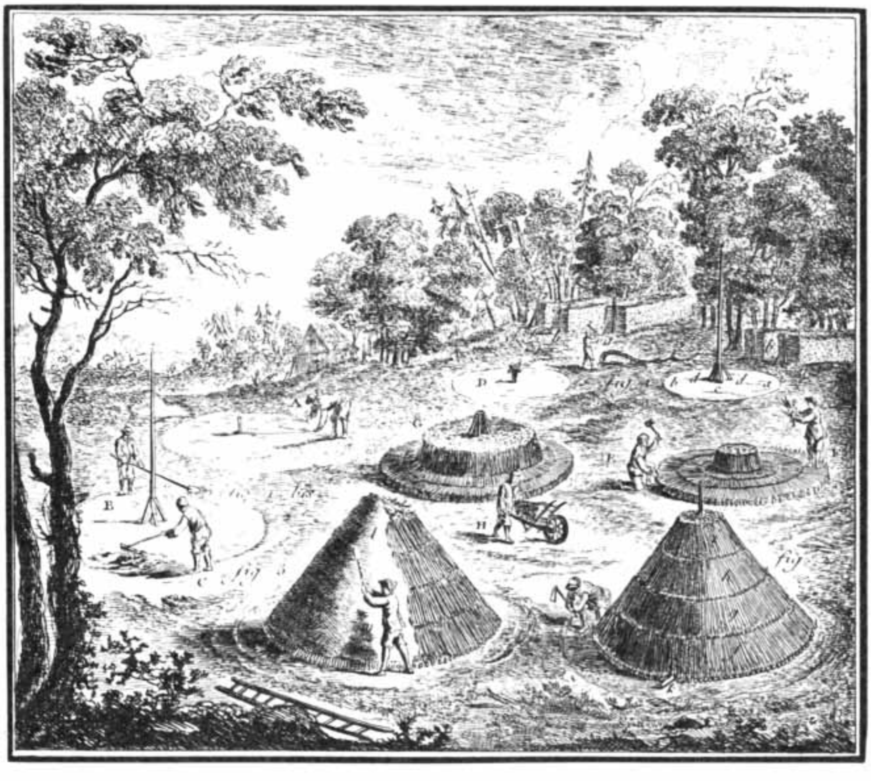
Even earlier, as is made clear by William Harrison's *Description of Britain* (1577) and by a petition London brew-

COAL WAS BRITAIN'S PRINCIPAL FUEL by the end of the 17th century. Coal heavers, such as the ones shown in this print from 1805, handled coal destined for homes and industries across Britain and for many foreign countries as well. In background are coal barges.

ers addressed to Sir Francis Walsingham, Queen Elizabeth's secretary of state (1578), coal was acquiring a new and important place in domestic and industrial heating. The surviving records of customs officials at Newcastle-on-Tyne (and later records of other towns) reveal a continuous and rapid growth in the shipments of coal between 1550 and 1700, first from Newcastle-on-Tyne and then from other ports. These records suggest that the coastwise shipments increased at least twentyfold between 1550 and 1700. Coastwise imports to London grew even faster, probably more than thirtyfold, which is not surprising in view of the multiplication of the city's population in that period. Lord Buckhurst, who became Queen Elizabeth's lord treasurer at the end of the 16th century, required the customs officials during the 1590's to determine the "rate of growth" in coal shipments from Newcastle, thereby introducing a new concept into human affairs. The calculations on which Buckhurst insisted indicated that taxes on coal shipments could be counted on to provide a continually increasing source of revenue, and so taxes on coal shipments were imposed in 1599 and 1600.

The most impressive rises in the growth rate of coal production occurred in the second half of the 16th century and at the beginning of the 17th. In fact, the growth rate in the volume of coal mined between 1556 and 1606 may even exceed the growth rate (computed from less incomplete statistics) in the volume mined during the first part of the 19th century, that is, at the height of Britain's Industrial Revolution. The actual quantities involved in the rapid growth of coal production in the earlier period may seem insignificant today, but it is the viewpoint of the Elizabethans and their immediate successors that needs to be recaptured. To them the expansion in the output of coal must have seemed extraordinarily rapid.

Coal was not only a source of energy but also a spur to technological development. Most products that could be manufactured with open wood fires were damaged by contact with coal fumes. John R. Harris has commented that as a result "coal was hardly ever adopted without significant alteration of industrial processes." Indeed, the technological advances of the Industrial Revolution were largely the culmination of the innovative period associated with the conversion to coal.



BEFORE THE ADVENT OF COAL wood was the main source of heat energy in Europe. Industrial power was provided by wind, animals and running water. It was often necessary to convert the wood to charcoal by partially burning it in furnaces such as the ones shown here. The wood was piled in stacks, covered with earth and powdered charcoal dust and then burned. The covering kept combustion at a minimum so that the end product was charcoal rather than ashes. For some manufacturing processes charcoal was preferred to wood because it is mostly pure carbon and so yields a greater amount of heat per unit volume of fuel. Illustration is from Diderot's *Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Art et des Métiers.*

New methods of firing had to be developed in which the materials to be heated were protected from direct contact with the burning coals and the gases evolved in their combustion. Otherwise the coal would have had to be reduced to coke and so purged of its noxious properties. After about 1610 glass began to be manufactured with mineral fuel in a variant of the reverberatory furnace, a system that later played an important role in the growth of other major industries. In this type of furnace an arched roof reflects the heat of the burning coal onto the material to be heated, thereby preventing the contamination of the material by substances originating with the fuel. The potash and sand to be melted down to form glass were enclosed in a clay crucible to further protect them from the fumes. Like the reverberatory furnace, the crucible was later employed in many other manufacturing processes.

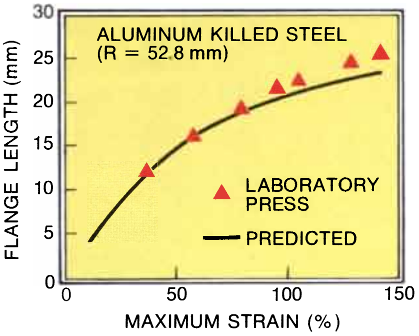
Over the decades following 1610 new technology brought coal into many kinds of manufacturing. The cementation process for converting wrought iron into steel with coal was introduced between 1612 and 1620. By 1618 a method of baking bricks in coal fires near London was described by the Venetian ambassador in words showing that Italians were no longer disposed to ignore this "faraway fuel" as Biringuccio had recommended. Before the British civil war of the 1640's coke was introduced for the drying of malt in connection with the brewing industry, which had expanded rapidly during most of the 16th century with the spread of hop gardening from the Netherlands.

One of the most important applications of coal following the restoration of the British monarchy in 1660 was in the adaptation of the reverberatory furnace for smelting nonferrous metals. This innovation of the 1680's made it possible to smelt the lead, copper and tin ores of Britain with coal. By the end of the 17th century only the production of pig and bar iron remained dependent on wood. Although the problem was not completely solved until the 1780's, an important step toward its solution was taken in 1709, when coke was introduced by Abraham Darby the elder at his blast furnace in Shropshire. In this kind of furnace the fuel and the ore are in contact. The trouble with Darby's process was that it yielded a kind of pig iron that, unlike the pig iron produced with wood, could not be converted to wrought iron, the form of iron then most in demand. In 1784 Henry Cort invented the puddling process, in which pig iron (even pig iron from a blast furnace) is remelted and manipulated in a

forming sheet metal... mathematically.

A request comes in to mathematicians here at the General Motors Research Laboratories. "How do we determine if this panel can be stamped without tearing?" it asks.

Wait a minute. Can't a half century of manufacturing know-how provide the answer? No, because in making cars lighter, designers are using new alloys that are often more difficult to form.



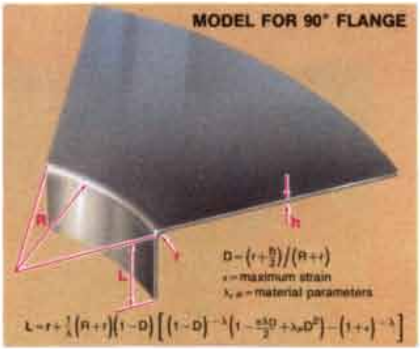
But why turn to mathematics? Well, our mathematicians have been devising models that describe the complex behavior of sheet metal during various forming operations. And the models work.

It's an interesting challenge, predicting panel formability. You start with the theory of plasticity, attempting to build a general model on this bedrock.

The model must take into account press forces, the resulting stresses on the metal, die-metal friction, the rate and direction of permanent deformation, and the work hardening and physical limitations of the metal.

Then comes the critical step of dovetailing all these elements into a comprehensive model that can predict with accuracy.

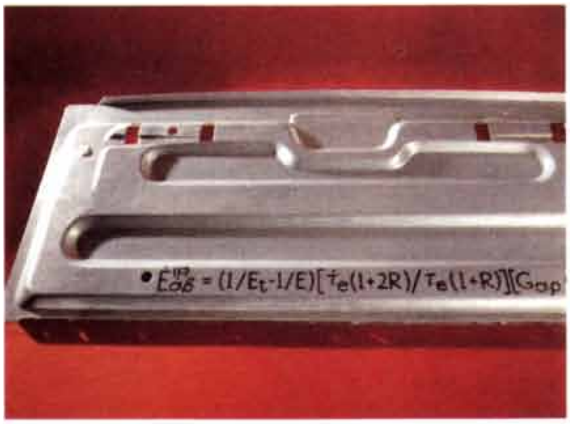
So far, we've developed models for several stamping operations. In use they give results that agree with laboratory and plant experience.



One, for example, computes the longest flange length possible on a curved panel without splitting. It told designers they could use length-radius combinations previously considered unworkable.

Another computes maximum pocket depth. It guided the design of a 1977 station wagon load floor panel (far right), permitting aluminum to replace steel and save 34 kilograms.

Mathematical modeling: Helping to improve designs and cut car weight... by the numbers.



GM

General Motors
Research Laboratories
Warren, Michigan 48090

At the Indian hospital in Sells, Arizona, Papago Indian Peter Ruiz checks the quality of the TV signal coming in from a mobile health van miles away. He's watching the screen of a TEKTRONIX waveform monitor in the STARPAHC* communications console. The TEKTRONIX automatic video corrector, just above the waveform monitor, automatically corrects distortions in both color and black and white signals, freeing Peter to concentrate on the other communication channels.

Small, isolated villages, in an area of the Sonora Desert roughly the size of Connecticut, regularly receive mobile health van visits. Two-way video,

"Getting health care to people in remote areas is a worldwide problem that telecommunications is helping to solve - whether the people are astronauts in space or Papago Indians on the Sonora Desert."

Norman Belasco, Project Officer, STARPAHC*
NASA's Lyndon B. Johnson Space Center, Houston, Texas

At NASA, Norman Belasco explains that one of NASA's early telemedicine projects involved the development of systems that would support biomedical research and provide clinical health care capabilities for long-duration, manned space flights.

"The STARPAHC* project originated when NASA was asked by the President's Domestic Council to examine ten pressing national problems — and one of them turned out to be the delivery of health care to remote areas."

The resulting program involved the cooperation of NASA, HEW and its Indian Health Service, and the Papago Indian Tribe. Lockheed Missiles and Space Company, Inc., was selected to assemble the system and support the field operations.

One of the requirements of NASA's remote-health-care program was that commercially available, off-the-shelf equipment — or as much as possible — be used in the project. That's how Tektronix became involved.

The communications industry uses a wide range of Tektronix electronic instrumentation. This includes sophisticated television broadcast equipment, which has found many uses beyond the commercial television broadcast industry. Noncommercial uses are as varied as NASA Control's elaborate system that enabled us to see man take his first step on the moon — to the production of video tapes that record what a physician sees through a bronchoscope.

The TV broadcasting industry around the world looks to Tektronix for instruments that help to maintain the quality of television transmission from the camera to the home receiver. The Grass Valley Group, a wholly owned Tektronix subsidiary located in California, is especially well known for its production and routing switchers, which are used in program editing and for special effects, such as the split screens, inserts, and montages often seen in applications such as sports programming.

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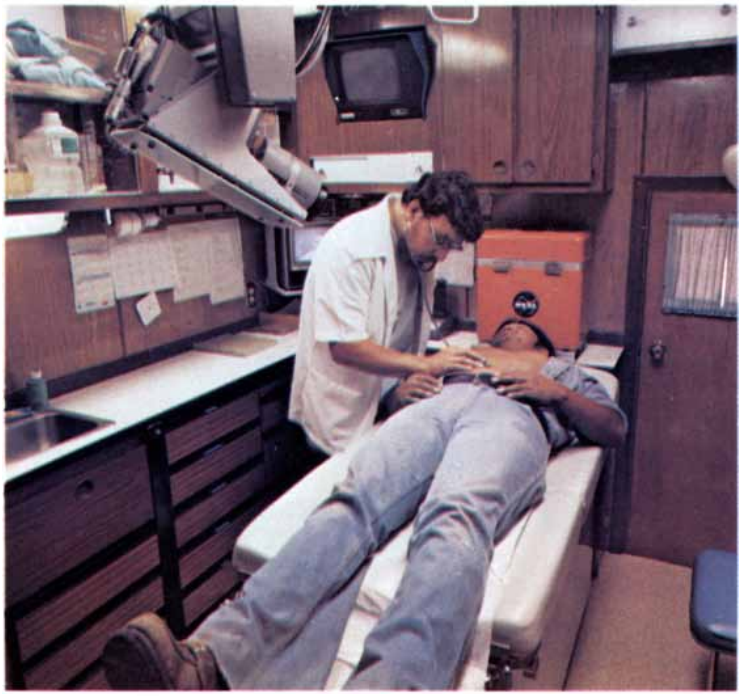
*Space Technology Applied to Rural Papago Advanced Health Care voice, and data signals are transmitted from the van to a mountain-top, microwave relay station that is aligned with the Sells hospital and a fixed, remote clinic at Santa Rosa. Sells has telephone tie lines to consultant and referral centers in Phoenix and Tucson, and to a computerized patient-record file in Albuquerque.

Inside the mobile van Medic Ken Tiokasin examines patient Alfred Pablo, while a doctor at the physician's console miles away in Sells conducts a two-way video and voice consultation. The physician can remotely control the TV cameras on the mobile unit and at the Santa Rosa clinic — zoom in on a patient's problem, read x-rays, examine color specimen slides under a microscope, receive an ECG readout, and send or receive pertinent health-record data. Now, with communication satellite technology, it will be possible for physicians to hold two-way visual consultations with colleagues and patients anywhere in the world.



What the engineer sees. The TV camera transforms images into complex analog signals. Special test signals, not visible on a home TV set, are sent along with the television signal. At each step in the broadcast chain, engineers use these test signals to evaluate picture-signal quality.

For example, in the STARPAHC system, color intensity and hue are controlled by the insertion of a relatively new signal called a VIR (vertical interval reference). The insertion is accomplished with a TEKTRONIX signal generator just after the camera picks up the image.

Then a TEKTRONIX Automatic Video Corrector samples the VIR signal and *automatically* adjusts both color and black and white values before the picture is transmitted to the doctor's (or home viewer's) receiver. The engineer can check the color signal on the TEKTRONIX waveform monitor periodically to be sure that the picture being transmitted is the same as the picture at the source.

Many other Tektronix products are used throughout the TV industry. Picture Monitors. Vectorscopes. Demodulators. Analog-to-Digital Converters. Spectrum Analyzers. Digital Photometers. And oscilloscopes for system servicing (including the computer in the STARPAHC system).

But TV is only part of the picture.

Tektronix serves the total communications industry. For example, when we saw that the telephone industry needed a faster and more precise way to find cable faults, Tektronix engineers solved the problem with a Cable Tester. We work to anticipate the needs of people working with everything from CB radios to communication satellites.

A half billion dollars in sales. Tektronix' diversified products are used in many industries worldwide.

Progressive managers are using TEKTRONIX computer graphics to solve problems in areas as diverse as international monetary exchange to the mapping of subterranean oil and coal deposits. Almost everywhere computers are found, TEKTRONIX portable oscilloscopes and other service instruments help to maintain them. Quantity buyers and suppliers of integrated circuits use TEKTRONIX IC Test Systems to help develop, select, and maintain quality control of "chips" for their products

Foundries save energy and man-hours with TEKTRONIX digital ultrasonic testing systems. Almost every R & D lab uses TEKTRONIX high-performance oscilloscopes to test, measure, and interpret electrical phenomena. Hospitals improve patient care with TEKTRONIX physiological monitors.

And now in microelectronics, TEKTRONIX logic analyzers and Microprocessor Labs give engineers an edge in designing new products that promise to revolutionize our business and personal lives.

These are just a few of the more than 800 Tektronix products that serve the test, measurement, and information display needs of thousands of customers, worldwide.

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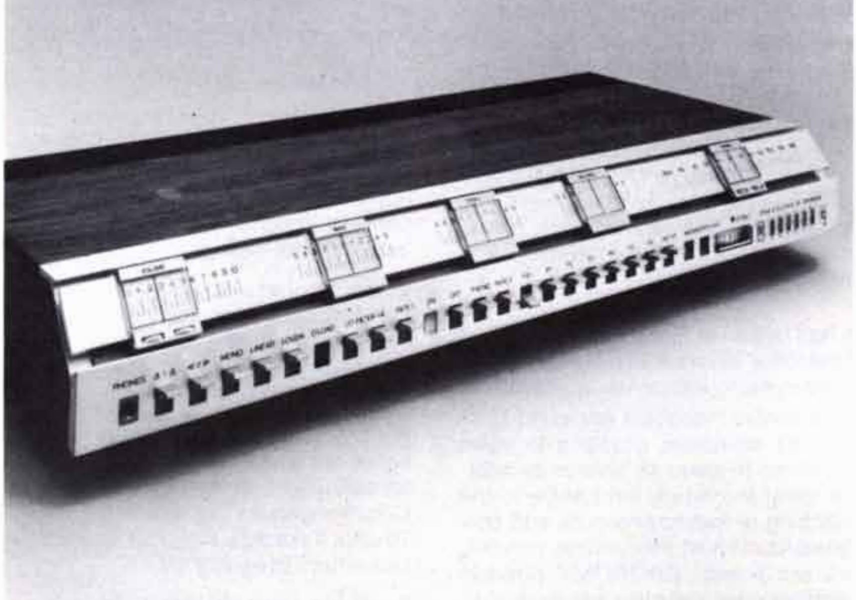


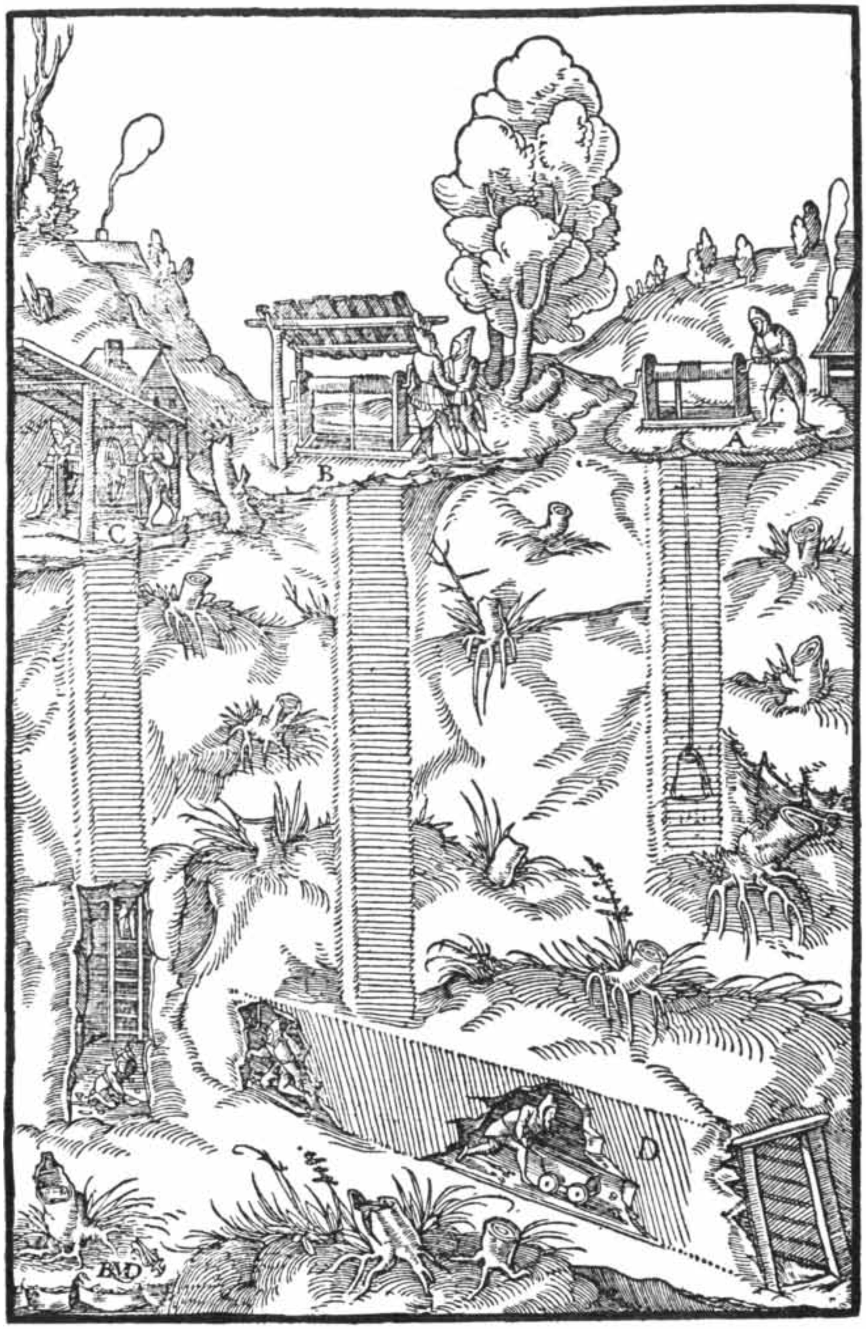
coal-fired reverberatory furnace to produce wrought iron. Until Cort's invention the making of iron remained largely dependent on charcoal. Thus although iron production in England had increased several times between 1540 and about 1620, this growth had been arrested by the shortage of wood for making charcoal in the 1620's. Beginning in that decade, however, an increase in iron imports, notably from Sweden, made possible a continuous slow growth in the output of finished iron wares, which were already produced by processes utilizing mineral fuel.

Samuel Eliot Morison has observed about innovations in shipbuilding and navigation that there is always "a gap between the invention of a device and persuading owners to supply it or sailors to use it." The same can be said about the spread of inventions connected with the introduction of coal in Britain after 1550. It took a substantial period of experimentation to make the new coal-based methods efficient. For example, in brickmaking (as also in the baking of clay tobacco pipes) there was much waste through breakage when coal-burning furnaces were introduced. Before the end of the 17th century, however, few bricks were lost in the course of coal firing.

As it became clear that coal could mean cheaper and more efficient production more industries turned to it as a fuel. Before the end of the 17th century in Britain's growing textile industry, where processes such as steaming and dyeing called for large quantities of fuel, that fuel was usually coal. Before 1700 the expanding manufactures of salt, alum, copperas (vitriol, or ferrous sulfate), saltpeter, gunpowder, starch and candles depended on coal. Coal was then also being employed extensively in the preparation of preserved foods, vinegar and Scotch whisky, and in brewing, soap boiling and sugar refining. A French visitor studying English technology in the Midlands in 1738–39 reported that the new coal-burning kilns (made of coal-baked bricks) had produced such a superior lime fertilizer that the yield of arable land had tripled. He considered coal "the soul of English manufactures."

The spread of coal into British homes that began early in Elizabethan times was continuous throughout the 17th century. This was not the only residential change brought about by the conversion of Britain to mineral fuel. The kingdom was extensively rebuilt under Queen Elizabeth and her Stuart successors. Brick and stone structures (with mortar made from coal-burned limestone) were replacing wood ones. Windows made of glass (produced in coal furnaces) were installed in buildings to retain the heat from the new coal-burning fireplaces (which had iron grates and brick chimneys manufactured with coal). In spite of its grime and stench coal had brought a new comfort to Britain's damp, chilly climate. Already in 1651 the author of *News from Newcastle* observed that the sacks of coal had heightened the joys of intimacy!

Coal had been so successfully incorporated into the British technology and economy that during the last four decades of the 17th century wood prices stopped rising. Some years ago I ventured a rough estimate of three million tons for Britain's annual coal produc-



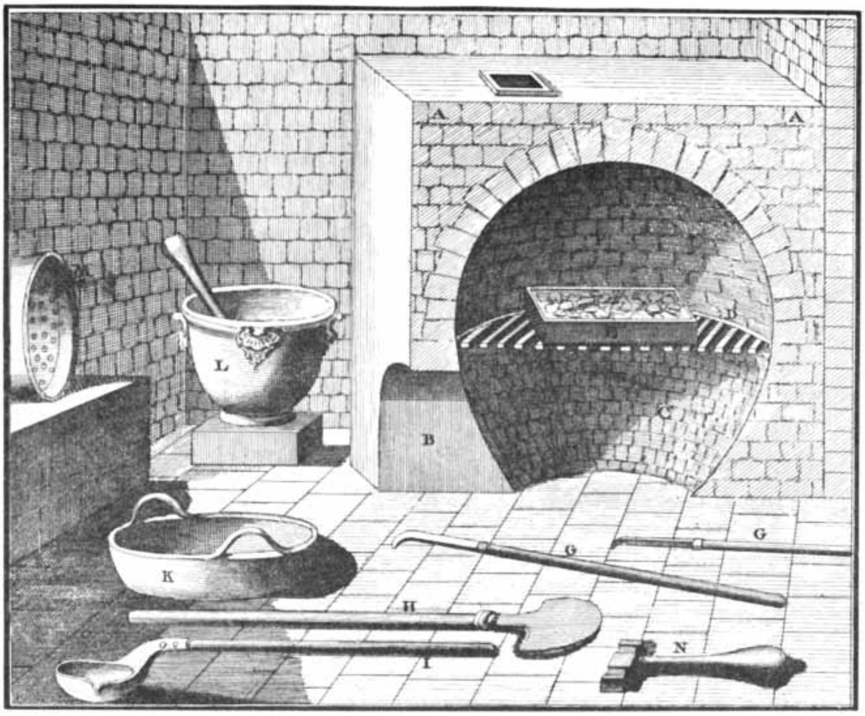
THE WOOD CRISIS of the 16th century coincided with the expression of a changed attitude toward mining. Until the Middle Ages mining had been widely considered an affront to nature. In *De re metallica,* published in 1556, however, Georgius Agricola expressed a new respect for mining. This careful account of metallurgy and mining gives a good picture of those industries at about the time when it was first necessary to increase coal production. In this illustration from *De re metallica* a tunnel, *D,* has been cut into a hill and three shafts have been dug from above. Although the mining was facilitated when a shaft connected with the tunnel, not all the shafts were meant to do so. In this case the shaft at *A* will be mined only from the surface; the shaft at *B* connects with the tunnel, and the tunnel will soon connect with the shaft at *C.* Material was hauled vertically out of a shaft with a windlass, which was usually covered with a shed to keep rain out of the shaft. Agricola pointed out that it was desirable to construct a separate building as a dwelling because "sometimes boys and other living things fall into the shafts."

tion in the 1690's. In Harris' opinion that figure "may eventually prove conservative rather than excessive." It appears that at least as much as four times more heating was done at that time with coal than was done with wood. Never before had a major country come to depend on underground resources for the bulk of its fuel.

Although the exploitation of coal had largely solved the fuel shortage before 1700, there was still a wood shortage because other demands for wood had increased. In 1618 a traveler from London described his time as a "rattling, rowling, rumbling age" and remarked that "the World runnes on [wood] Wheeles." Great quantities of lumber were required for the construction of the growing number of ships and horse-drawn vehicles needed to transport people and goods across water and land. Moreover, although there was some reforestation during the 17th century, more and more forest was being cleared for farms and pastures. In addition smaller areas were being cleared for the growing metallurgical industries and for the expansion of mining, particularly of coal mining. Britain's forests simply could not keep up with the island's demand for wood.

The British were forced to supplement their domestic supply with imports, mostly from the American colonies and from the Baltic region. (In his *Wealth of Nations,* published in 1776, Adam Smith remarked that in his native Edinburgh "there [was] not perhaps a single stick of Scotch timber.") The imports of wood were paid for in part by the mounting exports of coal and probably in greater part by the mounting exports of textiles manufactured in varying degrees with coal fuel. This foreign trade, and even more the rapidly expanding coastwise trade, had already resulted in the 17th century in the development of a large British merchant marine. New colliers, or coal ships, were designed to carry more coal with a smaller crew, and the coastwise coal trade was considered the chief training ground for seamen, a major factor in Britain's emergence as a sea power.

Yet in some instances coal made Britain less dependent on imported commodities, for example salt. As Robert Multhauf explains in his forthcoming book *Neptune's Gift: A History of Common Salt,* this commodity was an essential one in Europe during the 16th and 17th centuries. In Britain, where food from the sea was coming to occupy a more important place in an increasingly abundant diet, salt was indispensable for preserving fish. In southern and western France salt was obtained by allowing the sun to evaporate seawater in shallow pans, or ponds, but this method was impractical in Britain's climate. In the early 16th century two-thirds of the salt consumed in England had to be imported, mostly from France. Britain's almost total conversion to coal changed the situation. At the end of the 17th century some 300,000 tons, or nearly 10 percent of the coal mined annually in Britain, was burned to evaporate water for the production of salt in England and Scotland. As a result the country had become virtually self-sufficient in terms of salt.

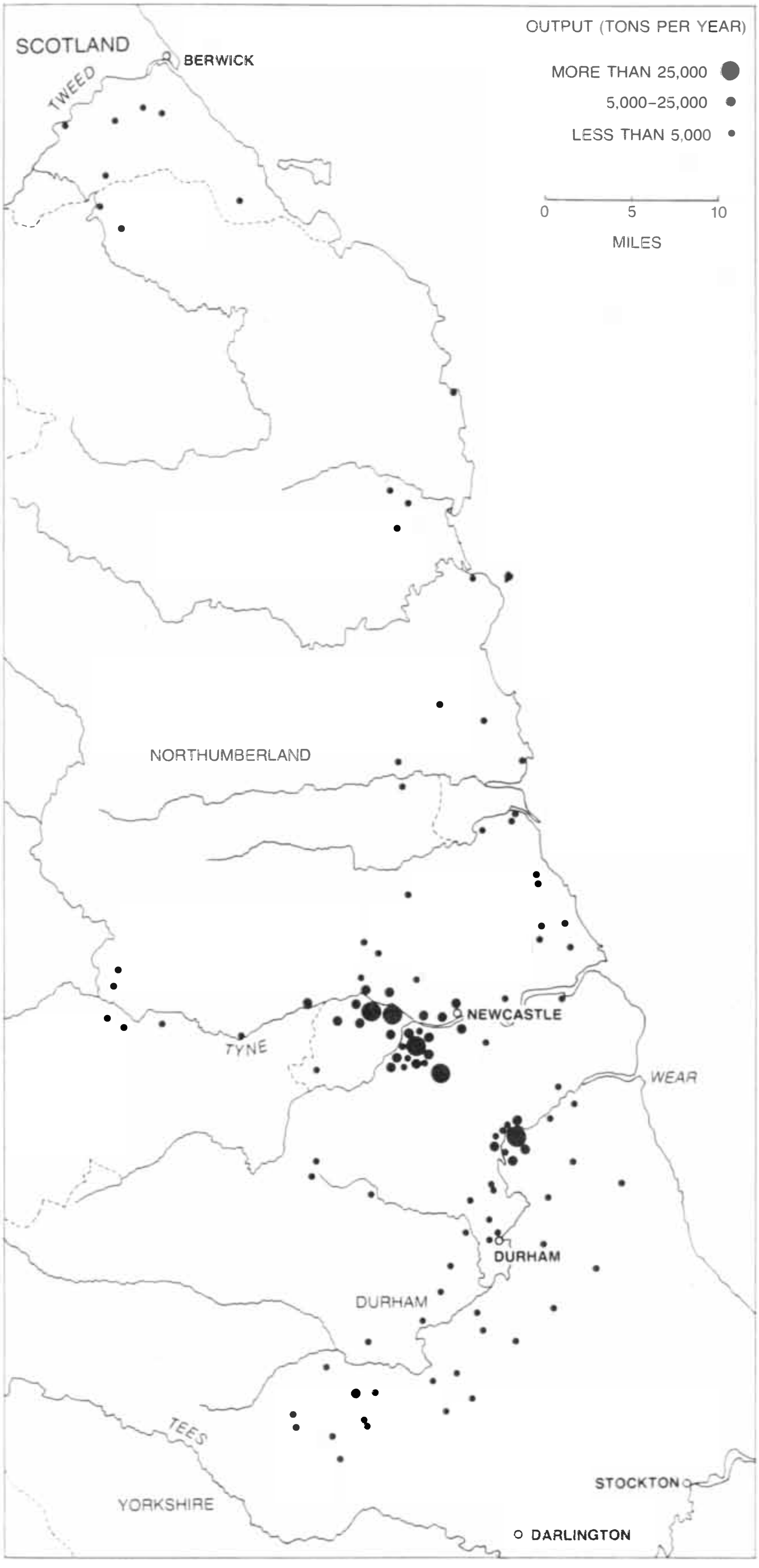


REVERBERATORY FURNACE made possible the utilization of coal in spite of the fuel's reactive smoke and flames. The arched roof of a reverberatory furnace reflects the heat of combustion onto the material to be heated. When the fuel being burned is coal, the arrangement prevents contamination of the product by the substances in the coal fumes. This view of a reverberatory annealing furnace is from the section on coinmaking in Diderot's *Encyclopédie.* Blanks, such as one shown in furnace, had to be annealed before coins could be struck.

The conversion to a new kind of fuel might have had less effect on the British economy if Britain had been poorly, or even only moderately, endowed with coal. Before the end of the 17th century, however, it had become clear that Britain possessed enormous coal reserves. A piece of coal-inspired technology provided new and reassuring information. The device, called a boring rod, was introduced at the beginning of the 17th century. Early boring-rod surveys were inaccurate, but before the 17th century had ended mining experts were able to determine the thickness and quality of coal seams without sinking shafts. Boring rods had become reliable tools and had revealed a newfound land of plenty under the soil and even under the surrounding seas. Much of the island was seen to be underlain with coal. This trove of energy resources began to exert a pull in the direction of a quantity production that had not been equaled in previous history.

It was not until the middle of the 19th century, after an unprecedented acceleration in the rate of growth of production had begun, not until the publication in 1865 of William Stanley Jevons' *The Coal Question,* that some became aware that the coal deposits were exhaustible. By this time resources of petroleum and natural gas were known outside Britain, although neither were much exploited until later in the 19th century. It was not until the 1920's that a few people began to realize the supplies of all fossil fuels had distinct limits.

The shift to fossil fuel in the 17th century led on after 1785 to the aggressive exploitation of the world's vast stores of iron ore. Without the coming of the first coal-burning economy the age of iron and steel might never have developed. The conversion to coal that began in Elizabethan England had further consequences in bringing into being the modern mechanized age. The utilization of steam power and of travel by rail were also vital to the coming of that age. Attempts to build steam engines and to introduce railed ways with horse-drawn wagons in Britain go back at least to the reign of James I, but it was not until 1712 that Thomas Newcomen installed



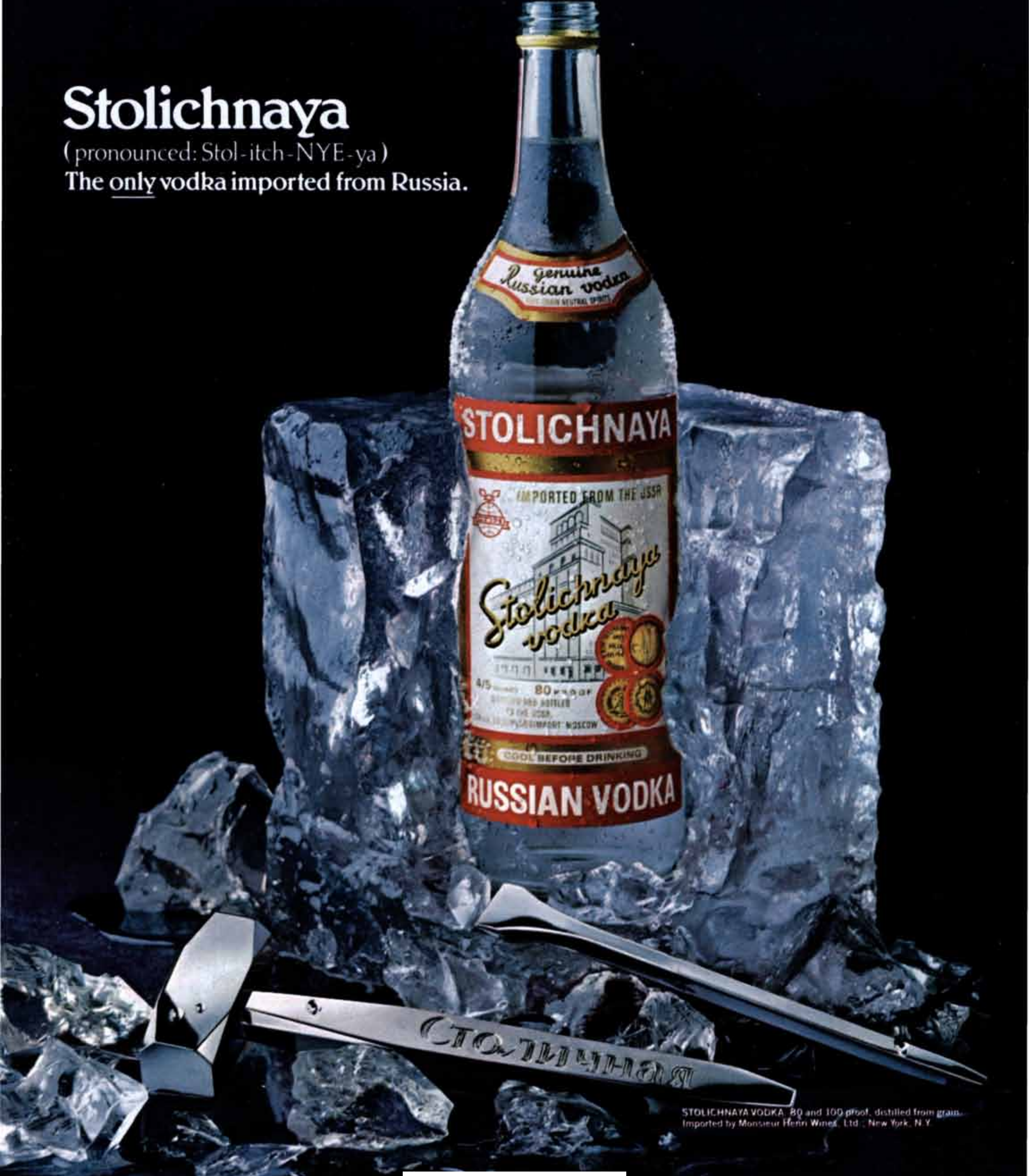
MAP OF DURHAM AND NORTHUMBERLAND COUNTIES in England shows the approximate locations of collieries in 1635. There were probably more collieries than are shown on the map. Illustration is adapted from map in author's *The Rise of the British Coal Industry.*

at a colliery in Staffordshire a steam engine that actually worked. It was to no small extent the needs of coal mining and coal transport that led to the steam engine and the railroad. Britain's damp climate made the damage of water in the multiplying coal mines a serious problem. Power from horses (which ate costly fodder) and from running water (which required capital for dams and overshot wheels) was diminishing the profits from coal mining throughout the 17th century. The compelling need for more efficient drainage systems in the British coal mines in that early age played an important part in the development of the Newcomen engine. Once these "fire engines" were invented, as John S. Allen and Alan Smith have shown, they spread rapidly across Britain between 1712 and about 1730.

It should be mentioned that coal appears to have been burned for many industrial purposes in China in the Sung era, in the 10th and 11th centuries. The episode was largely forgotten. It clearly did not lead, as it did in Europe much later, to an industrial revolution.

Studies made over the past 50 years, since I published my own two volumes on coal, have shown that the period of Britain's energy crisis—the late 16th and 17th centuries—was also the period of what has come to be called the scientific revolution. The revolution in thinking that brought modern science into being was an even more important factor than coal in the establishment of the mechanized age. By the 1620's and 1630's Europeans were becoming aware of the immense growth in production promised by the development of the new fuel. It was in those two decades that Francis Bacon wrote *The New Atlantis* (1627) and René Descartes his *Discourse on Method* (1637). Bacon's imaginary island over the seas was provided with a great institution of scientific research presiding over human destiny, and he was confident that a new abundance, made possible by the growth of scientific knowledge, would solve intellectual and moral problems as well as economic ones. And Descartes in his *Discourse* was no less confident. Even more specifically than Bacon he foresaw greater output, lighter labor and longer life for human beings everywhere. Even at that time there was talk of airships, submarines, devastating explosives and journeys to the moon. It was the scientific revolution in the late 16th and 17th centuries, together with the economic transformations brought about by the introduction of coal, that gave birth to the industrial world in which we live.

In Britain the period of the onset and resolution of the energy crisis (1550–1700) was characterized by increased returns from labor in all kinds of production. The British statesman and historian Lord Clarendon (1609–1674) was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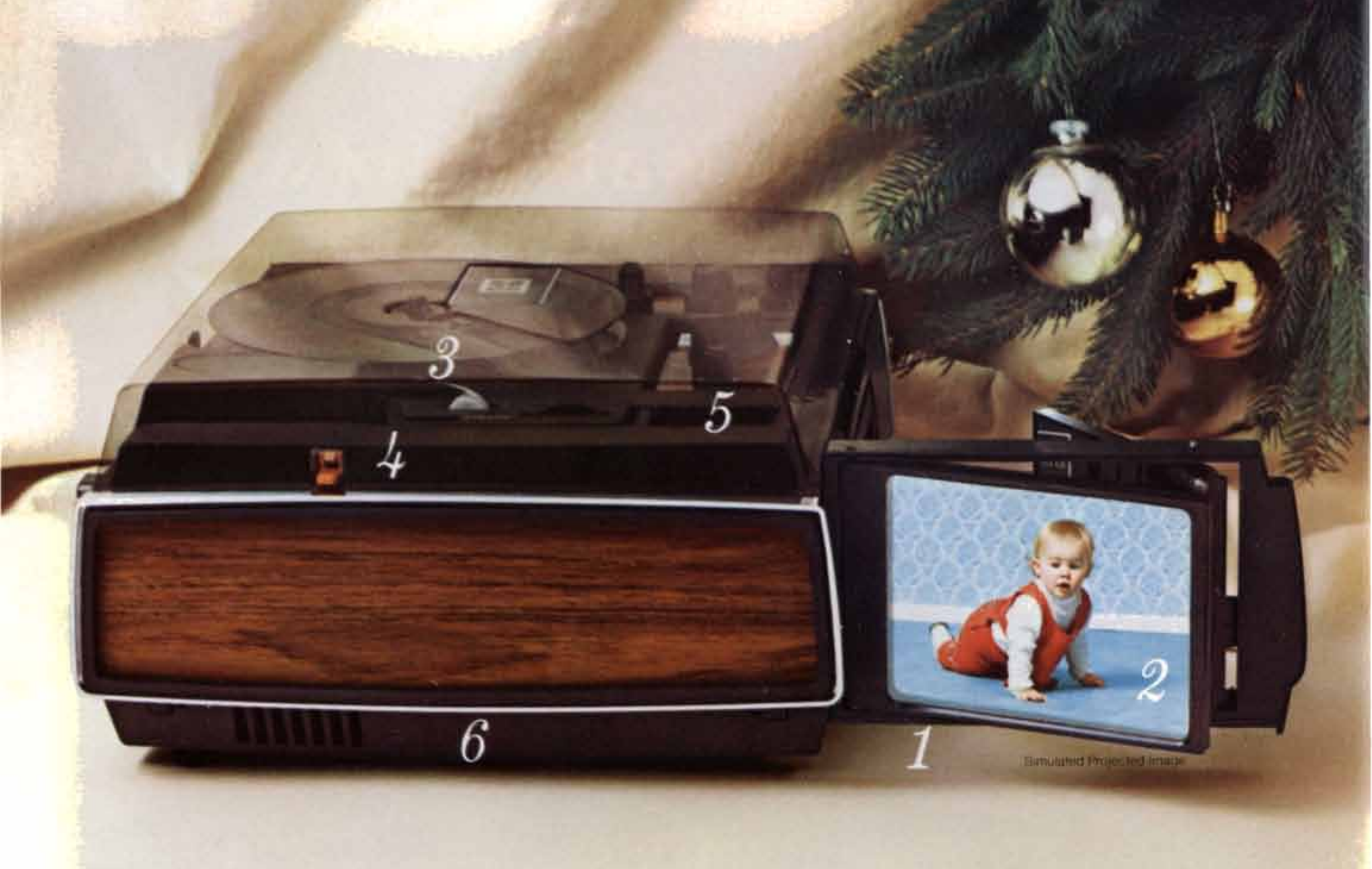

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referring to this prosperity when he wrote that during the period before the 1640's the English "enjoyed ... the fullest measure of felicity, that any people in any age for so long time together have been blessed with; to the wonder and envy of all the parts of Christendom." Clarendon did not base his assertion on what would today be considered reliable statistics, and indeed it is not possible to provide such statistics. Yet the new information on English economic growth contained in recent books of Eric Kerridge's and of mine supports Clarendon's statement. Britain, which lagged behind the rest of Europe in many economic areas during the later Middle Ages, was probably ahead of the other European countries in per capita agricultural and industrial output by 1700.

Kerridge has shown that whereas it has been thought that British agriculture was transformed in the 18th and early 19th centuries, the transformation actually took place between the late Middle Ages and the end of the 17th century. In this period, he writes, "the improvement of yields [from farming] must have been enormous. Corn [that is, grain] and grass yields rose about fourfold, and the yields of the fallows [the land not previously tilled] increased out of recognition. All told it is difficult to resist the conclusion that yields rose up to tenfold and fivefold on the average."

In the 1920's and 1930's most students of the coming of industrialism (myself included) accepted the explanations of Karl Marx, Sir William Ashley, Max Weber, Henri Hauser and others. The works of these scholars suggested that the advent of capitalism and of the "capitalist spirit" was the main factor leading to the overwhelming increase in the output of goods and services in the 19th century. I now think that an even more important factor was a growing faith in quantitative progress, in the multiplication of output.

Late in the 16th century a new attention came to be focused on concepts of quantity. The effects of this new concern could be seen in the more exact measurements employed in the developing natural sciences and in the replacement of the Julian calendar by the far more accurate Gregorian calendar. It was also reflected in a series of inventions designed to speed up numerical calculations, one made by Galileo (1564–1642), another made by the Dutch mathematician Simon Stevin (1548–1620) and two more by the Scottish laird John Napier (1550–1617), the originator of logarithms. A sophisticated mathematics—the calculus—was developed first in France after 1620 and more fully later in the 17th century by Newton and Leibniz. The idea of rates of growth introduced during the Elizabethan age brought a fresh precision to economic studies. The new point of view emphasized the probable value of quantitative goals to humanity. The transformation of industrial aims constituted a major advance toward an industrialized world.

In 1697 an Englishman named James Puckle wrote: "Our artisans [are] universally allow'd the best upon Earth for Improvements." This was certainly true in manufacturing that called for efficiency and quantity production. Yet a different evaluation needs to be made of the state of the arts and the luxury crafts in Britain following the conversion to coal. At the juncture of the 17th and 18th centuries Europe was eager to learn more efficient production methods from the British, but the British were equally eager to learn ways of fashioning beautiful products and environments from the Italians, the French and the Dutch. (Nowhere in 17th-century Europe was the quest for beauty and harmony in buildings and furnishings as remarkable as it was in the Netherlands of Rembrandt and Vermeer.) Harris has shown that in the 18th century the British, in spite of their aspirations to high fashion, had great difficulty copying the methods of making high-quality glass that were employed by the French at Saint-Gobain. In Britain the rise of the coal industry had weakened the position of craftsmanship and art as the heart and soul of production.

Moreover, the rise of coal mining had cast a shadow over the laborers connected with coal. Coal miners and coal carriers, stained by the black mineral, were often outcasts. They were seen as black men, and in the 17th century, when real black men were being shipped as slaves from Africa to America, coal laborers were being subjected to a new form of slavery in Scottish collieries and coal-burning salt pans.

As coal spread from Britain to the rest of Europe in the late 18th century and afterward the concern for beauty in manufactures and in the human environment weakened. Throughout history this kind of dedication to beauty has been important in setting reasonable limits to economic growth. The advent of coal seems to have diminished such dedication. The exploitation of the earth's resources has often violated the bounds of good taste. To make the most of these resources calls not only for ingenuity but also for restraint. At present man's dependence on fossil fuels is as problematic as his dependence on wood was some 400 years ago. The best hope for the fruitful exploitation of fuel resources may lie in a renewal and an amplification of the standards of beauty. If humanity is to advance, the making of history must become an art, that is, a search for beauty.

THE AMATEUR SCIENTIST

Wonders of physics that can be found in a cup of coffee or tea

by Jearl Walker

In a time when most of the results of science have to do with things remote from everyday experience—such as fundamental particles of matter, the inner workings of the living cell and the strange behavior of distant celestial objects—one tends to overlook the scientific opportunities that are to be found under one's nose. This month I have collected several examples based on nothing more complicated than a cup of coffee (or tea). You have undoubtedly encountered some of them, but you may not have given them much attention.

Late one night, escaping for a few minutes from work on his doctoral dissertation, my friend John Hudak was idly mixing instant coffee into a mug of hot water, clinking his metal spoon on the bottom of the mug as he stirred. The pitch of the clinking noise fell abruptly as the powder went into the water, meaning that the sound waves had become longer and had decreased in frequency. As Hudak stirred for the time required to mix the powder the frequency slowly increased to its former value. He obtained the same results when he added a spoonful of a powdered cream substitute. Indeed, any powder dissolved in the hot water caused the same type of frequency shift.

Before any powder is added a particular note is heard from the clinking because the spoon excites resonant standing waves in the column of water and in the rim of the mug. The waves are similar to the resonant waves in an organ pipe that are responsible for the sounds you hear from the pipe. The harmonic frequencies in the coffee cup, however, are a bit more difficult to calculate than those in the organ pipe. The frequencies depend on the thickness, radius, density and elasticity of the rim, the radius of the column of liquid and the speed of sound in the liquid.

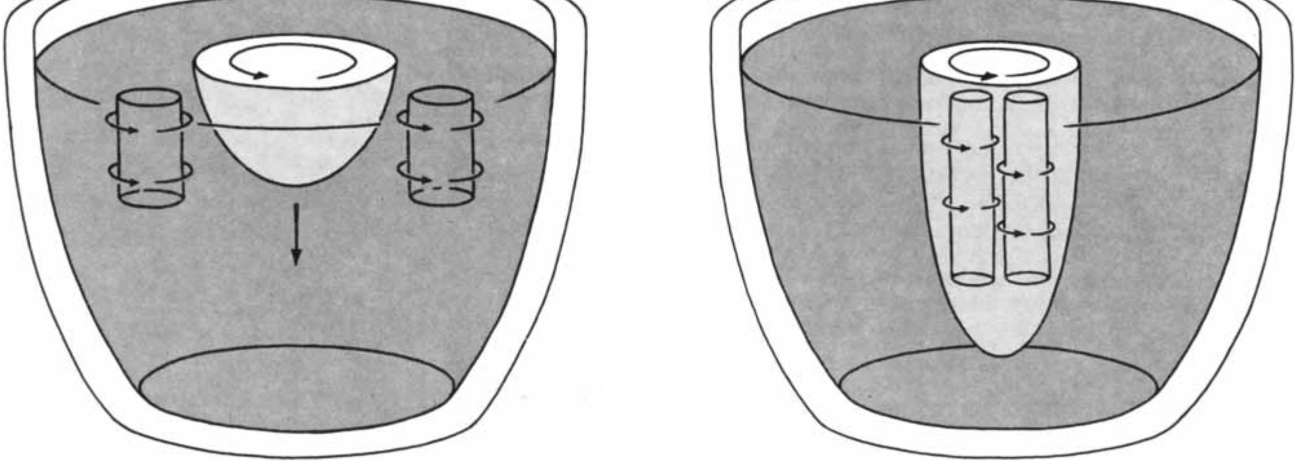
I first thought the powder would lie on top of the water and thus would have an influence in determining the resonant frequencies of the mug. It turns out, however, that any powder lying on the water only damps the oscillations in the mug, thereby muffling the clinking noise. It does not change the resonant frequencies. Moreover, the powder dissolves rather quickly.

When the powder first dissolves, tiny air bubbles are released from the powder grains. The speed of sound is considerably less in air (about 340 meters per second) than in water (about 1,450), so that the bubbles lower the speed of sound in the liquid. If the volume of the bubbles is a hundredth the volume of the liquid, the velocity of sound is reduced 30 times. As a result the frequency of any standing wave is lower when the bubbles are released. As the bubbles gradually burst, the speed of sound (and hence the frequency of the standing wave produced by the clinking) returns to normal.

A similar change in frequency can be observed in a freshly poured glass of beer. As the air bubbles in the beer (not the ones on top of it) dissipate, the pitch of the sound of a spoon tapped against the side of the glass rises slowly.

One rather simple experiment in a coffee cup serves as a rough model of vortex motion on a much larger scale in the atmosphere (dust devils, tornadoes, fire storms and hurricanes). Smoothly stir a cup of hot coffee or hot tea, lift the spoon out and then carefully pour cold milk or cream into the center of the cup. If the stirring and pouring are done carefully enough, a vortex develops in the center of the coffee. It is noticeable for two reasons. First, the angular speed of the fluid is greater in the center than it is just outside the region where the milk was poured. Second, the vortex may be so well developed that the surface in the center dimples. Neither characteristic appears if the milk is warm or hot. Instead the angular speed in the center of the cup decreases.

The different results with hot and cold milk stem from the difference in their densities with respect to the hot water in the cup. Cold milk is denser than the water and so will sink when it is added to the water. The descending stream captures existing small vortex columns



Stretching of vortex columns when cold milk or cream is poured into hot coffee

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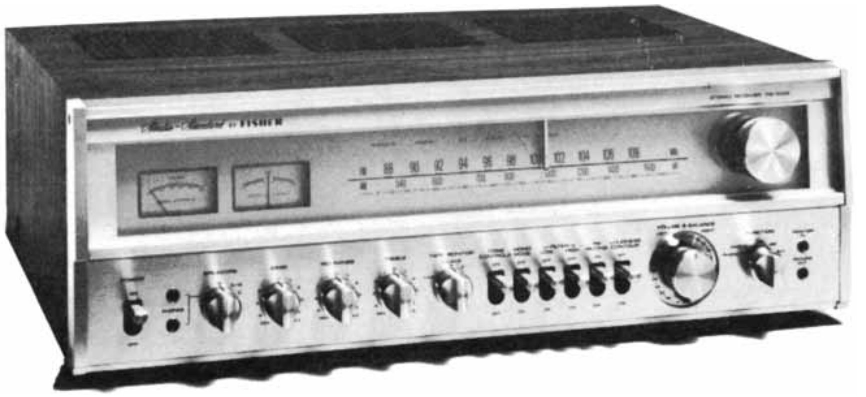
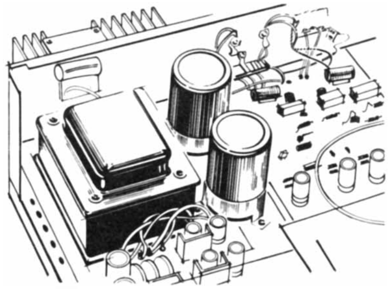


Today's music is more demanding than ever. Recording engineers easily capture the raw power as well as the subtle nuances of rock, classical and contemporary music. Playback of those recordings requires equipment of the highest caliber.

The RS1058 delivers 90 watts per channel minimum RMS continuous power output, both channels driven into 8 ohms, from 20-20,000 Hz with no more than 0.1% total harmonic distortion.

The RS1058 will produce discotheque sound pressure levels with practically any loudspeaker system. Equally important is its ability to combine high power output and low distortion with excellent dynamic range, transient reproduction, signal-to-noise ratio and stereo separation.



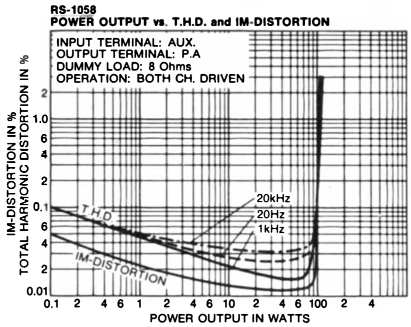
CAPTURE THE EXCITEMENT OF MUSIC.

A receiver's power supply is responsible for the excitement of music. It must recreate music's dynamic range, as well as the instantaneous bursts of sonic energy, called transients, of a live performance.

Some stereo receivers use a relatively small, inexpensive power supply for each channel. The RS1058 overcomes such limitations with a single low-impedance power supply capable of delivering its total voltage output (180 watts RMS) instantly to either channel as required by the music. Such a power supply results in significantly more reserve power for reproducing music's full dynamic range, and its transients for greater realism—not only at loud listening levels, but at normal listening levels as well.

LOWER DISTORTION FOR INCREASED REALISM.

The human ear is capable of discerning extremely fine differences between recorded and live music.



RS-1058
POWER OUTPUT vs. T.H.D. and IM-DISTORTION

For this reason Fisher engineers painstakingly pursued every opportunity to reduce distortion and extraneous interference to its absolute minimum. Intermodulation and total harmonic distortion are kept below 0.1% at full output.

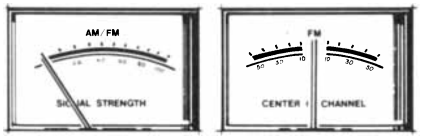
EXTREME TUNER SENSITIVITY.

FM performance of the RS1058 can only be described as impressive. Usable sensitivity of 1.7 microvolts, and a signal-to-noise ratio of 75 dB rival the most expensive receivers available. The RS1058 tuner utilizes an FM front end featuring a 4-gang tuning section AGC-controlled, dual-gate MOSFET RF stage for highly selective, noise-and interference-free reception. Exceptional stereo separation and clarity, extremely low distortion and maximum noise rejection are achieved by a phase-locked-loop FM multiplex decoder.

The large signal strength meter is provided for proper antenna orientation and coarse tuning, the center-of-channel meter pin-points station tuning.

HIGH FIDELITY CONTROL FLEXIBILITY.

All controls and indicators of the RS1058 are engineered to maximize utility and ease of operation.



The RS1058 features two phono inputs, two tape inputs and three speaker connections. The tape monitor control facilitates copying from one tape deck to another, and a front panel jack allows instant connection of an auxiliary tape deck. Baxandall tone controls deliver large amounts of bass and treble boost or cut, without affecting mid frequencies.

High and low filters with sharp roll-off characteristics can be engaged to cut extraneous noise and the speakers are protected by a relay circuit.

FORTY YEARS OF INNOVATION.

Fisher started the high fidelity industry in 1937, and introduced the first stereo receiver in 1959. That tradition of technological leadership continues with the RS1058 Studio Standard receiver.

When you consider the price, about $550,* the specifications of the RS1058 become even more impressive. Fisher components are available at fine audio stores or the audio department of better department stores.

Continuous RMS sine wave power per channel within stated bandwidth at no more than stated distortion and with an 8-ohm load	**90 watts**
Power Bandwidth	20 Hz-20kHz
Total Harmonic Distortion at rated power	0.1%
Total Intermodulation Distortion at rated power	0.1%
FM Usable Sensitivity	1.7μV/9.8 dBf
FM Signal-to-Noise Ratio	75 dB
Dimensions (WxDxH)	20¾"x14¼"x7"
Weight	31.3 lbs.

*Mfg, suggested retail price. Actual price is determined by dealer.

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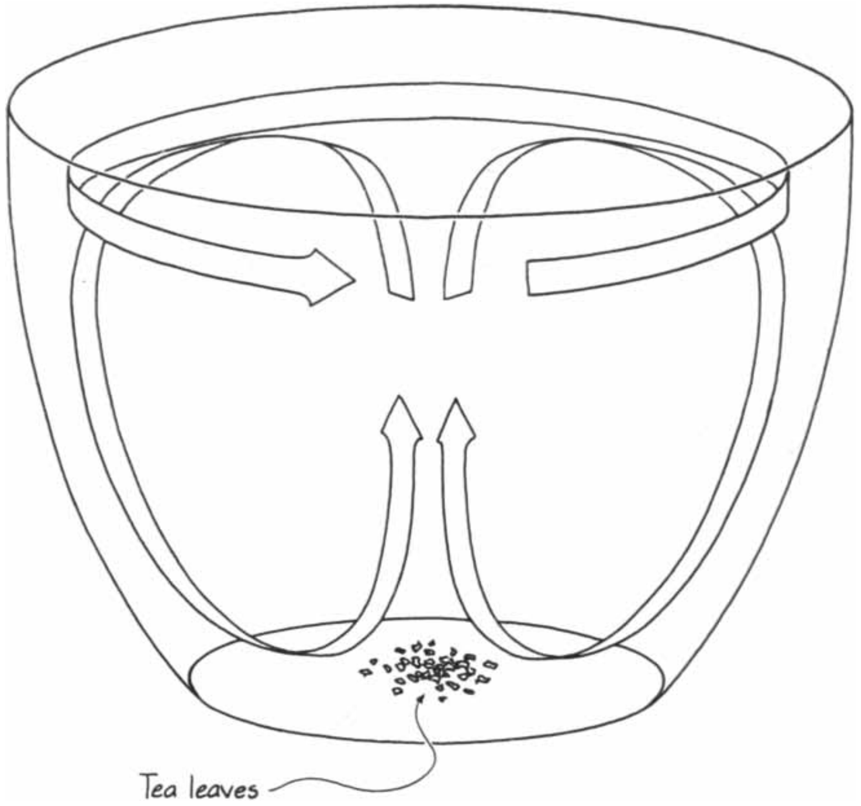


How the secondary flow in stirred tea carries tea leaves to the center of the cup

from the surrounding fluid, pulls them in toward the center and (on the average) stretches them. The angular speed of the fluid in the columns then increases, causing the fluid in the center of the cup to swirl faster than the fluid outside the area occupied by the milk.

If the milk is quite hot, it may be lighter than the water in the cup. With no descending stream (or a much smaller one) the vortex columns are not drawn into the center to be stretched, and so the angular speed around the center of the cup does not increase.

The demonstration with cold milk may be analogous to the amplification of vortexes in the air. Convective motion of the air may stretch already existing vortex tubes just as the descending milk stream does. Stretching increases the angular speed of the vortexes. In the air the necessary convection can be either up (if the stream is lighter than the surrounding air) or down (if the stream is heavier than the surrounding air). In either case the convection can intensify vortexes left by other sources, such as the swirling (due to overheating of the air near the ground) that can develop into dust devils.

If you stir a cup of tea or coffee in which you can see on the bottom a few specks, tea leaves or bits of undissolved sugar, you find that they are forced to the center of the bottom. The motion seems a bit paradoxical. One would suppose material lying on the bottom of the cup would be pushed outward to the walls by the centrifugal force created in the rotation of the fluid around the central axis of the cup.

The centrifugal force does attempt to push material to the walls. Consider a small parcel of water rotating around the central axis. The farther the parcel is from the axis, the greater the centrifugal force it experiences is. As a result the pressure in the liquid increases outward from the axis, in a sense to counter the centrifugal force. The rotating fluid should therefore have no radial motion, only angular motion around the center.

Radial motion does develop, however, because of the friction between the bottom layer of fluid and the bottom of the cup. The reduced rotation in the bottom layer means that the pressure difference there between fluid near the wall and fluid near the center is not as much as it is on the top surface. This reduced pressure in turn means that the pressure near the wall is greater in the top layer than in the bottom layer. As a result fluid is forced downward along the wall and then radially inward to the bottom center of the cup, upward along the central axis and radially outward in the top layer. This fluid motion, known as secondary flow, can carry tea leaves or other submerged objects along the bottom of the cup and deposit them in the center as the fluid begins its central ascent.

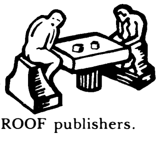
You can follow the secondary flow by carefully dropping food coloring into stirred water in a clear cup or beaker. Although the fluid flow is not as ideal as is implied in the illustration on the opposite page, the colored water does spiral around the center of the cup with a radial motion roughly like the one depicted.

The same type of secondary flow is partly responsible for the meandering of rivers. Similar meandering can also be seen in the Gulf Stream and other ocean currents and in water channels on the surface of a glacier. Even when a straight section of a stream is found, closer inspection usually reveals that the movement of the water is not really straight but rather exhibits a weaving back and forth between the walls of the stream. Small perturbations introduced into the course of the stream by the local terrain initiate the meandering. The mystery lies in the regularity of the resulting pattern.

When water rounds a bend, a secondary flow similar to the one in the teacup is created. Because of the retardation of flow near the bottom the pressure difference between the inside and the outside of the bend is different in the top and bottom layers of the water. The greater pressure on the outside top layer forces fluid down the outside wall. Reaching the bottom, the fluid is forced toward the inside of the curve, then upward and finally out again to the outside of the curve along the top surface. During this time the horizontal velocity of the water is greater on the outside of the turn than it is on the inside. The faster flow tears away portions of the outside bank, and the loose material is carried by the secondary flow to the inside bank. The result is an enhancement of the stream's curve, because the outside bank is eaten away as the inside bank is built up. Given an initially young, straight stream, the secondary flow will enhance any perturbations in its bed into small meanderings, which in turn will be enhanced into larger meanderings. If the looping becomes extreme, the stream eats its way from one loop to another to strand a loop in between.

Vincent J. Schaefer has described in *American Scientist* a surprising geometric pattern on the surface of his early-morning coffee. With bright sunlight shining almost horizontally across a cup of hot coffee filled to the brim, the surface exhibited dusty-looking polygons traced out with dark lines. This type of geometric surface pattern was first discussed in detail by Henri Bénard in 1901. Examples of the pattern can be found in other evaporating fluids and in circulation systems in both the atmosphere and the sea.

The pattern in the coffee cup is caused by the circulation of the hot water that rises from the bottom to the top, cools and then returns to the bottom. Over the



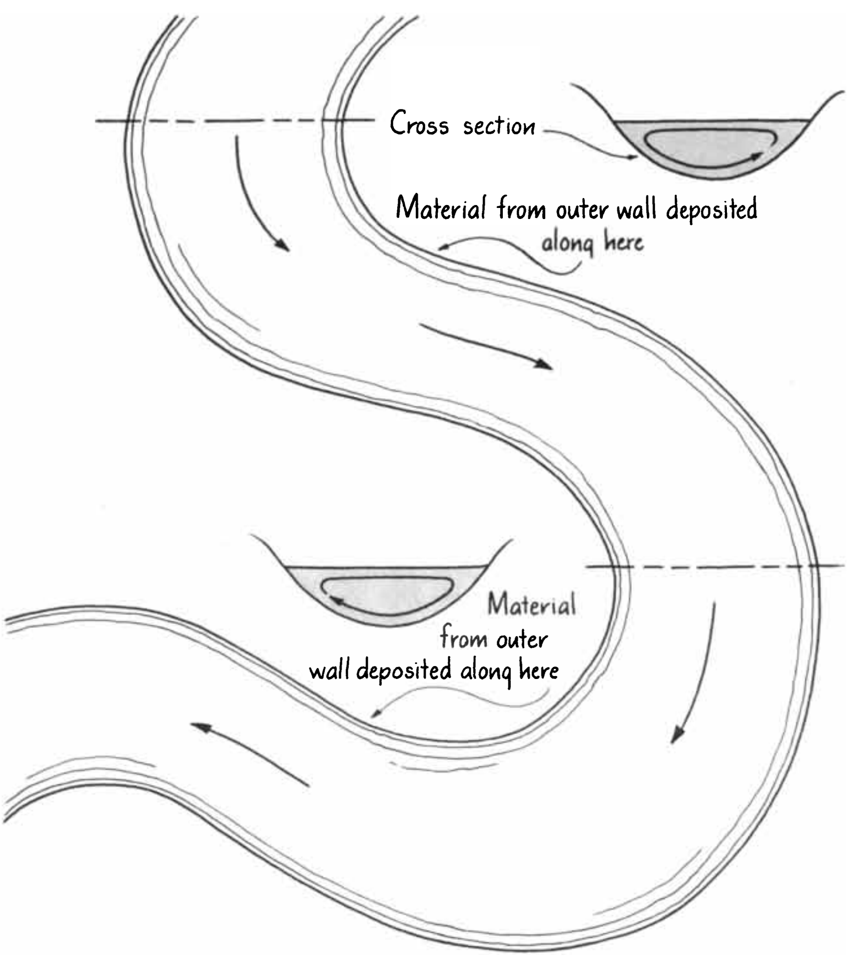
areas of rising hot water small drops condense, supported by the vapor pressure from the surface of the liquid. The drops are of roughly uniform size, because larger drops cannot be supported by the vapor pressure and smaller ones scuttle away. Over the areas where the cooled water descends there are no such suspended drops, and the surface appears clear. Since the coffee is dark these areas are also dark. What one sees on the surface is small patches of drops (over rising water) that are outlined by relatively narrow dark lines where the fluid descends.

If the lighter areas are examined with a microscope, they appear to consist of layers of closely packed drops. The density of the drops depends on the vapor pressure available from the liquid and on the number of condensation nuclei in the air. A dirty atmosphere will in principle provide more condensation nuclei for more droplets.

To observe such phenomena you need not wait for a setting or a rising sun. You can see the Bénard-circulation patterns more easily by directing the light from a slide projector or a motion-picture projector over the surface of a cup of coffee. If you would rather not waste coffee, substitute hot water dyed with a dark color (black food coloring or a dark ink). To maintain the heat in the water you can put the cup (or even better a Pyrex beaker) on a low-temperature hot plate. I initially brought the water nearly to the boiling point to degas it (the bubbles are a nuisance) and then allowed the water to cool. The best Bénard cells appeared several minutes later.

If the surface became contaminated with a film, I briefly laid a piece of paper towel on the liquid to collect and remove the film. If you would like to see the effect of such a contamination, place a drop of corn oil on the surface. The oil slowly spreads over the surface and eliminates the Bénard cells.

Schaefer has also described the effect of bringing charged objects near the light areas in the Bénard cells. Running a hard-rubber comb through your hair or across a length of wool or plastic charges the comb by transferring electrons either to the comb or to the other material. With some types of material the comb gains electrons and becomes negative. With other types of material the comb loses electrons and becomes

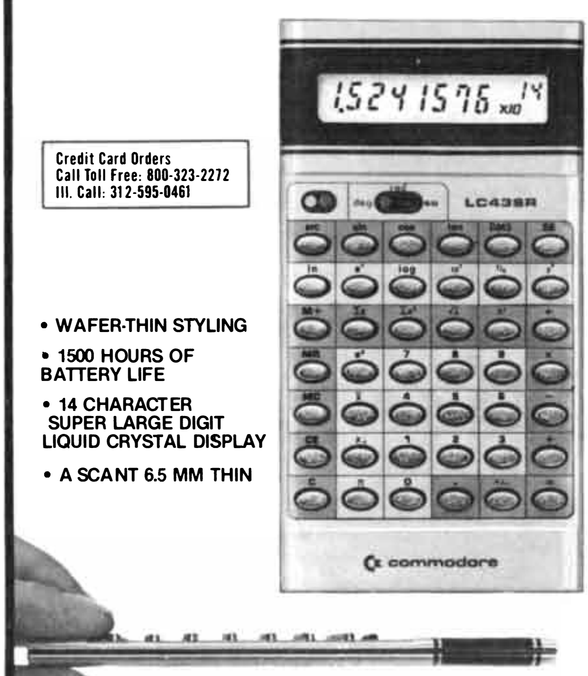

Cross section
Material from outer wall deposited along here
Material from outer wall deposited along here

Effect of secondary flow in enhancing a river meander positive. In either case the charged comb destroys the light areas, indicating that the drops already carried a charge.

When Schaefer held a charged hard-rubber comb near the surface of the water, he sometimes saw drops form near the teeth of the comb. I saw this phenomenon when I held a wire lead from an electrostatic generator near the surface of the water, with the other lead from the generator attached to the metal cup holding the water. In both cases the ions created in the air near the tip of the charged object are condensation nuclei for the formation of drops. A radioactive source accomplishes the same thing because it too provides ions in the air just above the water surface. A lighted match or any other source of small airborne particles will similarly increase the drop formation.

When the drops are illuminated in bright white light, they display rapidly changing colors, delicate and iridescent. The scattering of light that gives rise to these colors is called the higher-order Tyndall scattering, after John Tyndall, who investigated them starting in 1869. Tyndall scattering can also be seen in other natural phenomena. The corona that is sometimes seen around the sun, which can show several complete spectra of colors, is the result of Tyndall scattering from small drops in the thin clouds lying between the viewer and the sun. (It is not the corona seen during an eclipse.) So is the similar corona seen around the moon. The scattering is likewise responsible for the delicate colors seen in the mother-of-pearl, or nacreous, clouds that are occasionally visible after sunset in the high latitudes. The mathematical models of this scattering are complex because the size of the drops approximates the wavelengths of visible light. The drops are a micron or so in diameter and therefore lie between the larger drops that can produce rainbows (geometric scattering) and the smaller particles that are responsible for the blueness of the sky (Rayleigh scattering).

In addition to the constantly changing patterns on the surface of your coffee cup or some other vessel you will also find dark lines that scud across the dusty-looking areas. Schaefer points out that these lines are due to small whirlwinds that develop just above the surface and last for only a fraction of a second. The layer of air just above the liquid is unstable because it is much warmer than the air slightly higher up. You can create your own vortex by holding an index card vertically with one edge near the surface. Any small air current flowing past the edge sheds a vortex that then skims across the surface. Even without an edge larger whirlwinds occasionally develop over the surface, lasting for 10 seconds or so as

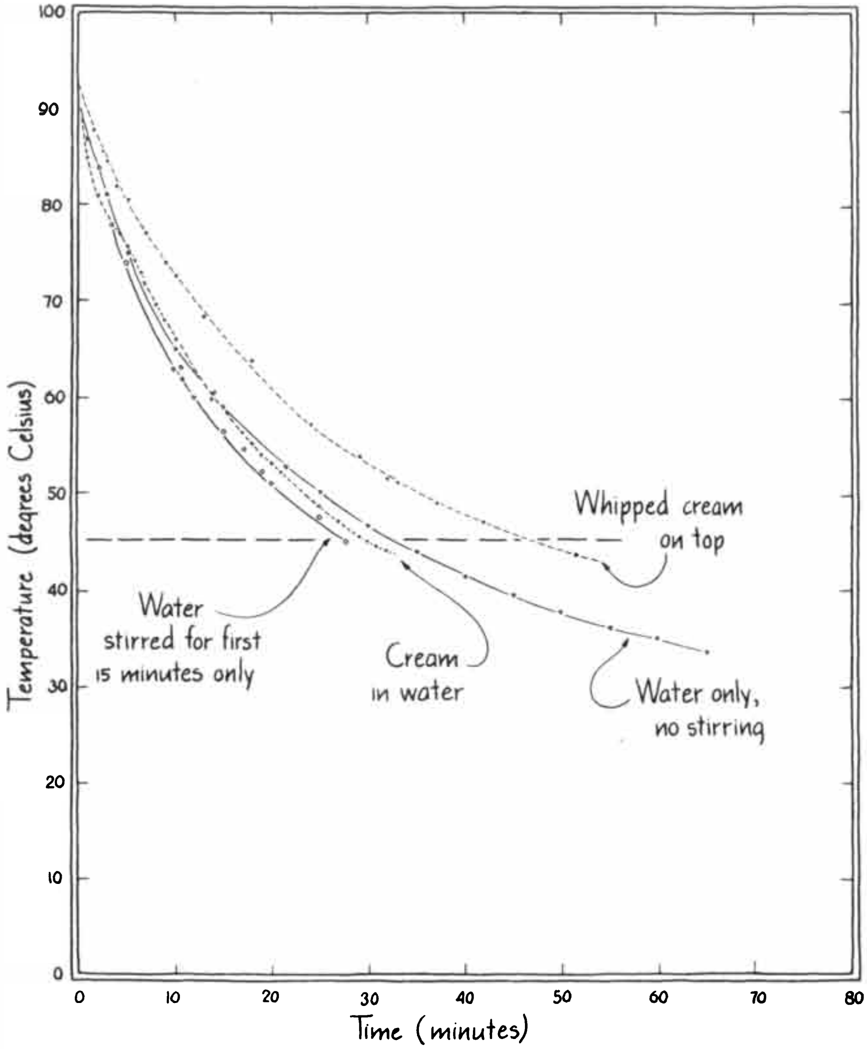


they whip the evaporating vapor and small droplets around.

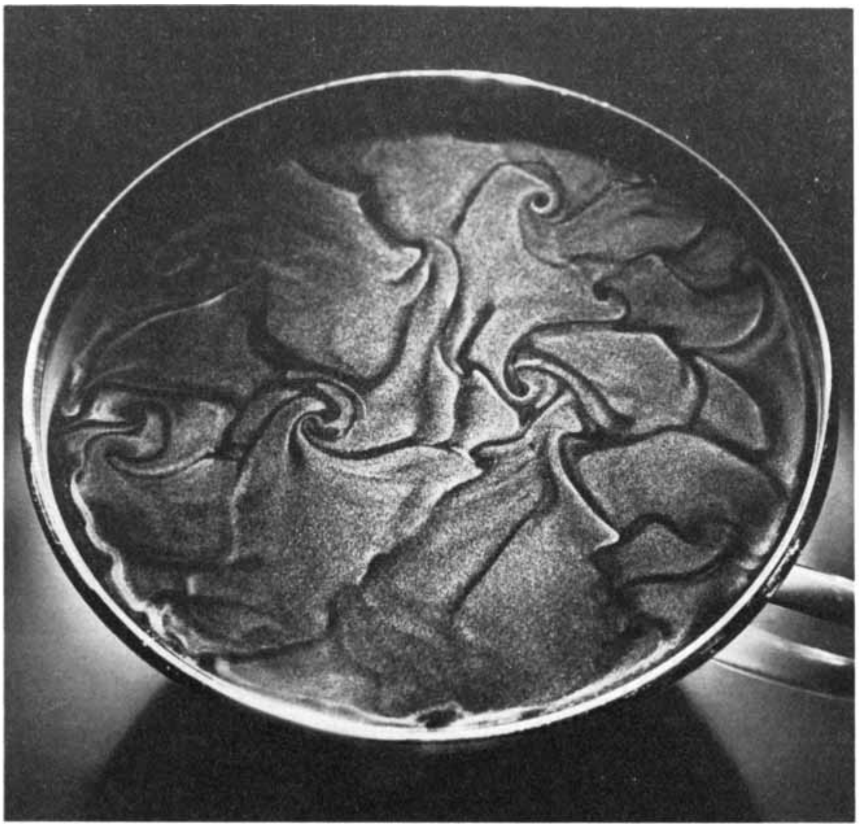
How fast does a cup of coffee or tea cool? To push back the frontiers of modern physics (at least a millimeter or two) I measured the rate at which water cooled from the temperature to which it would be heated to make instant coffee. I wanted to know which of several procedures would cause the water to cool fastest. I boiled water in a teakettle and poured 200 milliliters into a 250-milliliter Pyrex beaker, which was then left on a metal plate. The temperature of the water was measured with a thermometer (scaled from zero to 100 degrees Celsius) that was left in the beaker with the mercury reservoir resting on a corner of the bottom of the beaker. The initial water temperature in all the runs was 93 degrees C. I measured temperature until the water was below 45 degrees, which I believe would correspond to an unpleasantly cool cup of coffee.

Water with no additives and no stirring cooled smoothly, reaching 45 degrees in about 33 minutes. With a teaspoon of instant coffee put into the beaker before the water was added the water cooled in almost the same way for the first 15 minutes but then cooled faster than it had in the first run. The results were almost identical when three lumps of sugar were first placed in the beaker and when a metal spoon was left in it (nothing else having been added). One might guess that the inclusion of instant-coffee powder would cool the water faster for two reasons. The powder, being initially at room temperature, absorbs heat from the water. It also darkens the solution, thereby increasing the thermal radiation somewhat. The latter effect must be negligible, since the addition of sugar to the water did not darken the solution but gave similar results. The spoon can be expected to increase the cooling rate of the water because initially it absorbs some of the water's heat and thereafter acts as a radiator of heat to the room.

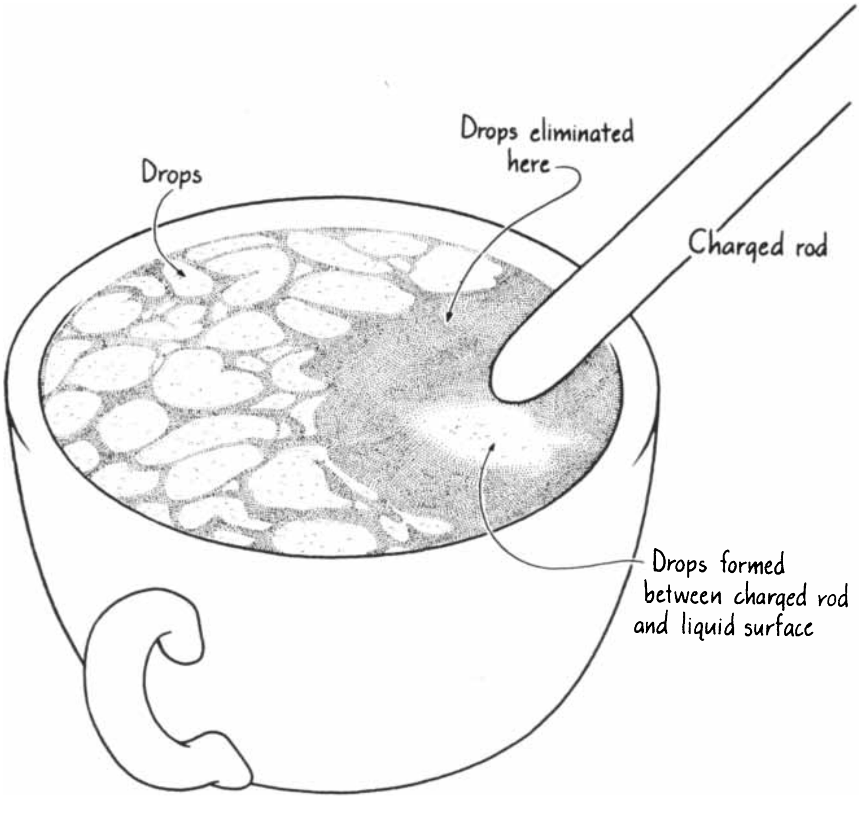
In another run I added 20 milliliters of light cream at an initial temperature of 10 degrees C. immediately after the water was poured. The water was stirred only three times to mix the cream with-



Cooling rates of hot water



Geometric patterns on the surface of hot coffee



Effect of bringing a charged rod close to the surface

out producing a cooling effect by the stirring. The temperature immediately dropped about four degrees, but after five minutes the mixture of cream and water began to follow the same cooling curve followed by water alone. After 15 minutes, however, the cream mixture cooled faster.

The addition of alcohol might increase the cooling rate because of the enhanced evaporation from the top surface. After I had added 20 milliliters of 80-proof vodka that was at room temperature the cooling rate was almost the same as when I added cream.

Of all the additives the one most effective in altering the cooling curve of the water was Reddi wip (a whipping cream in a pressurized can) that I applied to the top of the water, much as one would do in making Irish coffee. The cream was cool and might have initially lowered the surface temperature of the water somewhat, but its main effect was to trap the heat in the water and eliminate evaporation. As a result the water took an additional 14 minutes to reach 45 degrees C.

I figured that stirring unmodified water during the cooling would significantly increase the cooling rate. Vigorous stirring with the thermometer for the first 15 minutes, however, typically reduced the water temperature by only a couple of degrees. Apparently my stirring was not much better than the normal convection cells in the water at transporting hot water from the center to the surface.

In my last test I sprayed the outside of the beaker black. With a black surface the walls should radiate heat better, causing the liquid to cool faster. The water did cool faster, approximately following the cooling curve I had obtained by stirring the water.

Two conclusions emerge from these data. If you want to cool your coffee quickly but without adding a large amount of cream and sugar, stirring the coffee vigorously with a metal spoon in a black coffee cup is the best procedure. The cooling seems hardly worth the effort, however, since it amounts to only a few degrees. On the other hand, if you want to keep your coffee as hot as possible, the best thing to do is to fix yourself an Irish coffee and relax.

If you would like to do more work on the problem, you might consider the effects of adding cream, sugar or a powdered cream substitute five or 10 minutes after the water is poured. Is the temperature of the coffee lower if the coffee is allowed to cool by evaporation and convection before the cream, powdered substitute or sugar is added? You might also like to find out how the temperature of an Irish coffee depends on the proof of the whiskey. Investigating this question would be a particularly enjoyable experiment for two.

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