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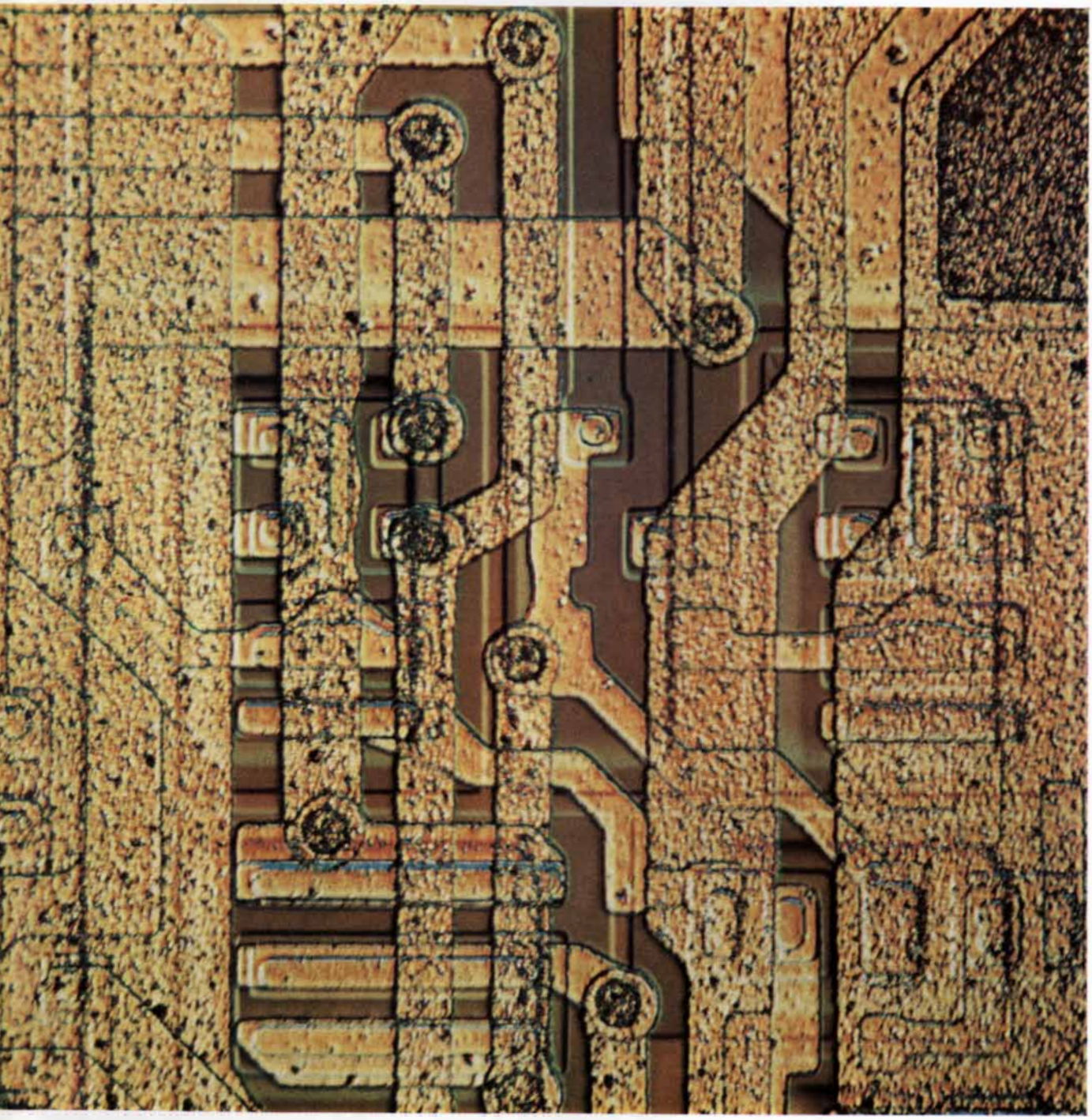

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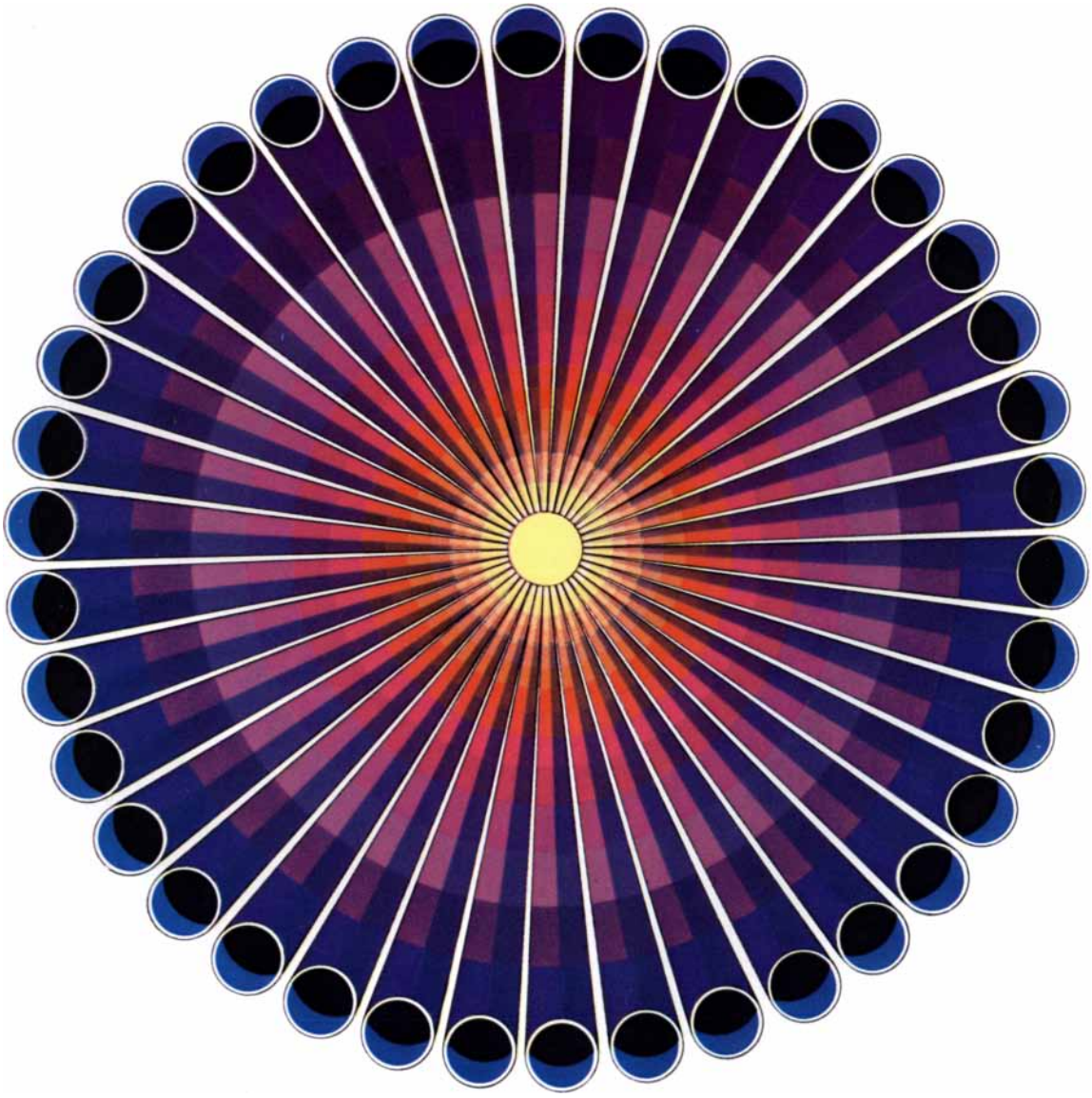

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[1]Sir J. J. Thompson, *Recollections and Reflections*, p. 249, MacMillan, New York, 1937.

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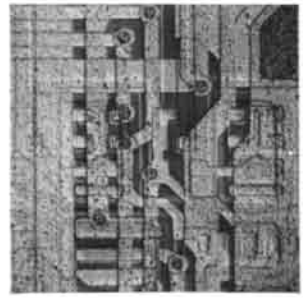

THE COVER

The photograph on the cover is a 450-diameter enlargement of a small portion of an electronic circuit manufactured by the new "LSI" technology (see "Large-Scale Integration in Electronics," page 22). Although the complete circuit is actually only 145 mils square (.145 by .145 inch), it contains some 860 transistors, diodes and resistors, interconnected to form 96 circuit cells, or logic gates. The fragment on the cover includes four transistors and parts of two resistors. The interconnections are supplied by two thin layers of aluminum, visible as broad, gold-colored bands. The interconnection paths can be varied to suit the customer's requirements. The density of individual electronic devices in this LSI circuit, manufactured by Fairchild Semiconductor, exceeds 40,000 per square inch. In some large-scale integrated arrays the density of devices exceeds 100,000 per square inch—a factor of 10 greater than the density achievable only five years ago.

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SCIENCE/SCOPE

A new launcher for the Phoenix missile now being built by Hughes has a fail-safe device that prevents accidental separation of missile from launcher during aircraft maneuvers. It uses no exotic or critical materials, weighs only two-thirds as much as an earlier model, and can be installed on either side of the fuselage.

A self-cleaning gas system makes it unnecessary to remove the launcher for maintenance after each mission. Hughes is building the launcher for the U.S. Navy's new F-14A fighter under contract to Grumman Aerospace Corp.

An imaging photopolarimeter for the Jupiter probe is being developed for NASA's Ames Research Center by Santa Barbara Research Center, a Hughes subsidiary, for the Pioneer F and G spacecraft to be launched in 1972 and 1973. Instrument will map the density and distribution of "asteroidal debris", measure the gas above Jupiter's cloud layers, and send back two-color spin-scan images of the planet.

Los Angeles has turned to aerospace technology for help in meeting the increasing demands for police, fire, and ambulance service. The city council recently chose Hughes to make a one-year study of the city's over-burdened services and to draw up a plan for a command-&-control system that would provide rapid pinpointing of field forces, computer dispatching, automated status displays, computerized information files, individual communications for hazardous-duty personnel, and automatic transmission and signaling for police vehicles.

NASA's Atmosphere Explorer satellite, now under study at Hughes, will carry a propulsion system that will enable it to climb to an apogee of 2500 miles in its variable orbit around earth. Every two hours it will dip back into the upper atmosphere for 10 to 20 minutes, swooping within 90 miles of earth.

The "yo-yo" satellite's scientific objectives will be to obtain data on the behavioral relationship of the upper and lower atmosphere, solar energy absorption, density of the atmosphere's charged-particle structure, and the diurnal bulge that appears to circle the earth as the sun heats the atmosphere.

Career opportunities for engineers at Hughes include: Signal Processing Systems Analysts, Computer Software Analysts, Radar Systems Engineers, and Circuit Designers. B.S. degree, two years of related experience, and U.S. citizenship are required. Please write: Mr. J. C. Cox, Hughes Aircraft Company, P.O. Box 90515, Los Angeles 90009. Hughes is an equal opportunity employer.

A laser proximity fuse and larger fins are being given to the U.S. Air Force Falcon in a program now underway at Hughes to make the air-to-air missile more effective against maneuvering targets. The proximity fuse's optically focused laser beam, which is reflected off the target, cannot be confused by electronic countermeasures and is virtually impossible to detect.

Because the laser gear is extremely compact, it can be tucked into a collar around the nozzle of the Falcon's rocket motor, leaving space in the missile for a larger and more powerful warhead.

LETTERS

Sirs:

Lester Grinspoon in his article "Marihuana" [SCIENTIFIC AMERICAN, December] states that marihuana is "far less potent" than LSD, mescaline or other hallucinogenic drugs. The comparison with mescaline is incorrect. Tetrahydrocannabinol, the active constituent of marihuana, is some 30 times more potent than mescaline, if potency refers to the quantity required for psychotomimetic effects. Potency, however, is a relatively meaningless basis for comparison. It is irrelevant whether the effective dose of a drug is a microgram or a gram, so long as the drug is administered in appropriate dosage. On a weight basis, ethyl alcohol is thousands of times *less* potent than tetrahydrocannabinol, but in sufficient amounts it produces ill effects. There is evidence that marihuana in sufficient amounts also produces ill effects, but for a fair and balanced review of this evidence the reader must turn elsewhere than to the Grinspoon article.

The author's pro-marihuana bias is obvious and unfortunate, since it detracts from the many accurate and useful points in the article. It is obvious even in small ways, such as his comment about Baudelaire. "Hashish," he writes, "is supposed to have been responsible for Baudelaire's psychosis and death, but the story overlooks the fact that he had been an alcoholic and suffered from tertiary syphilis." This sentence could have been written: "Alcoholism and tertiary syphilis are supposed to have been responsible for Baudelaire's psychosis and death, but the story overlooks the fact that he smoked hashish." This, however, would have betrayed an anti-marihuana bias, allegedly grounds for lynching in the Boston area.

Or take the nowadays routine assertion that marihuana is "not an addictive drug." If only those drugs that produce both high degrees of tolerance and severe withdrawal symptoms are considered addictive, marihuana apparently is not addictive (nor is any hallucinogen by these criteria). If, however, psychological dependence is considered a characteristic of addiction (as it is by the World Health Organization), then it may be incorrect to call marihuana unaddictive. G. S. Chopra, having studied hundreds of cannabis users in India, concluded that "repeated use of cannabis leads to craving and psychological dependence," and even observed withdrawal symptoms in chronic users ("... pronounced physical and mental discomfort similar to that brought about by other drugs of addiction").

Grinspoon, in fact, is never more tendentious than when quoting Chopra. For example, he mentions that Chopra found a low rate of psychosis among cannabis users, but he does not mention the high incidence of debilitating illnesses reported in the same study. Chopra's speculation that cannabis may suppress rather than incite criminal behavior is mentioned, but not his finding that cannabis users had a considerably higher crime rate than the general population did. Grinspoon indicates, correctly, that it is difficult in these studies to identify cause and effect. (Does cannabis promote crime or crime cannabis, etc.?) Given a choice of alternative explanations, Grinspoon invariably chooses the one least incriminating to marihuana. He is entitled to his bias—and the reader to the whole story.

DONALD W. GOODWIN, M.D.

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Sirs:

In his attempt to prove me wrong in my assertion about the relative potencies of the drugs marihuana and mescaline, Dr. Goodwin ascribes what I have to say about marihuana to tetrahydrocannabinol. Since it is clear from his discussion that he understands the concept of potency, he will, I believe, agree with me that marihuana or "bhang" is far less potent than mescaline. Had I chosen to compare potency with tetrahydrocannabinol (THC), then what Dr. Goodwin says would be substantially correct. But Dr. Goodwin is wrong in implying that THC is the only active constituent in marihuana. Furthermore, marihuana, and not THC, is the commonly used form of the drug. Therefore, the limitations of a comparison of potency notwithstanding, it makes more sense to try to put marihuana rather than THC into perspective with mescaline and the other hallucinogens.

My statement with regard to Baudelaire is one in complete consonance with the well-known myth that appears frequently in the biographical literature and suggests that hashish was responsible for Baudelaire's psychosis and death. Dr. Goodwin's restatement not only greatly distorts the myth but also introduces an element of the ridiculous. Although it is well known that either alcohol or syphilis can lead to both psychosis and death, it is not certain that even large amounts of hashish will invariably lead to psychosis, and there is no recorded case of its leading to death.

In reference to the Chopra article, a closer reading on Dr. Goodwin's part would dispel his illusion that I am guilty of selective editing in support of a pro-marihuana bias. Chopra makes the statement: "In the large number of habitual users studied by us, 6.24% had been convicted once and 7.92% more than once. The figures for conviction are of course very much higher than those usually met with amongst the general population in India." Whereas on the surface it might appear that there is a causal relationship between crime and the use of cannabis, there are other factors that Chopra takes into account. He states that "cannabis drugs are cheap and generally used by the poorer classes, who belong to the lower strata of society, to which most criminals belong." The lower strata are therefore responsible for two important sociological factors: the majority of India's criminals as well as a large number of her cannabis users, but one is not necessarily related to the other. Most likely a sample of nonusers of cannabis from the lower strata would also have a higher rate of convictions than the figure for the general population.

In response to Dr. Goodwin's statement that I conveniently did not mention Chopra's references to the many debilitating effects of marihuana, the following is cited from the section Dr. Chopra devoted to this topic in the article in question. "Health does not as a rule suffer when cannabis drugs are taken in doses below 20 grains daily.... According to the Indian Hemp Drug Commission (1893–1894), bhang was considered as a refreshing beverage corresponding to beer in England and moderate indulgence in it was attended with less injurious consequences than similar consumption of alcohol in Europe. This view was corroborated by the above-mentioned studies of a large number of persons who took bhang habitually and is borne out by our own observations." He then goes on to cite numerous debilitating effects that occur when the drug is taken in "large quantities for prolonged periods." In each instance mentioned—"chronic catarrhal laryngitis, asthma, chronic sore throat and pharyngitis, bronchial irritation, impairment of vitality and digestive processes, anaemia, etc."—the context either states or strong-

ly implies marked and prolonged indulgence rather than moderate and occasional indulgence, which is the obvious focus of my article.

If we accept Dr. Goodwin's reasoning with respect to psychological dependence where marihuana is concerned, then with respect to tobacco it may (to paraphrase him) be incorrect to call tobacco unaddictive. In fact, it may be more incorrect with respect to tobacco, inasmuch as in a study of 34 marihuana users conducted by J. F. Siler and his colleagues (*Military Surgeon*, Vol. 73, pages 269–280, 1933) it was found that only 15 percent of the users missed marihuana when deprived of it and 71 percent stated that they preferred tobacco. Finally, I find the concept of psychological dependence a hazy, poorly defined one. I seriously wonder if Dr. Goodwin can distinguish between the psychological dependence attributed to marihuana from the psychological dependence I presume he has for his wife or his automobile.

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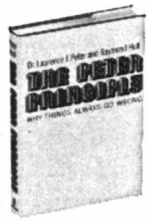

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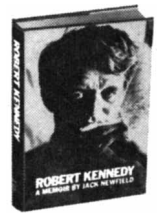

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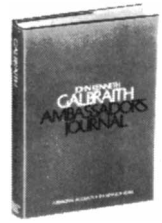

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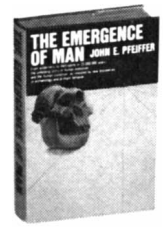

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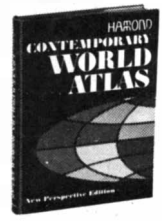

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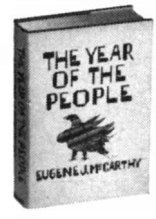

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1920: "The public was startled recently by newspaper announcements that a rocket had been invented which would carry as far as the moon. Sensational as this statement appeared to be, it was nevertheless issued by the Smithsonian Institution and was based on the work of Dr. Robert H. Goddard of Clark University, who has been conducting a long series of experiments on existing forms of rockets. He has developed a method of increasing the efficiency of this type of projectile to such an extent that it will be possible to propel a rocket beyond the influence of the earth."

"What shall we do when our coal and oil supplies are exhausted? It is true that we may obtain power from water, from the wind and from ocean waves and tides. These sources will not begin to supply us with all the power we need. Tides yield but small returns on large investments for extensive plants, and the difficulties of harnessing the ocean are almost insuperable. Where then shall we turn for future sources of power? This question was taken up in a very interesting lecture delivered recently by Sir Oliver Lodge before the Royal Society of Arts. He pointed to the vast sources of atomic energy which as yet have not been touched. It may be that we shall someday find a method of utilizing these sources of energy."

"The peyote, often popularly miscalled 'mescal' through confusion with the maguey cactus from which a fiery intoxicant is prepared, is a species of small cactus widely used for both medicinal and ceremonial purposes by the Indian tribes of the southwestern U.S. and a great part of Mexico. The first careful study of its ritual uses was made by James Mooney of the Bureau of American Ethnology in 1891, and a digest of the subject will be found in *Handbook of American Indians.* The peyote cult has been highly developed and has attained greater territorial extension since Mr. Mooney's original studies were made. Accordingly, last year Mr. Mooney accepted an invitation from the various tribes with which he has long-standing friendly relations to make further observations of the medical and ceremonial uses of peyote and spent several months in these studies among 20 tribes in Oklahoma as well as others in the U.S. and Mexico."

"A recent issue of *The Physical Review* contains a summary of a paper read by S. O. Hofman at the Washington meeting of the American Physical Society on the subject of detection by heat radiation. In trench warfare on the Western front operations took place mainly at night, as any movement during the day quickly attracted hostile fire. An attempt was therefore made to detect men moving in No Man's Land by recording the heat radiated from their bodies. The receiver for this purpose was a thermopile at the focus of a 14-inch parabolic mirror and connected to a D'Arsonval galvanometer. It was found that with this sensitive apparatus the presence of a man could be detected at a distance of 600 feet, and the device appears to have proved very useful for detecting hostile raiding parties creeping toward the trenches by night."

"The London *Times* of recent date states that the Handley-Page Transport Company has introduced in connection with its air services the novel feature of a luncheon basket, consisting of a small carton containing six sandwiches, fruit and chocolate, at a cost of 72 cents, while wicker holders for bottles and glasses are affixed to the walls of the stateroom. Up to October 4, 15 London-Paris trips had been accomplished by this company each way, with a total of 219 passengers and approximately 6,000 pounds of freight."

SCIENTIFIC AMERICAN

FEBRUARY, 1870: "The great German chemist Liebig has finally broken the silence with which he has borne the attacks upon his theory of fermentation on the part of many chemists during the past 10 years, and has come out with one of those exhaustive and convincing replies that recall the best days of his great intellect. The reticence he has observed has emboldened some of the younger chemists to disclose weak points in their attacks, while others have looked upon the dead lion as a harmless creature and have incautiously come too near his claws. All this small game is scattered like chaff before the wind with trifling effort, and the whole power and force of his argument is leveled at the French Academician and renowned champion of the new school, Professor Pasteur of Paris. It was Pasteur who announced nine years ago as a result of his experiments that Liebig's explanation of the action of yeast upon sugar was entirely without scientific foundation. Since that time Pasteur has had it his own way, and the views published by him have been fast gaining in popularity until they appeared destined to be accepted by a majority of scientific men everywhere. Liebig's paper is therefore a perfect bombshell in the camp, and as soon as the smoke has cleared up and the fragments have been collected, we shall probably have about as nice a fight as has been witnessed among chemists for many a day. We shall not fail to inform our readers of the progress of the controversy, if anything practical grows out of it."

"At a late meeting of the American Academy of Arts and Sciences the Rumford medal was bestowed upon Mr. George H. Corliss of Providence, R.I., for his improvements in the steam engine. This is the fifth medal awarded by the Academy to authors of improvements or discoveries in heat and light, the recipients and their discoveries and inventions being as follows, in the order stated. (1) Professor Robert Hare, for his oxy-hydrogen blowpipe. (2) Capt. John Ericsson, for his hot-air engine. (3) Professor Treadwell, for his improvements in the construction of ordnance. (4) Mr. Alvan Clark, for his new mode of grinding and perfecting large lenses. (5) Mr. George H. Corliss, for his improvements in steam engines."

"Some French bankers and a dozen American capitalists have organized a company in Paris to construct a canal across the Isthmus of Darien, and it is said that the capital has been subscribed. The company await the report of the U.S. exploring expeditions."

"We are in receipt of the first numbers of *Nature,* a new weekly illustrated journal of science published by Macmillan & Co. It is devoted to rather abstract scientific discussions and the record of scientific events. This new journal will be apt to find favor among the professed scientists of the day, but will hardly become a popular journal in the broadest sense. It is printed in excellent style."

THE AUTHORS

HARVEY BROOKS and RAYMOND BOWERS ("The Assessment of Technology") are respectively dean of engineering and applied physics at Harvard University and professor of physics and member of the Laboratory of Atomic and Solid State Physics at Cornell University. Brooks was chairman and Bowers a member of a panel convened by the National Academy of Sciences to examine the assessment of technology; their article is based on the panel's report. Brooks, who was graduated from Yale University in 1937 and obtained his Ph.D. from Harvard in 1940, is chairman of the Committee on Science and Public Policy of the National Academy of Sciences. Bowers, who was born in London, obtained his bachelor's degree at the University of London in 1948 and his Ph.D. from the University of Oxford in 1951. For 14 months in 1966 and 1967 he was a member of the staff of the Office of Science and Technology in the Executive Office of the President.

F. G. HEATH ("Large-Scale Integration in Electronics") is professor of digital processes at the Institute of Science and Technology of the University of Manchester and scientific adviser to International Computers Limited. After completing his education at Manchester he worked in the electronics industry designing radio tubes and photoelectric multipliers. Joining Ferranti Ltd., he worked increasingly in the area of digital electronics up to the time the firm produced the prototype Argus process-control computer in 1957. "When this machine was demonstrated to the Duke of Edinburgh," he recalls, "I as project leader had a most important job: to see that under no circumstances hot hydraulic oil squirted on the royal visitor." On his return to the University of Manchester, Heath served as lecturer in electrical engineering at the Institute of Science and Technology and as chief engineer at the Manchester engineering facilities of International Computers Limited. He is the author of a book, *Digital Computer Design,* published last year.

HAROUN TAZIEFF ("The Afar Triangle") is with the French Center for National Research. "My childhood was devoted to the idea of becoming a sailor and an arctic explorer," he writes. "Eventually I became a geologist and spent 99 percent of my field time between the Tropics. Once a geologist, I dreamed of high-mountain tectonics and of central Asia; I was confined to old cratons and Africa or Southeast Asia and western America." Tazieff was born in Warsaw and educated in Belgium; he was graduated from the Free University of Brussels in 1932 and has degrees in agronomy and geology from the State Agronomic Institute at Gembloux and the University of Liège respectively. "Besides my interest in investigating the mechanisms of volcanic eruptions and of rift genesis," he writes, "I am fond of Van Gogh's, Gauguin's and some others' painting, of rugby football (by now I am one of the oldest forwards in the world, I think), of knowledge theories, of Stephane Mallarmé's and Robert Vivier's poetry, of mountaineering, of international politics, of the geology of the moon, of architecture and of many other things."

RAYMOND J. HOCK ("The Physiology of High Altitude") is professor of zoology at the University of Nevada at Las Vegas. "My major interest," he writes, "is in the ways in which wild animals survive in several environments, and particularly in the physiological adjustments they make. My chief study has been of hibernation, encompassing bats, ground squirrels, marmots and bears. I studied this, plus the effects of cold on Arctic animals, for 10 years in Alaska. The work described in the present article was done over six and a half years in California. Then I had a diversion, working for industry and being principally concerned with the U.S. Navy's experiment in undersea living—Sealab. Now I am at Las Vegas to pursue studies on desert animals. Next—the tropics?" Hock was graduated from the University of Massachusetts in 1943 and obtained his master's and doctor's degrees from Cornell University in 1946 and 1949 respectively.

GERALD FEINBERG ("Particles That Go Faster than Light") is professor of physics at Columbia University. He was graduated from Columbia College in 1953 and remained at the university from 1953 to 1956 as a National Science Foundation fellow. Obtaining his Ph.D. from Columbia in 1957, he spent a year as a member of the School of Mathematics of the Institute for Advanced Study in Princeton and two years as a research associate at the Brookhaven National Laboratory before returning to Columbia as a member of the faculty. His major field of research is elementary-particle physics. Another of his interests is treated in his recently published book, *The Prometheus Project,* which deals with ethical problems associated with technological advances.

GERALD OSTER ("Phosphenes") is professor of biophysics at the Mount Sinai School of Medicine of the City University of New York. "My interest in optics," he writes, "led me to moiré patterns, which led me to art, which led me to the mother of art: the eye-brain complex. In my next art exhibit (I've had a few with my moiré constructions and phosphorescence paintings) I shall wire up the viewers with electrodes from a pulse generator and make a phosphene program. It could be a great art form: the neurological cinema!" Oster received his Ph.D. from Cornell University in 1943; his thesis was on the structure of water. He served on the staff of the Rockefeller Institute for Medical Research and more recently was professor of polymer chemistry at the Polytechnic Institute of Brooklyn.

R. MERTON LOVE ("The Rangelands of the Western U.S.") is chairman of the department of agronomy and range science at the University of California at Davis, with which he has been affiliated since 1940. Born in Canada, he was graduated from the University of Saskatchewan in 1932 and obtained his master's degree there in 1933; he took his Ph.D. at McGill University in 1935. His agronomical researches have taken him to many parts of the world, including Australia and New Zealand and a number of countries in Europe. Love writes that "music, travel and photography are my leisure interests."

MICHAEL W. BERNS and DONALD E. ROUNDS ("Cell Surgery by Laser") are at the Pasadena Foundation for Medical Research; Berns is associate director of the department of laser biology and Rounds is director of the department and research coordinator of the foundation. Berns received his bachelor's, master's and doctor's degrees from Cornell University, the last in 1968. In September he will become assistant professor of zoology at the University of Michigan, where he will continue research with the laser microbeam and in the genetics and development of the unusual variant blue frog and the post-embryonic development of millipedes. Rounds was graduated from Occidental College in 1951 and took his Ph.D. at the University of California at Los Angeles in 1958. He has been in the field of laser biology since 1963.

HOW ROUND IS ROUND?

Grammarians assure us that something is either round or it is not, not more nor less. But what is so in the world of grammar may not be necessarily so in the world of dynamics. Take an ordinary automobile tire for example. At rest it may look round, measure round, and, indeed be round. But at 60 MPH, it is subject to enormous stresses of centrifugal force as 87.5 feet of tread-face whip past a given point in a second's time. How now, round tire? How round? How imbalanced? The time to answer these fair and important questions is not after the fact but during the manufacture. And that is just what a solid-state control system engineered by EAI is doing daily for a number of tire manufacturers. Result: a superior product with a much lower reject rate, a faster manufacturing cycle, and added peace of mind for grammarians and others travelling at 60 MPH.

If you're concerned with making things that must maintain their geometry under dynamic as well as static conditions you'd be well advised to see what we have for you. Write and request "Tire", Dept. 206A. Please mention what you want to measure and control, too.

GC PEAKS AND THE SOFTWARE DEMON

As with motherhood and the flag, consensus holds that computerized data reduction is with us to stay. But, in practice, it all gets a bit hairy. Take data from an analytical instrument like a GC. A few giants in the industry continue to stumble over problems in GC like noise, signal processing, or really useful software. EAI is still the pioneer here in its PACE III analytical data system. One seemingly small thing is a software technique for resolving complex GC peaks. It consistently and accurately apportions complex areas, ranging from overlapping components to poorly resolved shoulder peaks. Part of the technique accommodates the usual "skew" in component elution to give consistent improvement is accuracy of quantitative analysis. (Our research people gave a paper on it at the 158th National ACS meeting.) It's all part of the whole PACE III system--a turnkey data system for many analytical instruments--GC, mass spec, and the like.

For a copy of the paper and a detailed booklet on PACE III write to Dept. 206A.

IMITATION POLLUTION CAN BE A SOLUTION

A topic destined to polarize the citizenry these days is pollution--any kind of pollution. Take a simple thing like free oxygen in water. Overload the water with oxygen-hungry chemicals--no oxygen. Or develop too many organisms--plant life prospers (called eutrophication) and no oxygen. Either way, no fish. And with no fish, you've upset the water ecology. Pragmatic scrutiny tells us we can't shut down our industries to bring back pristine, airy waters. Fortunately, we can imitate these conditions by computer simulation, and get a grip on the ameliorative aspects of a solution.

Recently, EAI provided the HEW with a hybrid-computer simulation of the Delaware River Estuary. From this simulation engineers can tell where to best locate stand-by reservoirs, what flow rates to employ, and when to do it. We've written this one up. A request to "Delaware", Dept. 206A, will get you a copy, and get us both cracking on another solution.

KINETIC DATA MEANINGFULLY SHAPED BY COMPUTER

In olden times petrochemical process design involved finding rate and equilibrium constants for several reactions required a trial-and-error method. Much trial. Much error.

Most process designs involve the solution of ordinary differential equations --in a lumped-parameter system where changes are taking place in time but not space. With the use of analog computers, solutions poured forth. However, distributed parameter systems involve changes in time and space simultaneously--expressed by partial differential equations. Many approaches to PDE solution have evolved for digital computers. But such solutions consume more and more hardware, with ever-present error creeping back in as problem complexity increases.

Hybrid computers clear this difficulty up. Kinetic data is programmed into the analog portion, actual results go into digital computer memory. The analog makes a series of process condition runs, the digital stores the data, matches the results from the plant and computes least mean square deviations. The "solution" has been found when results of simulation most closely match actual conditions, and no further reductions can be made in mean square deviation values. Optimization is achieved--in time, money and results.

After much struggle, EAI is pleased to offer a software package in this arcane speciality--write to "Kinetic", Dept.206A, Electronic Associates, Inc., West Long Branch, N.J. 07764.

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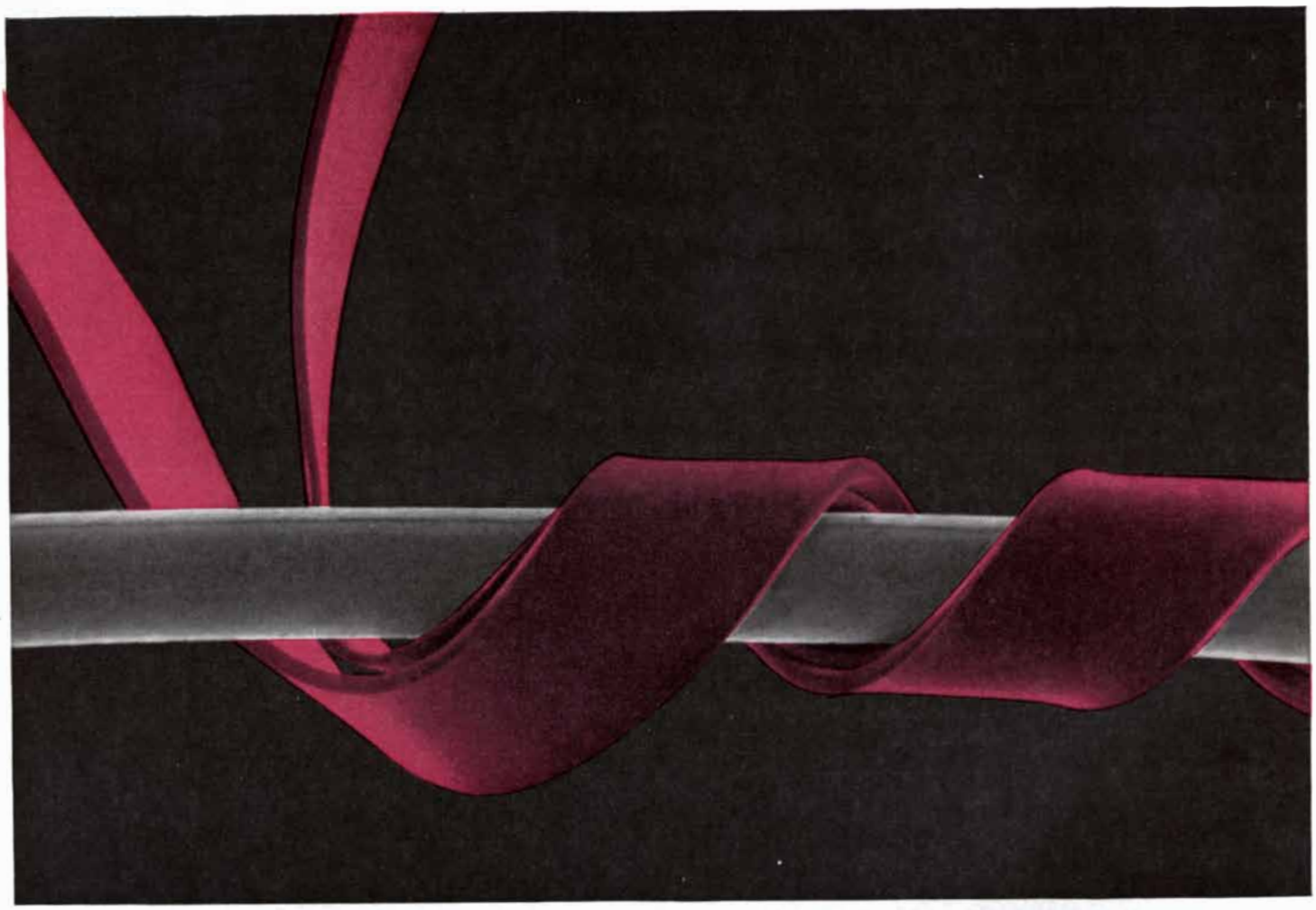


Customizing a magnetic alloy

Bell Laboratories scientists have custom tailored a magnetic alloy for the "piggyback twistor," a memory device used in electronic switching systems.

In this device, metal tapes (enlarged 225 times above) are wound into a tight spiral—subjecting them to considerable mechanical stress. The magnetic properties of the alloys must be essentially independent of such stress. That is, they must have low magnetostriction. In addition, the outer tape must be magnetically "hard"—with high coercive force (resistance to change in direction of magnetization). And finally, it must be ductile enough to be formed into tape. No known alloy had this combination of properties. So, E. A. Nesbitt, G. Y. Chin, and D. Jaffe of Bell Laboratories made one to order.

Tailoring the new alloy for the outer tape required a precise knowledge of the relationship between the magnetic behavior of materials and their structure. So, the Bell Laboratories scientists began with 90% cobalt and 10% iron, a composition they knew had the necessary ductility and low magnetostriction—two of the essential requirements. But, since the coercive force of the composition was inadequate, they were faced with another knotty problem.

To solve it, they went back again to a basic principle—a precipitate in an alloy impedes the motion of magnetic domain walls when a field is applied to reverse the magnetic polarity. With that foundation, the scientists formulated a composition of 4% gold, 84% cobalt, and 12% iron. (The gold is the precipitate.)

When this new alloy was cold-drawn to produce a 97.5% reduction in cross section and then heat treated, its coercive force increased to the point required for piggyback twistors.

By simplifying the manufacture of piggyback twistors for use in the electronic switching systems now being built by Western Electric, the new magnetic alloy puts basic research in metallurgy at the service of telephone customers.

From the Research and Development Unit of the Bell System—

Bell Labs

Established 1845 SCIENTIFIC AMERICAN February 1970 Volume 222 Number 2

The Assessment of Technology

A panel convened by the National Academy of Sciences recommends new Federal mechanisms to consider the broad social consequences of advancing or retarding particular technological developments

by Harvey Brooks and Raymond Bowers

Technological developments in the U.S. arise and evolve out of a multiplicity of decisions in industry, government and the marketplace. When individuals, corporations and public agencies consider exploiting or opposing a particular development, they attempt to project the potential gains and losses to themselves, and their decision usually turns on what they believe will maximize the gains and minimize the losses. This system has created an economy of great strength and versatility, but it also gives rise to troublesome imbalances that are evident in such phenomena as polluted air and deteriorating cities.

The difficulty is that self-interested analyses of the kind usually made are likely to ignore important implications of particular choices for sectors of society other than those represented in the initial decisions. In their pursuit of benefits for themselves or the segment of the public that they represent, those who make the relevant decisions often have little incentive, responsibility or authority to consider the possibility that a technological application might have undesirable consequences. For the same reasons they may fail to pursue technological opportunities that, from a broader perspective, might clearly deserve exploitation.

Rising concern over the imbalances that result has led to a number of proposals to create what is plainly lacking in the economy: a mechanism whereby the broad social effects of exploiting or restricting a technological development could be considered and effectively expressed. Among the proposals is a bill that Representative Emilio Q. Daddario of Connecticut, chairman of the Subcommittee on Science, Research and Development of the Committee on Science and Astronautics of the U.S. House of Representatives, has introduced "as a stimulant to discussion." The bill would establish a Technology Assessment Board "to provide a method for identifying, assessing, publicizing and dealing with the implications and effects of applied research and technology."

At the request of the Daddario subcommittee both the National Academy of Sciences and the National Academy of Engineering convened panels to examine the problem of assessing technology. One of us (Brooks) was chairman of the panel established by the National Academy of Sciences, and the other (Bowers) was a member of the panel; the other members are listed in the box below. This article summarizes the panel's report, *Technology: Processes of Assessment and Choice.*

At the outset it should be emphasized that the panel began with (and retained) the conviction that the advances of technology have yielded benefits that on the whole vastly outweigh the injuries they have caused. The reader should bear this attitude in mind as he considers what may seem to be a catalogue of technological deficiencies—

EDITOR'S NOTE

In addition to the authors of this article the members of the panel convened by the National Academy of Sciences to study the assessment of technology were Hendrik W. Bode of Harvard University; Edward C. Creutz of Gulf General Atomic, Inc.; A. Hunter Dupree of Brown University; Ralph W. Gerard of the University of California at Irvine; Norman Kaplan of Northeastern University; Milton Katz of Harvard University; Melvin Kranzberg of Case Western Reserve University; Hans H. Landsberg of Resources for the Future, Inc.; Gene M. Lyons of Dartmouth College; Louis H. Mayo of George Washington University; Gerard Piel of SCIENTIFIC AMERICAN; Herbert A. Simon of Carnegie-Mellon University; Cyril S. Smith of the Massachusetts Institute of Technology; Morris Tanenbaum of Western Electric, and Dael Wolfle of the American Association for the Advancement of Science. Laurence H. Tribe of Harvard University served as executive director of the panel.

instances where the technological developments chosen for exploitation now seem to have been needlessly injurious to certain social or environmental interests; instances where alternative technologies could have achieved comparable objectives at lower social cost; instances where technological developments were accompanied by inadequate or inappropriate systems of supporting institutions and technological or legal safeguards. If it appears that the panel was, to borrow an expression of a member of the panel, "quick to lament the fallen sparrow, but slow to celebrate the fall of 'Typhoid Mary,' " the reason was not that we overlooked the benefits of technology but that our mission was to explore how such benefits might be achieved with less injury to the society and the environment.

Indeed, although political attention appears to be focused now on the negative effects of technology, the panel believed an effective system of assessing technology would as often stimulate the development and application of desirable new technologies and underemployed ones as it would give warning of possibly harmful side effects. Many of the problems that are identified as undesirable results of technological development can also be seen as the result of failure to develop or apply technologies that would have mitigated the undesired effects. A scheme for the manufacture of housing units at low cost could have counteracted the deterioration of housing; improved systems of controlling air traffic would have forestalled the problem of crowded airways, and better design of power plants would have made a significant impact on the problem of air pollution.

The panel also believed an effective system of assessing technology would strengthen rather than weaken technological innovation, and could shield it from the capricious political action that will surely result if the nation moves from one social or environmental crisis to another in the absence of adequate planning. Already one can see that a number of efforts at applying technology—the routing of interstate highways, the location of airports and power plants and the development of larger and faster airplanes—are encountering unanticipated public resistance, at substantial cost not only to technology but also to the public in the form of postponed benefits. Since the progress of science in recent years has greatly broadened the spectrum of technological possibilities, the nation is in a position to choose among many technological paths to a given objective. Thus two important aspects of technology assessment are the evaluation of alternate means to the same end and a comparison of their social and economic costs.

Choices between alternative technologies are partly economic and political decisions. In our opinion it is neither feasible nor desirable to develop an assessment mechanism that would circumvent the political processes or the push and pull in the marketplace that are crucial in the accommodation of the conflicts of interest and values that must arise. We view assessment as one of many inputs to the system of private and public decisions that together shape the growth of technology and direct its integration into human life.

One can approach the problem of assessing technology in a number of ways. A standard commonly raised is that technology should be in "the public

INTERSTATE ROUTE 80, which is the light-colored road running horizontally across the center of this aerial photograph, was planned as a limited-access route between New York and San Francisco but is interrupted in Paterson, N.J., 10 miles west of New York, because of disagreement over the course it should take through the heavily urban area. Opposition to the interstate high-

interest" or should maximize the "net gain to society." Such phrases have the merit of brevity and the appearance of objectivity, but it is far from clear that they convey any operationally useful meaning.

Almost without exception, technological developments will affect some people or interests beneficially and others adversely. There is no accepted arithmetic wherewith one can neatly subtract the pains from the pleasures in order to arrive at a net index of social desirability. How are the interests of suburban commuters and the residents of central cities to be balanced in the evaluation of urban transport systems? How should the future needs of radio astronomy be weighed against the present uses of television in allocating the electromagnetic spectrum? How are the desires of conservationists to be balanced against the economic needs of local industry? Because there are many values other than economic efficiency but the buyer and seller rarely confront them in their transactions, the idea of attempting to compute net social benefits is useful only as a rough first approach.

Another consideration is that a basic principle of decision-making should be to maintain the greatest practicable latitude for future action. Other things being equal, the technological projects that should be favored are the ones that leave maximum room for maneuver. The reversibility of an action should thus be counted as a major benefit, its irreversibility as a major cost.

way system has arisen in a number of cities because of conflict of interest between urban residents and convenience of motorists.

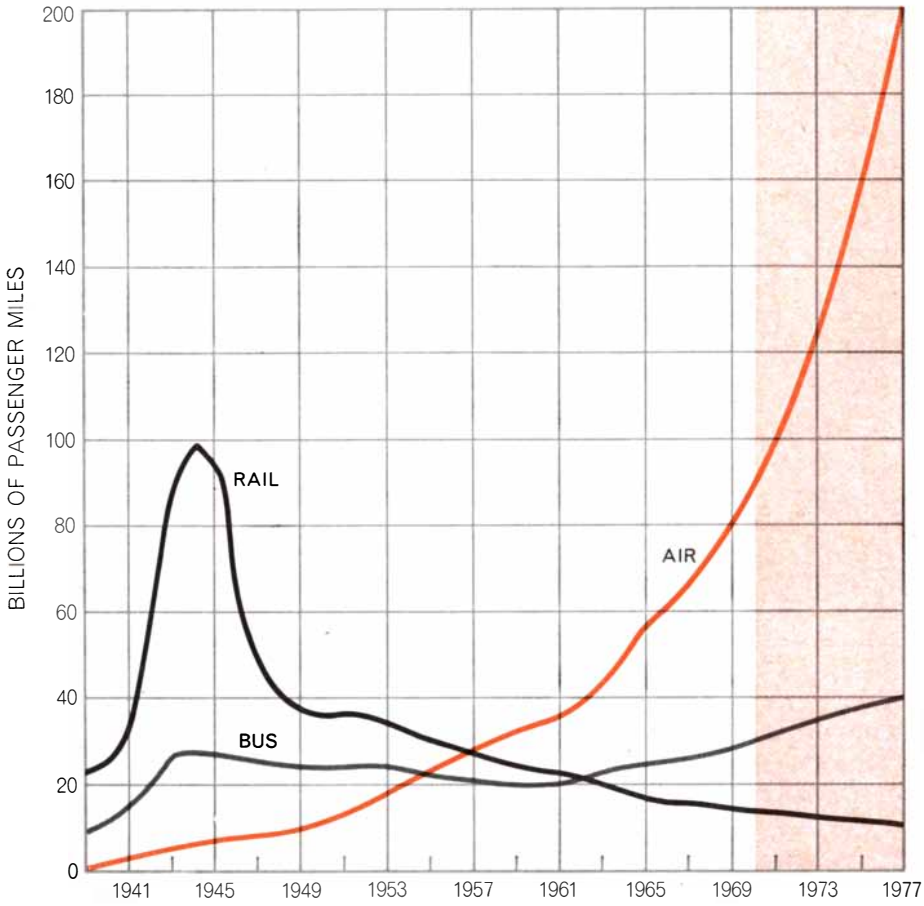
Policy-making should therefore reflect the fact, for example, that pollution of a lake is more difficult to reverse than pollution of a river, or that the disposal of municipal wastes in streams may create an overload that is harder to reverse than disposal on land would be. (The recycling of wastes, which has only begun to be considered on a large scale, provides a major opportunity for lowering the irreversibility of the disposal process.) The construction of dams and reservoirs, which fill up with silt and hence have a finite life, precludes the possibility of using the same sites for waterworks when waterworks may be more urgently needed.

Another approach is to consider where the burden of uncertainty should fall when the consequences of a contemplated action can only be surmised and when its costs and benefits cannot be clearly assessed. Historically the burden has tended to fall on those who challenge the wisdom of a technological trend. The usual presumption has been that such a trend ought to be allowed to continue as long as it can be expected to yield a profit for those who are exploiting it, and that any harmful consequences that might ensue either will be manageable or will not be serious enough to warrant a decision to interfere with the technology. So it was, for example, that drilling rights were leased to oil companies operating in the Santa Barbara Channel without sufficient consideration of the possible effects of massive oil leakage near the coast and with inadequate preventive measures to minimize the damages; that vast quantities of chemicals have been released into the biosphere with little attention to their potential hazard; that the number of internal-combustion automobiles has been allowed to mount steadily with only sporadic efforts to study alternatives that would entail less pollution and crowding, and that repeated decisions have been made to proceed with a supersonic transport although the problem of sonic boom has yet to be solved.

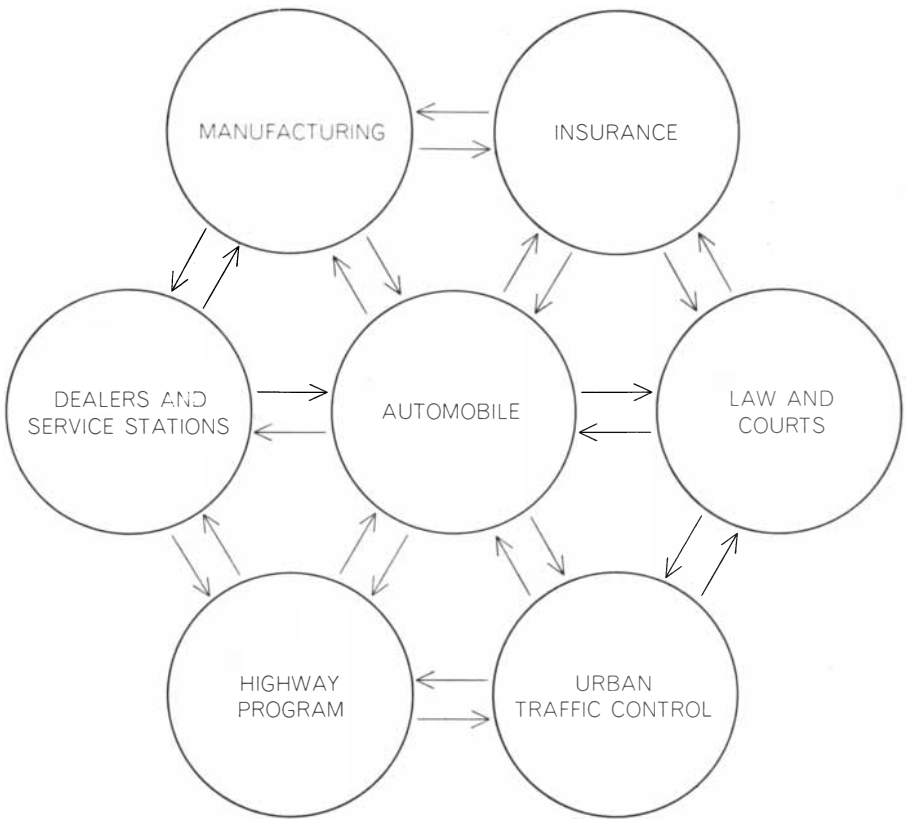
The panel believed there should be limits on the extent to which any major technology is allowed to proliferate or to stagnate without the gathering of evidence on the possible harmful effects and on the relative merits of alternatives. The nation's experience with certain chemical pesticides is strongly suggestive. Although the pesticides have undoubtedly prevented a great many deaths from starvation and disease, it is now apparent that they have also inflicted unintended but widespread losses of fish and wildlife, and it is increasingly suspected that they are causing injury to man. The experience suggests that carefully designed experiments in the early days might have influenced the technology of pesticides before the nation was so committed to certain forms of pest control as to make any significant alteration of the technology extremely difficult. Knowledge has advanced to the point where, in spite of many uncertainties, it is possible to predict at least some of the ecological effects of building another Aswân Dam or opening a sea-level canal through the Isthmus of Panama, or the effects of paving and housing on the reflectivity of the earth's surface, or the effects of high-altitude aircraft exhaust on the radiation balance of the earth. The panel saw an obligation to undertake the necessary research and monitoring at the earliest possible stages of development.

All these considerations—the questions concerning the general welfare, the preservation of options and the burden of uncertainty—reflect a lack of constituencies potent enough to inject diffuse and poorly articulated interests into the decision-making process. Here one encounters not only the lack of effective voices in opposition to a potentially harmful technology but also the problem of finding support for a potentially desirable technology that is opposed by vested interests. When a faster or cheaper building technique might affect alignments in the construction industry, for example, one can rely on opposition from those interests but not on organized advocacy from residents of the ghetto who might benefit from cheaper housing. The difficulty lies not with groups that perceive their interests to be affected but rather with the representation of groups for whom the consequences are less obvious and more remote. The panel was convinced that more must be done to give all affected interests effective representation in the crucial processes of decision.

The existing processes of technology assessment are diffused throughout the society in both the private and the governmental sectors. In the private sec-



PATTERNS OF PUBLIC TRANSPORTATION are recorded for the past 30 years and projected to 1977 on the basis of information assembled by the National Academy of Engineering. The chart covers domestic intercity travel by railroad, bus and airplane.



RAMIFICATIONS OF TECHNOLOGY are exemplified by the automobile, which represents a system of social and technological activities with a combined effect on the environment. The elements of the system also interact, as indicated by the arrows between circles.

tor technology assessment takes place whenever a business enterprise contemplates an investment that would introduce a new technology or expand or modify its use of an existing technology. In the larger industrial enterprises the assessment takes place in connection with research and development. Assessment is also done by the investment companies and banks to which business enterprises turn for capital.

Whether or not the assessors are aware of the fact, the existing legal order infuses their calculations. It determines which of the anticipated costs and benefits are taken into account by the enterprise and which are ignored. A power company, for example, that contemplates the installation of a new generating station will treat the fuel to be consumed as a cost but not the smoke that may pollute the surrounding air or the waste products that may be discharged into nearby streams. Pollution of the community's air or streams is not legally charged against the company; it is a social cost and not a cost to the enterprise. The legal system can change this relationship by laws or court decisions that put on the company the burden previously borne by the public in the form of air or water pollution.

The assessment of technology that is done by governmental agencies is also profoundly affected by the legal system. The predominant mission of each agency, as set forth in the law, determines its pattern of assessing technology. Weather modification provides an example. The Bureau of Reclamation looks for ways to increase rainfall in the dry Western states. The Department of Agriculture, mainly concerned with reducing crop losses, sponsors research in suppressing storm damage. The Federal Aviation Administration is interested in ways to dissipate fogs that hang over airports. None of these agencies considers the total effects. In the case of regulatory agencies, limitations by law often prevent the agency from considering the complete problem.

Within the set of governmental and market processes the initial assessment of the costs and benefits of alternative technologies is normally undertaken by those who seek to exploit them. As a result the frame of reference is often quite limited. Although such groups as professional societies and conservation organizations may add inputs to the evaluation, the assessment is usually based on the contending interests of those who already recognize their stake in the technology and are prepared to enter the public arena to defend their position. In

KENNEDY INTERNATIONAL AIRPORT near New York has only one major road (*top center*) for ground traffic, and there is no rail service between the airport and the city. The question is whether, with the increasing number of flights and the introduction of "jumbo jets" carrying more than 350 passengers, the ground facilities will match the sophisticated technology of the airport itself.

all but a few cases, usually when Congress takes a special interest, no other assessment occurs. The central question asked is what will the technology do for the economic and institutional interests of those who want to exploit it or to the interests of those with a stake in competing technologies. If the technology leads to social problems, they are usually recognized only when they have reached serious proportions and generated acute public concern.

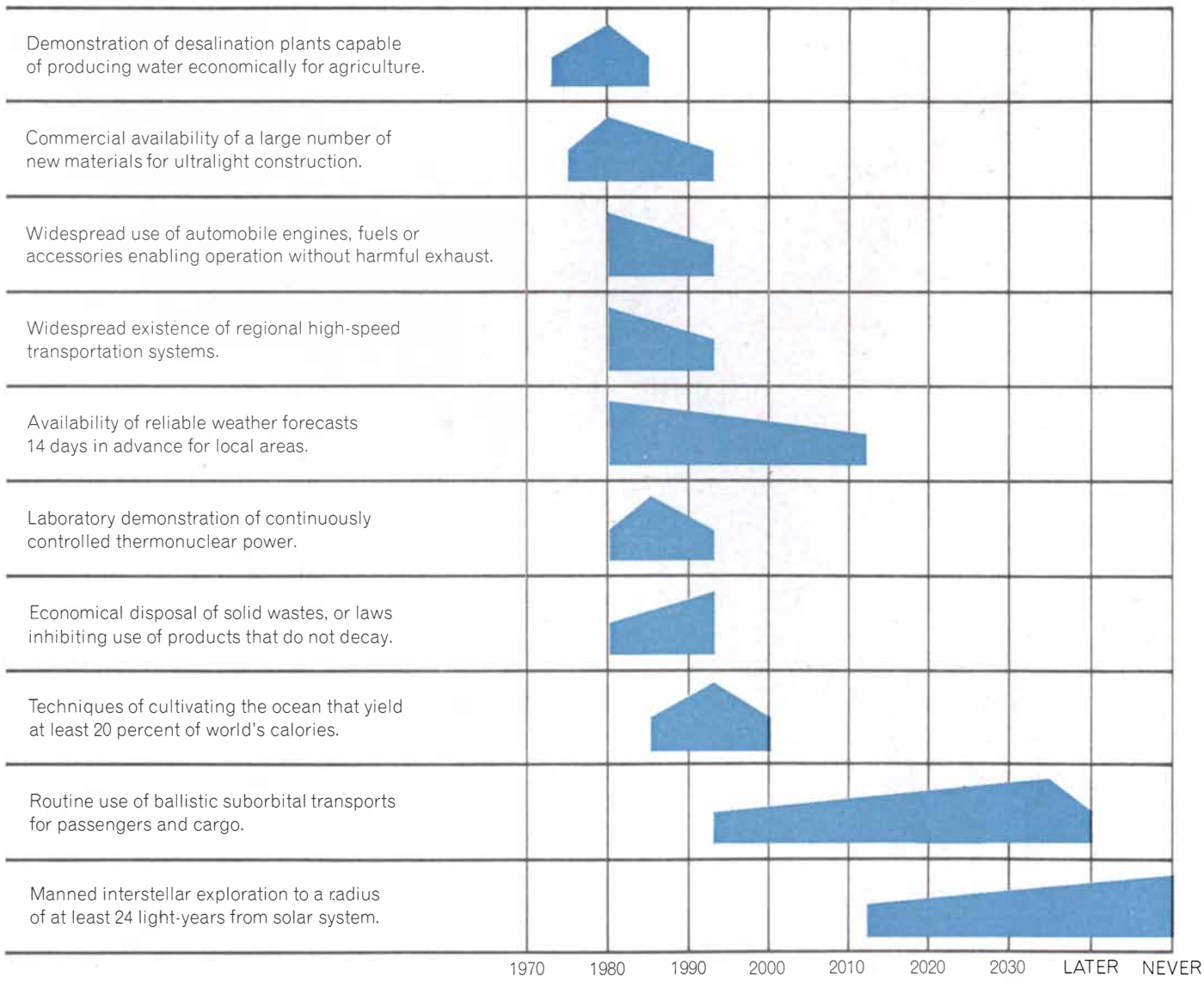
The achievement of a better system for assessing technology faces major obstacles. The society is ill equipped to handle conflicting interests. It does not know how to value in a quantitative way such goals as a clean environment and the preservation of future choices. Analytical tools are primitive, and crucial knowledge is often missing.

Projections of the impact of technology are limited by failure or inadequacy of imagination, particularly in forecasting cumulative effects of scale. For example, the number of television sets in the U.S. rose from 100,000 in 1948 to a million a year later and 50 million a decade later. The social and psychological consequences of such an explosive growth are hard to contemplate, let alone predict.

The history of asbestos demonstrates the effects of scale in one of its most insidious forms. Asbestos is so diversely useful that it has found its way into every automobile, train, airplane, factory and home and thence into human lungs, where, remaining as indestructible as it is in nature, it can cause grave disease. So too with the proliferation of automobiles: as recently as 1958 an authoritative book on the consequences of the automobile failed to mention atmospheric pollution.

A closely related problem has resulted from the failure to foresee the supporting systems that new technologies would demand. One can fly from London to New York in six hours and then encounter difficulties getting from the airport to the city because the roads are often crowded and there is no rail service between the city and the major airports. Courts of law have huge backlogs, in large part because of litigation involving automobile-accident claims.

Political and jurisdictional problems also abound. When a city discharges untreated sewage into a river without consideration of the effect on communities downstream, or a nation engages in a cloud-seeding experiment or conducts a nuclear test without concern for its effects on other countries, the reason is



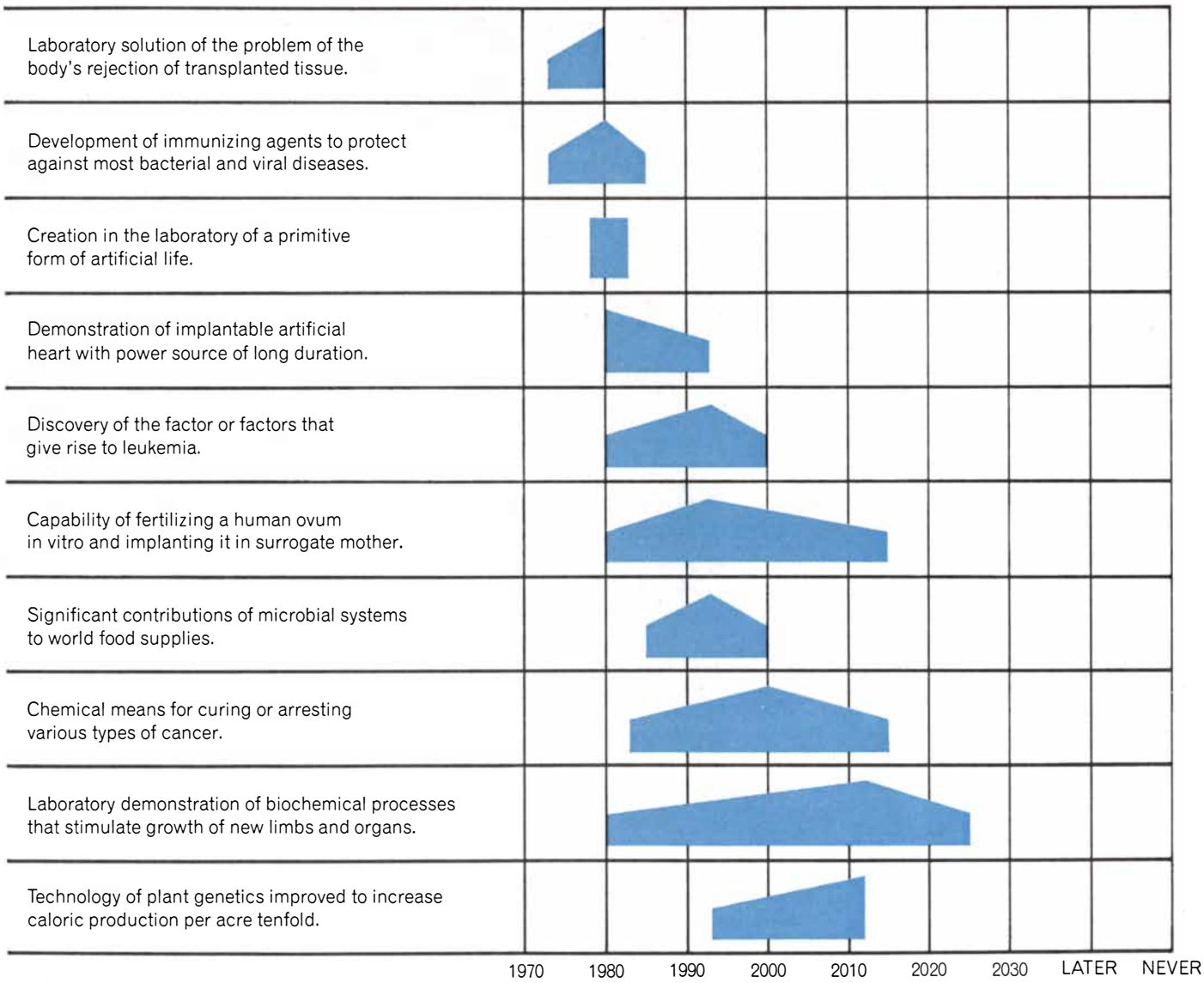
TECHNOLOGICAL DEVELOPMENTS foreseen by panelists consulted by the Institute for the Future are charted, with developments in the physical sciences at left and developments in the biological sciences at right. Each polygon represents estimates made

that a decision-making unit smaller than the area affected by the decision tends to view the effects as someone else's problem. There is also artificial narrowness of jurisdiction. The Army recently denied permission for a private dredging-and-filling operation in navigable waters of Florida, responding to the argument of health and conservation agencies that the project would injure fish and wildlife. A Federal court overturned the decision on the ground that the law makes interference with navigation the only basis for refusing permission to dredge and fill.

Our conclusion was that the best place to begin the formidable task of improving the assessment of technology is the Federal Government, which is already deeply involved in the support and regulation of technology. If the Federal Government can point the way to more responsible management of technological change, it will have accomplished no mean task; if it cannot, little more can be expected of other institutions in the society.

In recommending new Federal mechanisms for supplementing and broadening the present means of assessing technology, we were mindful of several principles that ought to guide the new procedure. To maintain its credibility among diverse interests, a new mechanism for assessing technology must adopt as neutral a stance as possible. For this reason it should not have policy-making authority, regulatory powers or responsibility for promoting any particular technology. Unlike the Atomic Energy Commission, for example, it should not be charged with advancing reactor technology and at the same time promoting radiation safety. Unlike the Federal Aviation Administration, the new mechanism should not be entrusted with the realization of a supersonic transport. Unlike the Public Health Service, it must not be held responsible for protecting the public from hazardous drugs. To give it responsibilities of this kind would clearly generate internal conflicts of interest.

A governmental institution assessing technology must also be sensitive to the dangers of the process. The major danger is that the institution could stultify the delicate mechanisms of technological innovation by magnifying risks or ignoring the possibility of finding solutions. If innovation is discouraged, the cure may be worse than the disease. Hence the new entity must be given no authority to screen or "clear" new technological undertakings. In short, it



by half of the group; estimates by the quarter of the panel that foresaw an earlier date and the quarter that chose a later one are excluded. Peak of each polygon indicates the median date when the panelists foresaw a 50 percent chance that the event would occur.

should be empowered to study and recommend but not to act; it must be able to evaluate but not to sponsor or prevent.

At the same time, any new assessment mechanism must be influential. It would have no hope of materially affecting public policy unless it were located close to the centers of political power. Accordingly there must be a close relation between some component of the new mechanism and the President, and some component of the new mechanism must be linked closely to Congress. The new entity must be designed to supplement, coordinate and improve the multiplicity of existing mechanisms rather than to supersede them. We rejected the concept of a highly centralized process of technology assessment as being unworkable in practice and even dangerous in principle.

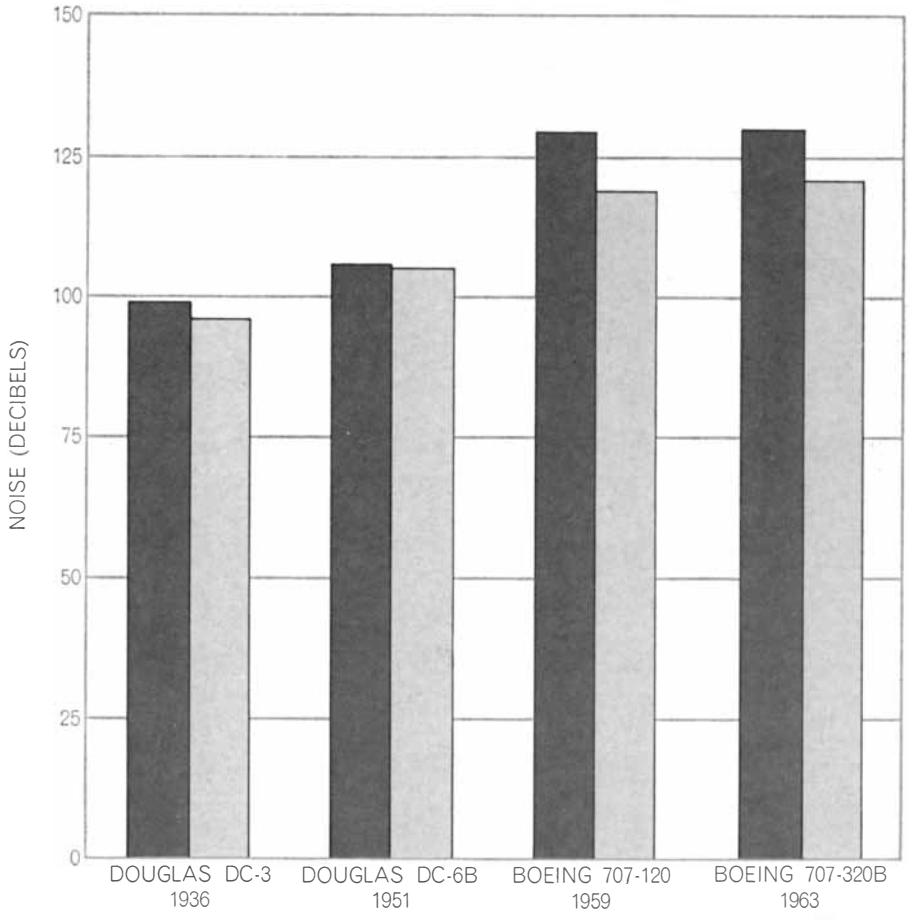
With these considerations in mind the panel recommended the creation of a constellation of organizations that would have components located strategically in both the executive and the legislative branch of the Government and would constitute both a focus and a forum for technology-assessment activities throughout government and the private sector. For the executive branch the recommendation is that the President's Office of Science and Technology be expanded and given the authority to collect information on technology assessment, make an annual report on priorities in the area, initiate conferences and prepare policy papers. This office would review specific assessments carried out by other agencies but would confine the review to an evaluation of the criteria, procedures and evidence used and the adequacy of the representation of potentially affected interests. The Office of Science and Technology would cooperate with a new Technology Assessment Division of the National Science Foundation, which would award contracts and grants for the assessment of specific developments and for research on methods of assessment. Most of the work would be done in nongovernmental agencies such as universities, independent research organizations and industry.

For Congress the recommendation is the creation of either a Joint Congressional Committee on Technology Assessment or a Technology Assessment Office that would be an arm of Congress analogous to the Legislative Reference Service or the General Accounting Office. In either case the principal functions of the mechanism would be to provide Congress with better access to the professional judgments it needs in considering assessments of technology and to provide within or close to Congress a forum for the assessment activities of individuals or groups operating outside present government and industrial institutions. Existing committees of Congress do not seem promising in these respects because of fragmentation by jurisdictional divisions and internal rivalries.

The panel considered and rejected the idea of an independent Federal commission. Such a body would have the advantage of freedom from political interference, but the separation of the assessment process from the center of political decisions seemed too high a price to pay.

One major matter that received little attention from the panel is the assessment of military technology. The reason was its special character: military technology is strongly conditioned by the interpretation of intelligence, and much of the technological information is classified. Control over the flow of this information, however, is effectively in the hands of people who assess technology only in terms of national security, viewed in the narrowest sense. Our panel was convinced of the importance of establishing some mechanism for the assessment of military technology by a group of experts having the requisite security clearance but without direct responsibility for national security. Presumably such a group could bring broader social, political and environmental considerations to bear on the assessment of military technology.

Our panel was convinced that, however our specific recommendations might be viewed, some form of constructive action to improve the assessment of technology is imperative and that it cannot be long delayed without increasing the difficulty of implementation and diminishing the prospects of success. The future of technology holds great promise for mankind if greater thought and effort are devoted to its development. If society persists in its present course, however, the future holds great peril, whether from the uncontrolled effects of technology itself or from an unreasoned political reaction against technological innovation—a reaction that could condemn mankind to poverty, frustration and the loss of freedom.



AIRCRAFT NOISE has increased with the weight and propulsive power of transport planes. Dark bars represent noise on takeoff, light bars landing noise. Dates refer to the year when the aircraft was introduced into widespread airline service. The prospect of supersonic transports and the certainty that the airlines will use more planes and make more flights indicate that noise problem will become worse unless an effort is made to reduce it.

SMOKE EMISSION of a Boeing 727 jet aircraft is reduced by the redesign of combustion chambers and fuel nozzles in an experiment undertaken to reduce air pollution. Above is the takeoff of an airplane that has not undergone the smoke-reducing adaptations; below, an aircraft of the same type takes off after the adaptations have been made. A number of states and communities have been pressing the airlines to reduce the emission of smoke by jet aircraft by converting engines or installing smokeless ones.

Large-Scale Integration in Electronics

Within the past five years the size of electronic devices has been shrunk by a factor of 10. Now one can connect more than 1,000 transistors into a circuit only a tenth of an inch square

by F. G. Heath

The most volatile technology of the present industrial age is that provided by electronics. Since the introduction of the transistor in 1948—which in its day seemed a marvel of compactness compared with the glass vacuum tube—the size of electronic devices has been reduced by a factor of 10 roughly every five years. This works out to a compression approaching 100,000 between 1948 and 1970. Ten years ago, when the term microelectronics first came into use, a chip of silicon a tenth of an inch square might hold 10 to 20 transistors, together with a few diodes, capacitors and resistors. Today such chips can contain well over 1,000 separate electronic components. The chip shown in the photomicrograph on the opposite page measures .11 by .14 inch and contains 1,244 transistors, 1,170 resistors and 71 diodes.

The technology that produces such high-density electronic circuits is called large-scale integration, or LSI. Although the term has no precise definition, it is usually reserved for integrated circuits that comprise 100 or more "gates," or individual circuit functions, laid down with a density of 50,000 to 100,000 components per square inch. If the upper value could be achieved throughout a cubic inch of material (which may be done in another decade or so), the density of electronic components would be about a fourth the density of nerve cells in the human brain.

A great part of the stimulus for miniaturizing electronic circuits came from ballistic-missile programs. As the microtechnology was developed, however, it was speedily applied to commercial computers, with the result that the central processing unit in the current generation of machines is frequently smaller than the input and output devices that connect the processor to the outside world. It now seems inevitable that microelectronic circuits, including LSI's, will soon find their way into a variety of new applications whose impact on everyday life —in the home, in the office, in the school and on the highway—will be profound. For many of these potential uses the main attraction of the miniature circuits will be not so much their microscopic size as their low cost per function and their high reliability. Because the integrated-circuit technology uses optical and photolithographic methods for creating transistors and other circuit components, costs are related directly to the number of steps involved and hardly at all to the pattern or density of the images produced. For comparable production runs, therefore, it should cost little more or no more to fabricate 100,000 transistors on a chip the size of a postage stamp than to fabricate 100 or 1,000.

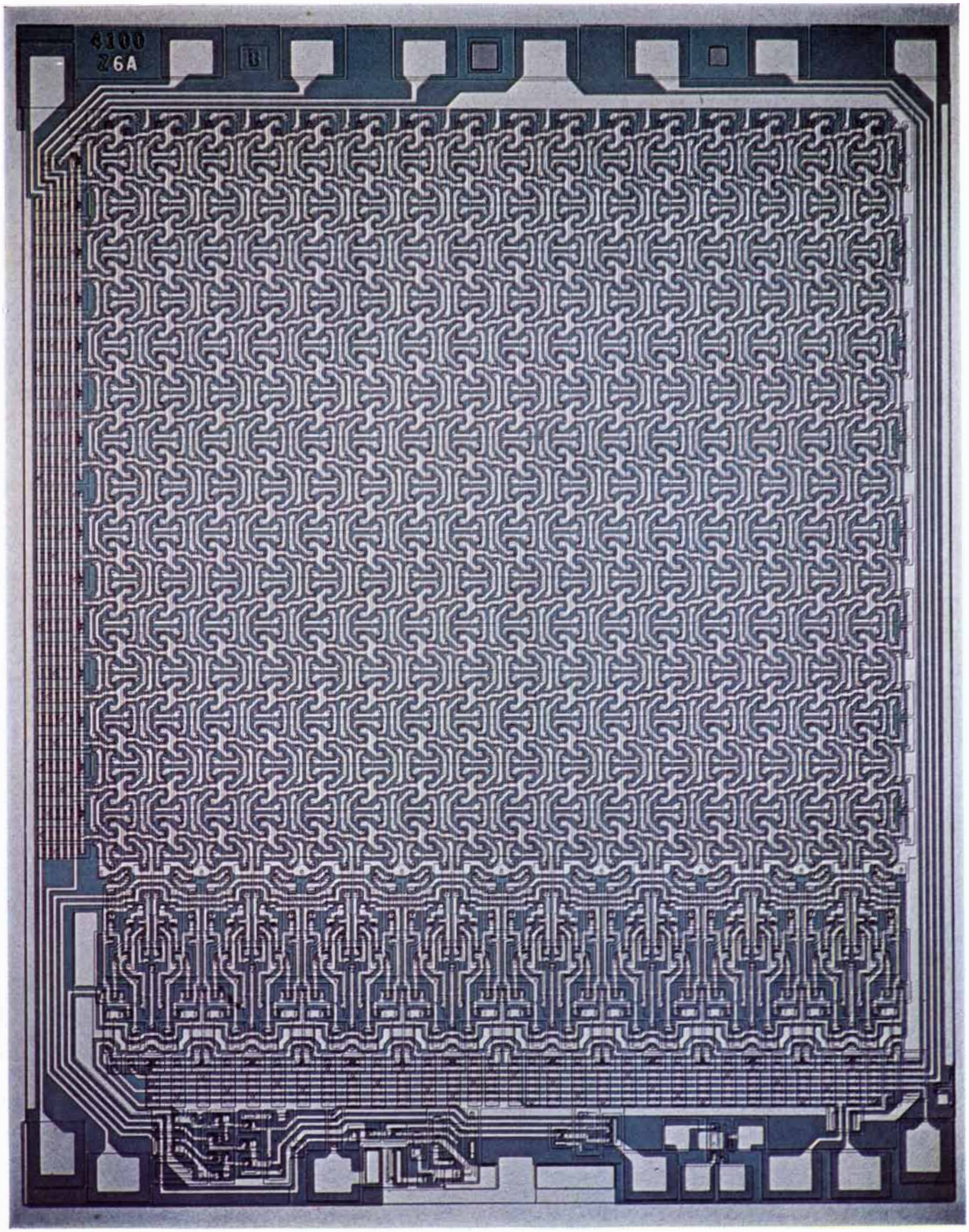
Until the advent of the transistor each type of component in an electronic circuit was fashioned from one or more materials having the required electrical characteristics. For example, carbon was used for resistors, ceramics as a dielectric for capacitors, tungsten for the emitters in vacuum tubes and so on. These components, with characteristics defined by their composition and construction, were then used like building blocks in creating a circuit with specified characteristics and responses. Circuits were combined into systems, such as a radio transmitter, a radio receiver, a radar set or a computer.

From the earliest days electronics has been a technology of complex interconnections. A small radar set can easily have as many connections as an oil refinery. The refinery, however, may cost millions of dollars and require a crew of maintenance men around the clock. The radar set, on the other hand, may cost only a few thousand dollars and is expected to work reliably for weeks on end. When it does need repair, the job will be done by a repairman who may not have seen it for many months. The complexity and inherent reliability of electronics is taken largely for granted.

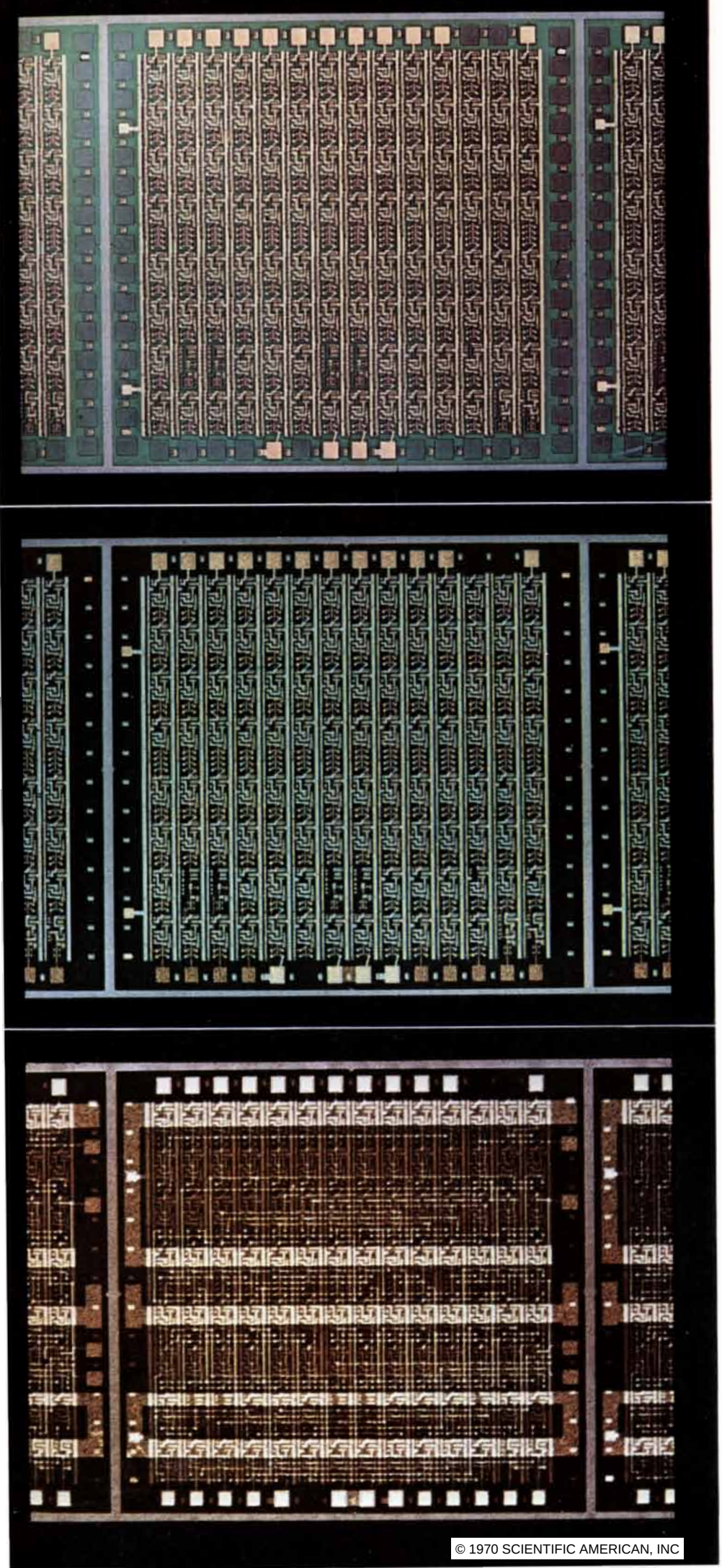
The great advantage of the transistor, an advantage scarcely appreciated at first, was that it enabled one to do away with the separate materials—carbon, ceramics, tungsten and so on—traditionally used in fabricating components. At the same time the transistor raised the ceiling that sheer complexity of interconnections was beginning to place on system design.

At first the transistor did little to alter the requirement for connecting individual components, but the technique of its construction did. The transistor was the first electronic component in which materials with different electrical characteristics were not interconnected but were physically joined in one structure. The preferred material for making the transistor soon came to be silicon; it was produced in the form of a single crystal resembling a sausage, which was sliced into thin round wafers. By suitable masking and "doping" techniques, which selectively altered the electrical behavior of small regions, several score transistors could be created on each wafer. The individual transistors were then cut apart and sealed in a package about the size of a pencil eraser. The problem of soldering individual transistors and diodes into a circuit remained.

As a first step toward simplifying system design and reducing the number of interconnections, computer engineers began to develop a series of standard circuit modules, each of which performed a specific function, and used them as logical building blocks for cre-



COMPUTER MEMORY CIRCUIT, incorporating 1,244 transistors, 1,170 resistors and 71 diodes, is an example of large-scale integration (LSI). The term is usually reserved for integrated circuits whose density is 50,000 or more devices per square inch. This unit, manufactured by Fairchild Semiconductor, has a density exceeding 160,000 devices per square inch. Its actual size is .11 by .14 inch, roughly the area occupied by the word "the" in this typeface. The circuit can store 256 bits of information and, with similar units, will provide the high-speed memory for the advanced *Illiac 4* computer now under development at the University of Illinois. It provides faster access than conventional high-speed memory units, which consist of tiny rings of ceramic threaded on wires.



ating their systems. The transistor, being much smaller than a vacuum tube, could readily be assembled with resistors and capacitors of about the same size on a small plastic board. These modular circuit boards, typically the size of a playing card, could then be plugged together as needed.

With the growing complexity of systems, however, the interconnection problem again asserted itself. In small systems, engineers had been able to position individual components quite freely, worrying only about electromagnetic interference from such components as transformers. In the much larger new systems the fabrication of complex wiring networks became very costly. What was even more important, the increased speeds of operation possible with transistors were in fact outstripping the speed with which signals could travel along the interconnecting wires. It was rather like trying to drive a 150-mile-an-hour sports car behind a long queue of traffic traveling at 40 miles an hour; the shorter the queue, the easier it is to overtake the cars ahead and move to the front of the queue. It is much the same with electronics. By keeping the interconnecting wires as short as possible, one can step up the speed of operation.

As transistor technology developed and the switching speed of the circuits became faster, it was increasingly important to decrease the size of components and the length of interconnections. The physical limit of finding room

COMPUTER LOGIC CIRCUIT is shown in three stages of manufacture. Each circuit contains 112 identical cells, or logic "gates," made up of three transistors and four resistors. The complete circuit, which measures .133 by .142 inch, thus contains 784 devices, equivalent to an average density of about 40,000 devices per square inch. The 112-gate circuit, which fills most of each picture, is only one of about 100 created on a single chip of silicon. The three pictures show three stages of metallization. The first metallization (*top*) connects the transistors and resistors in the individual gates; the second metallization (*middle*) interconnects the gates, and the third (*bottom*) provides the leads for the power supply. The interconnections can be patterned in many ways to provide custom circuits. The circuit is manufactured by Motorola Semiconductor Products Inc. Like the circuit on the preceding page and on the cover of this issue of SCIENTIFIC AMERICAN, it employs the "bipolar" technology. The newer metal-oxide-semiconductor (MOS) method provides a still higher density of circuit elements. The two techniques are compared on pages 28 and 29.

for connections in an ever decreasing area was fast approaching. This limitation, coupled with increasing complexity of system design, made the search for a new technology imperative.

The technology that resulted was microelectronics, embodied in the integrated circuit. Beginning in the mid-1950's engineers in two American companies, Texas Instruments Incorporated and Fairchild Semiconductor, saw the possibility of producing as part of a single chip of silicon not only transistors and diodes but also resistors and capacitors, and joining them into a complete circuit. The special properties needed for the various circuit elements were achieved by selectively diffusing traces of impurities into the silicon or oxidizing it to silicon dioxide. The principles of photolithography were used to expose selected regions of the silicon to diffusion while protecting other regions [*see top illustration on pages 28 and 29*].

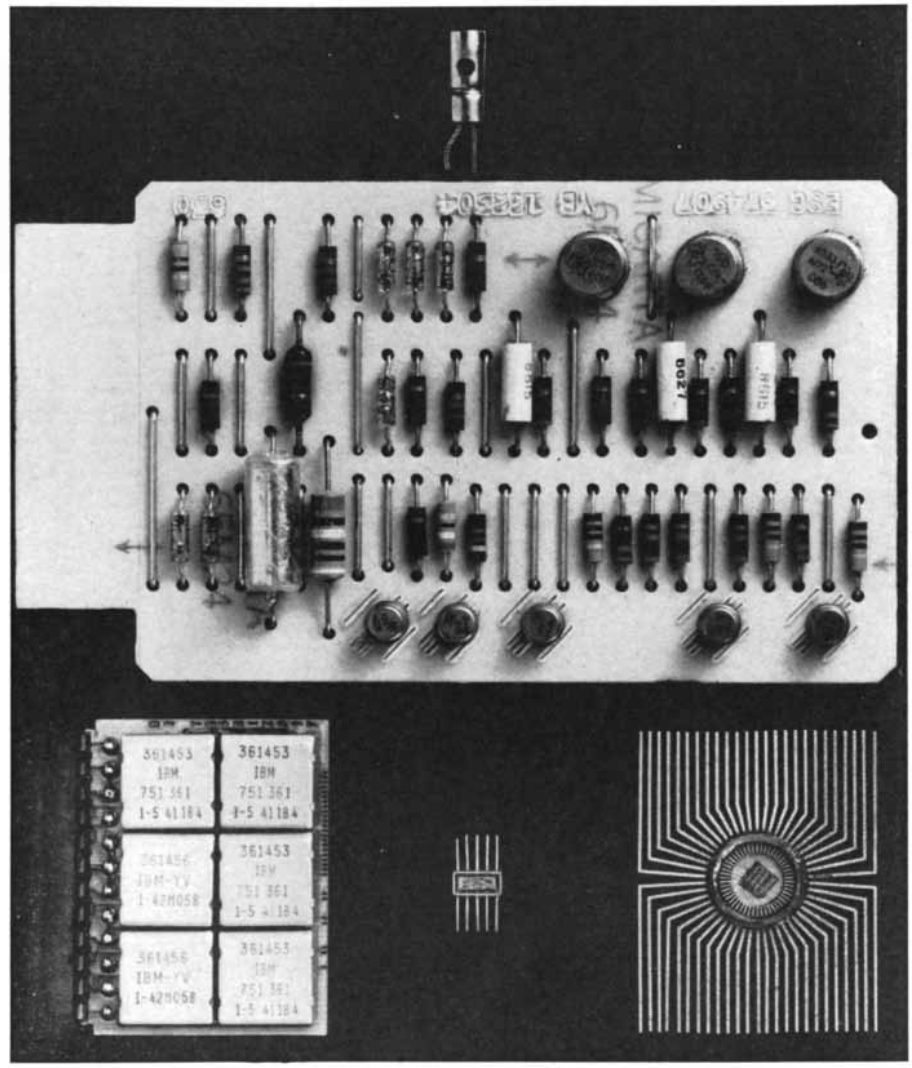
At first Texas Instruments used fine wires for bonding the various elements into a functional circuit. Fairchild achieved the same result more simply by evaporating a thin film of aluminum over the circuit elements and etching it selectively to leave a two-dimensional network. The Fairchild technique produced what became known as planar integrated circuits [see "Microelectronics," by William C. Hittinger and Morgan Sparks; SCIENTIFIC AMERICAN, November, 1965].

The standard integrated circuit incorporates between 100 and 500 identical logic circuits on a thin slice of silicon in an area roughly an inch square. These circuits are cut up into individual units. Each is sealed in a package containing anywhere from half a dozen to two dozen minute connections needed to bring the circuit in contact with the outside world, which is to say in contact with scores, hundreds or thousands of similar building blocks required for a complete signal-processing system.

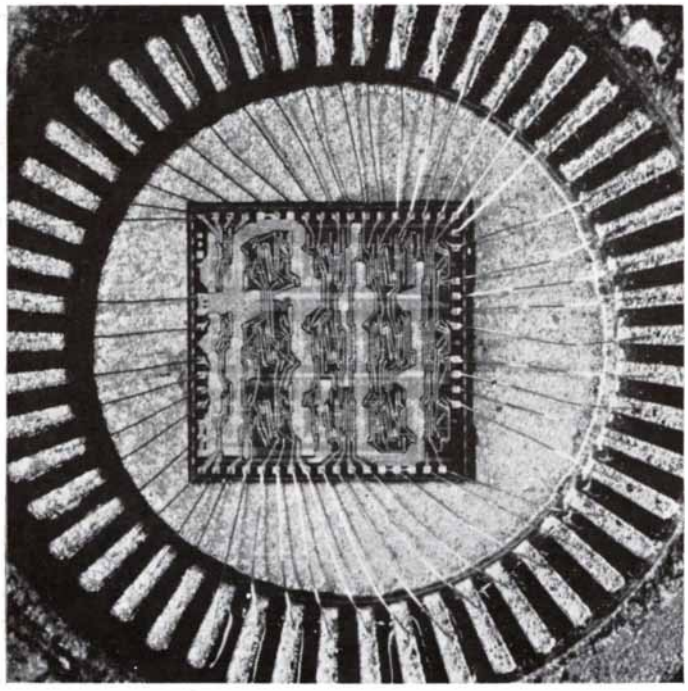
The concept of using circuit building blocks as "logic" units in a computer can be traced back to George Boole, who demonstrated in 1854 that all mathematical and logical processes can be synthesized by a binary system using only three operators: "and," "or" and "not." (Boole would probably be appalled by this simplification as well as fascinated by what computer designers have achieved with his concepts.) The central processor of a computer typically employs several thousand of these logic operators, realized by the circuits termed gates. The general theory of the functioning of more than, say, six interconnected gates is beyond human comprehension.

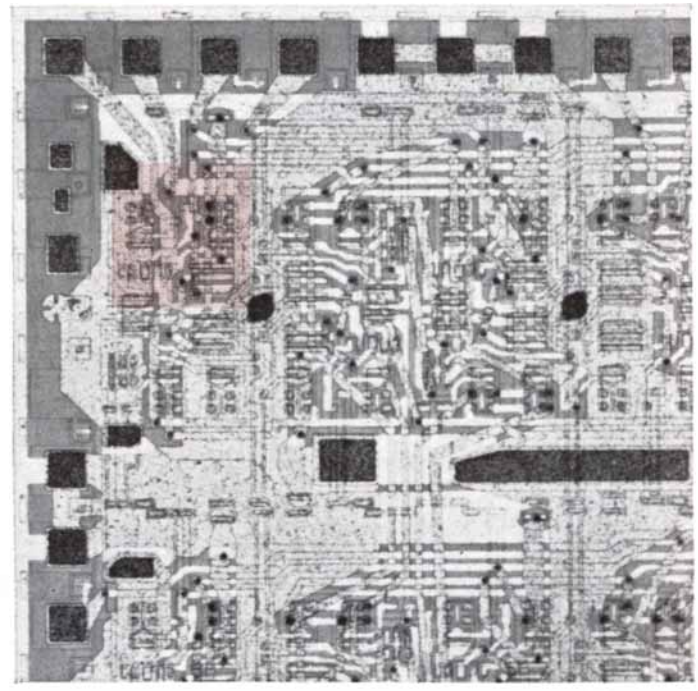
For lack of such a theory computer engineers have to work with simplifying concepts that enable them to understand and manipulate large chunks of logic. One method is to organize computer operations around "registers" in which binary digits represent a particular quantity or number. These registers and the connections between them specify the data flow; they are organized in regular structures. The extreme example is provided by the computer memory, which consists of vertical stacks of identical registers. Data are moved from one register to another by a series of timing signals. The sum total of such signals defines the computer's microprogram. It is largely the microprogram, with its near-random properties, that complicates the interconnection pattern in a large computer. The more modular the physical construction of a computer can be made, the easier it is to create a satisfactory system. The use of standard integrated circuits eased the circuit-design and interconnection problem at the lower level, but at the higher level serious problems remained.

If, for example, one wanted to design



EVOLUTION OF MICROELECTRONICS began with the introduction of the transistor in 1948. A 1952 transistor is shown at the top. (All the objects are depicted actual size.) The next step (*directly below*) was to assemble several transistors, diodes, resistors and capacitors on a circuit board that could be plugged into a computer or other kind of system. The example shown here is a circuit board of the type used in the 7,000-series of IBM computers in the early 1960's. It incorporates 45 electronic devices. The IBM 360-series of computers employs a technology called solid-state logic (*bottom left*); it provides 40-odd devices in six tiny cans. The late 1950's saw the development of the first integrated circuits in which transistors, diodes and resistors were all formed on a single chip of silicon and linked into a circuit. The example in the middle of the bottom row was made in 1965 by Texas Instruments Incorporated; it contains 91 transistors and resistors. The LSI example at the bottom right, made by Fairchild, contains 864 devices. This unit, in various magnifications, reappears at the top of the next two pages and on the cover of this issue of SCIENTIFIC AMERICAN.

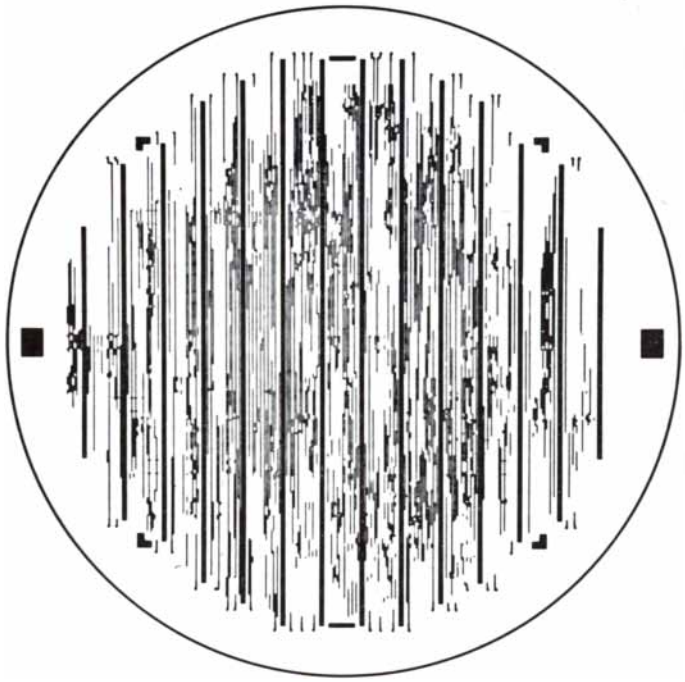




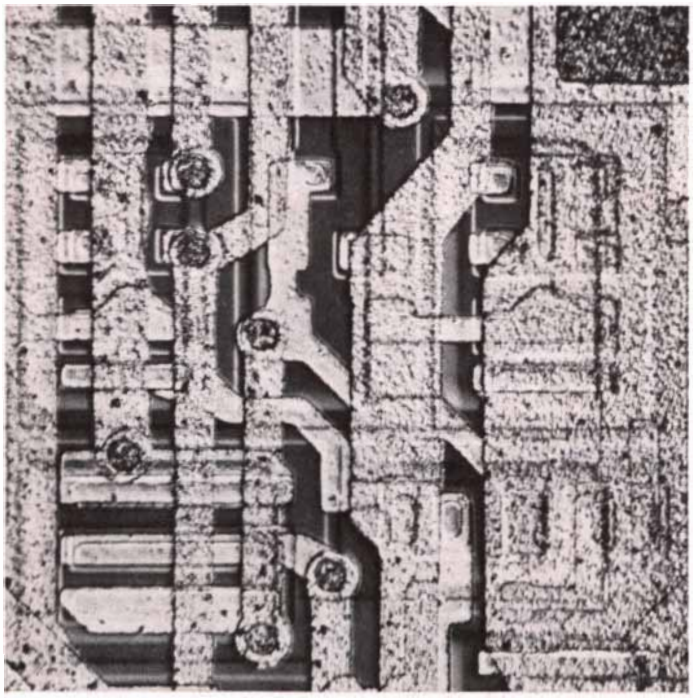
SEQUENCE OF MAGNIFICATIONS reveals the fine structure of circuits made by the LSI technique. The Fairchild circuit depicted in the illustration on the preceding page and on the cover is shown here magnified 10 diameters (*far left*), 50 diameters (*second from*

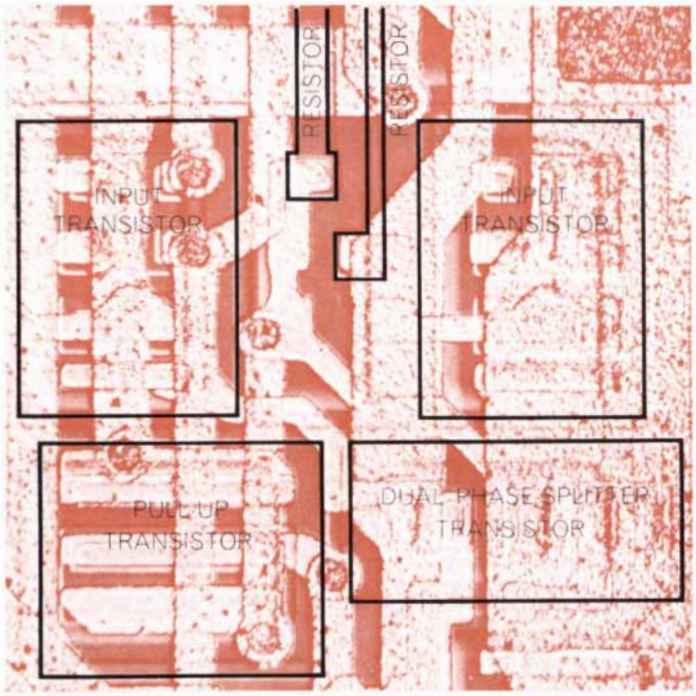
a central processor with 1,000 logic elements, one could begin by selecting 200 integrated-circuit packages, each containing an average of five gates of the kind desired. Tying the 200 packages together, however, might easily require 6,000 connections. Since each connection must be kept as short as possible, the solution depends on two things: first, a good miniature wiring method and, second, computer programs that can transform the designer's logic into a good layout with simple interconnections. The conventional two-sided printed circuit board was incapable of doing this job.

A practical solution to the problem was found by designing multilayer printed circuit boards about a foot square on which 100 to 200 integrated circuits could be mounted. The board is a laminate of double-sided printed circuits,



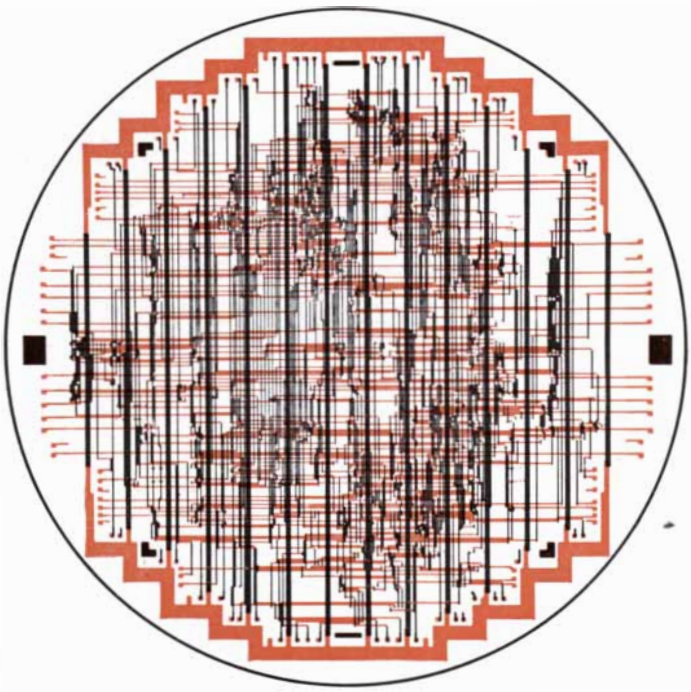
DISCRETIONARY WIRING is employed by Texas Instruments in some of its LSI circuits. The one shown here contains 250 gates, but as many as 4,000 could be placed on a single silicon wafer 1.5 inches in diameter. A 4,000-gate array would require at least 12,000 transistors. In this approach, which has low cost as a goal, the devices are individually tested and defective units are recorded in a

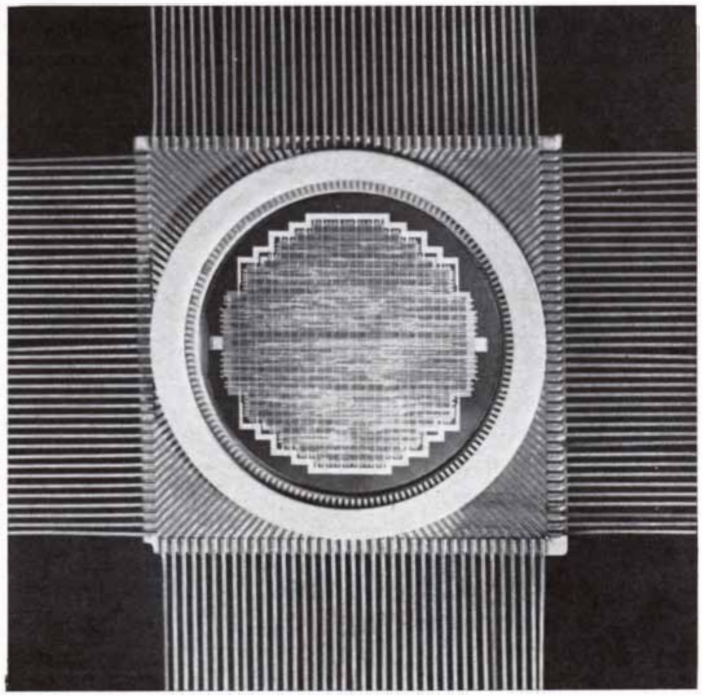




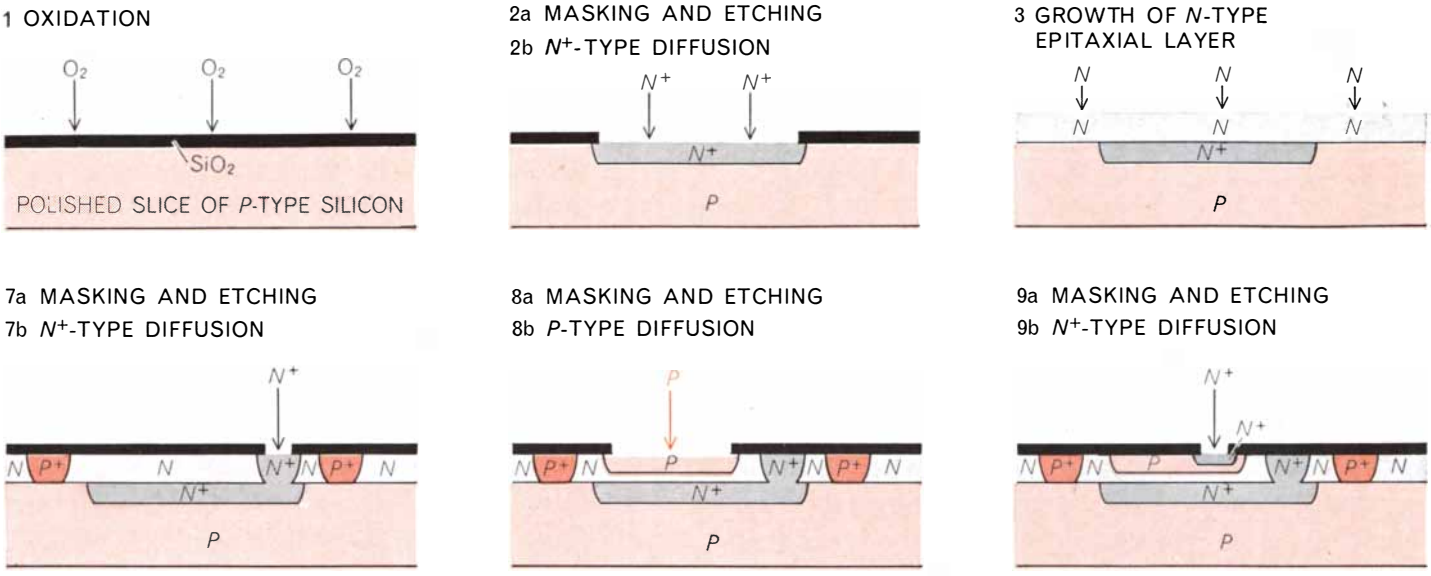
left) and 250 diameters (*third from left*). The diagram at the far right shows the location of individual transistors and resistors in the 250-diameter enlargement. The complete circuit contains 864 devices, packed with a density of more than 40,000 per square inch.

each fabricated to an accuracy of about a thousandth of an inch. Typically 12 layers of wiring crisscross through an insulation of reinforced plastic. This precise and rigid three-dimensional structure replaces the bird's nest of wires found inside earlier computers. Since it is not humanly possible to lay out 6,000 connections in an area a foot square and 12 layers deep, computer programs had to be developed to do the job. This involved an immense programming task requiring hundreds of thousands of words of instructions. The end result was that a very large central processor could be assembled from only about 60 multilayer boards, linked together by relatively few hand-wired connections. The task of testing such high-density electronic structures was solved with the help of automatic testing machines.





computer memory. The computer then figures out an efficient wiring plan to link as many good devices as needed to produce a custom circuit. A cathode-ray tube generates vertical and horizontal wiring patterns separately (*first two patterns at left*); together they provide the complete wiring scheme (*third pattern from left*). The finished circuit package is shown actual size at the far right.

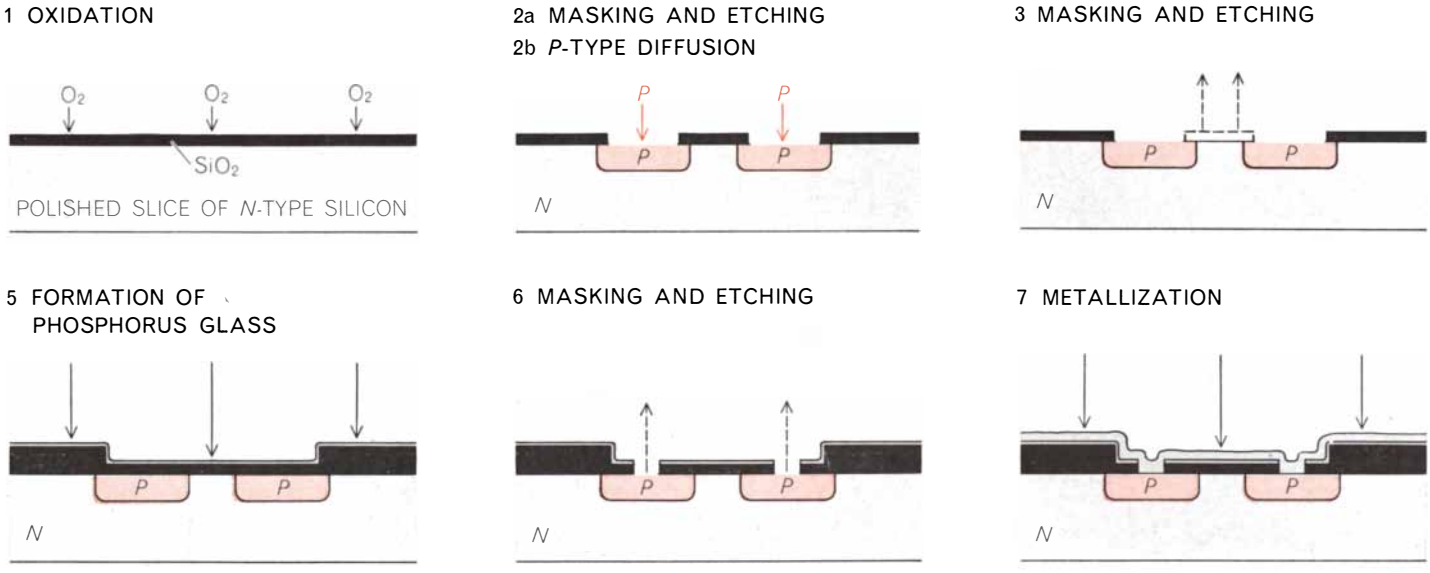


CONVENTIONAL INTEGRATED CIRCUITS are made by the bipolar technique, in which transistors are formed from *n* (negative) and *p* (positive) regions. In *n* regions free electrons are the natural carriers of electricity; in *p* regions "holes" with positive charge are the natural carriers. The process begins with a polished wafer of silicon containing impurities of the *p* type. Oxidation produces a thin layer of silicon dioxide (*1*). The next step, photoetching (*2a*), is fundamental to the entire process; it creates the high-resolution patterns essential for making microelectronic circuits. As in photolithography, the wafer is coated with a resistant material that hardens on exposure to light. An extremely accurate mask, produced by precision optics, is placed between the light source and the wafer. In areas not exposed to light the resist is dissolved and the underlying silicon dioxide is removed by etching.

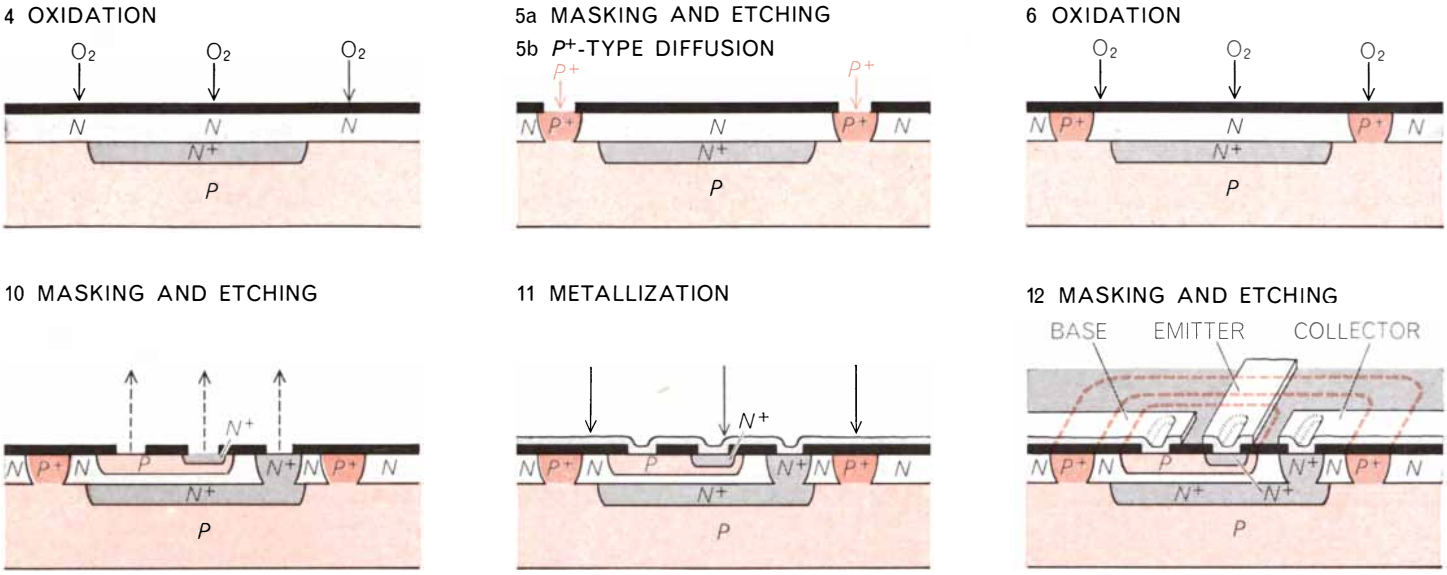
One can see that no great leap of the imagination was required for the next step: large-scale integration. The makers of integrated circuits had learned how to produce chips about an inch square that held several hundred logic circuits, which were then cut apart and packaged individually. Why not fabricate a chip in which the several hundred circuits were interconnected and sold as a single large package?

One obstacle, and a major one, was that a multicircuit chip would have to incorporate logic gates of several different types and all would have to function perfectly. When the manufacturer had put several hundred identical gates on one chip, he could test each one individually and discard any that were defective. A 60 or 70 percent yield was considered good.

One way around this obstacle to large-scale integration was not long in coming: Lay down more gates than needed, identify the bad ones by testing and interconnect only the good ones by multilayer metallization. Again computers were called on to supervise the testing and to lay out custom interconnections for each chip. It also became a simple matter to interconnect the gates in a chip so as to meet the special requirements of different customers. The result was LSI with discretionary wiring [*see bottom illustration on preceding two pages*]. So far manufacturers have



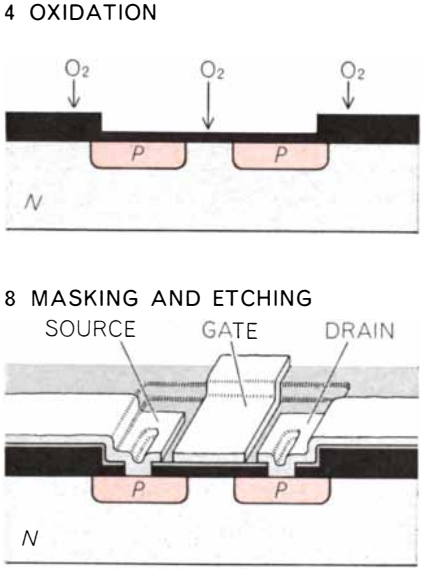
NEWER TYPE OF INTEGRATED CIRCUIT employs the metal-oxide-semiconductor (MOS) technology. It can create circuits with five to 10 times as many transistors per unit of area as the bipolar technique. The process starts with a wafer of *n*-type silicon, which is oxidized (*1*). The openings that will provide the "source" and "drain" of a field-effect transistor are photoetched (*2a*) and exposed to *p*-type diffusion (*2b*). The gate region is removed (*3*) and a new oxide layer is created over the entire surface (*4*). For stabilization a thin layer of phosphorus glass is formed (*5*) and windows are photoetched to expose the source and drain (*6*). The



The wafer is then placed in a controlled atmosphere so that n^+-type impurities can be diffused into the formerly *p*-type silicon (*2b*). Next the silicon dioxide layer is removed from the entire wafer and a mild *n*-type epitaxial layer of silicon is grown on the surface (*3*). "Epitaxial" signifies that the underlying crystal structure is continued without interruption. The surface is again oxidized (*4*), etched (*5a*) and exposed to a p^+-type diffusion (*5b*). This is followed by oxidation (*6*), etching (*7a*) and an n^+-type diffusion (*7b*). After oxidation (*not shown*) the surface is again etched (*8a*) and exposed to a *p*-type diffusion (*8b*). After another oxidation and etching (*9a*) there is a final n^+-type diffusion (*9b*). Another etching (*10*) produces the openings needed for a layer of aluminum (*11*) to make contact with the *p* and n^+ regions of a transistor. A final etch leaves a network of leads on the surface (*12*).

achieved three layers of metallization. The more layers of connections, the more the components can be packed together, thus improving the yield and reducing the cost. Recently manufacturers have succeeded in producing LSI units in which all the gates are usable.

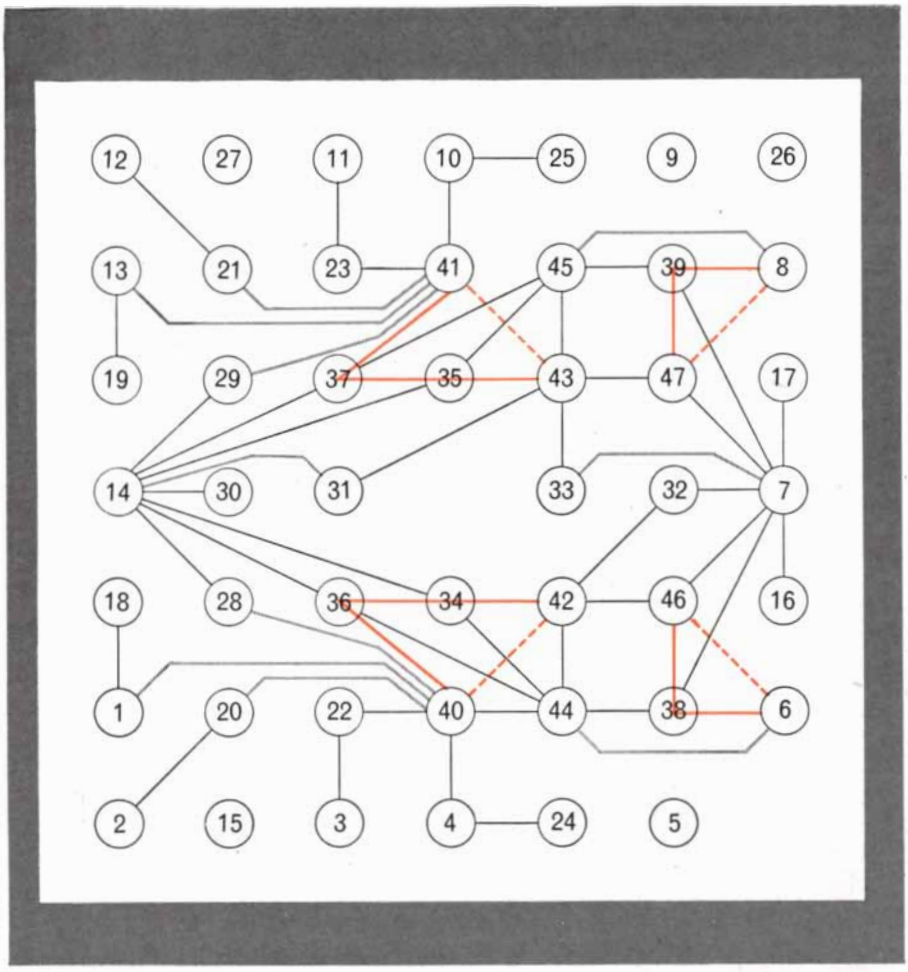
Faulty circuits, which reduce the yield, are caused by a point fault on the semiconductor crystal; such faults are randomly distributed over the surface of the silicon chip. A newer type of transistor element—the field-effect transistor—has come into use because it has better properties, occupies less area on the chip and therefore is less likely to be spoiled by a point fault. These newer kinds of transistor are produced by the metal-oxide-semiconductor (MOS) technique [*see bottom illustration on these two pages*]. The MOS technique can provide circuits some five to 10 times more complex than the "bipolar" technique used for making conventional transistors and still achieve the same yield. There are, however, subtle operating differences in the transistors produced by the two techniques, with the result that one or the other may be preferred, depending on the particular circuit application. Recently ways have been found to mix the two techniques, so that circuit versatility is enhanced.



surface is aluminized (*7*) and given a final photoetching (*8*). Transistors produced by the MOS technique, unlike bipolar transistors, have electrical characteristics quite similar to those of old-fashioned vacuum tubes.

The production of LSI circuits with computer logic gates is still modest in volume. A number of companies have directed their initial LSI effort toward producing computer memory arrays, which have a highly regular structure and potentially a very large market [*see illustration on page 23*]. In most memory arrays under development all the gates must operate, so that very high standards of production are required to attain satisfactory yields. By 1972, if not sooner, it should be economic to replace the standard magnetic-core memory of the computer (the type of memory in which tiny magnetic rings of ceramic are threaded on a matrix of thin wires) with a series of LSI memory modules. Each LSI memory module will use chips with about 1,000 gates and will hold 256 words, each 32 "bits" long. Between 25 and 50 of these modules, interconnected by some suitable microwiring method, should be able to fit in a cube no more than four inches on a side. This is an achievement that would have been inconceivable even five years ago.

The development of LSI discretionary-circuit modules and LSI memory modules offers an exciting prospect for the system designer. They mean that the central processor for a high-capacity computer could be built from perhaps 100 LSI chips, making such a computer readily portable. It will be difficult, however, for the LSI-chip manufacturer to quote low prices if all 100 chips have to be different. To minimize the variety of chips needed, system designers are investigating new computer system structures. For example, it should be possible to design computers consisting of blocks of identical LSI chips in which arithmetical operations are performed in parallel rather than sequentially, as they are at present. Such parallel systems would be ideal for time-sharing applications, where large numbers of users want simultaneous access to the same computer. Because each LSI building block is virtually an independent processor in its own right, one can readily imagine LSI chips joined together in various ways to provide computers tailored to



each customer's special needs. The end result of LSI technology will be to increase computer processing speeds, to reduce the amount of basic programming required, to increase the capability of small processors built into terminal devices (thus reducing the load on the main computer) and to reduce costs all around.

To give the reader some idea of how an LSI chip is designed, let me describe briefly a computer-aided design program we have developed at the University of Manchester Institute of Science and Technology, with the support of the International Telephone and Telegraph Corporation [*see illustration at left*]. The designer first prepares a diagram of the logic operations required in the finished LSI. This is punched on a paper tape and fed into a computer, to be used in conjunction with a library of standard circuit elements. A program called PLACE examines the interconnections needed and locates the elements to provide the simplest connection pattern. At this step the elements are connected by straight lines.

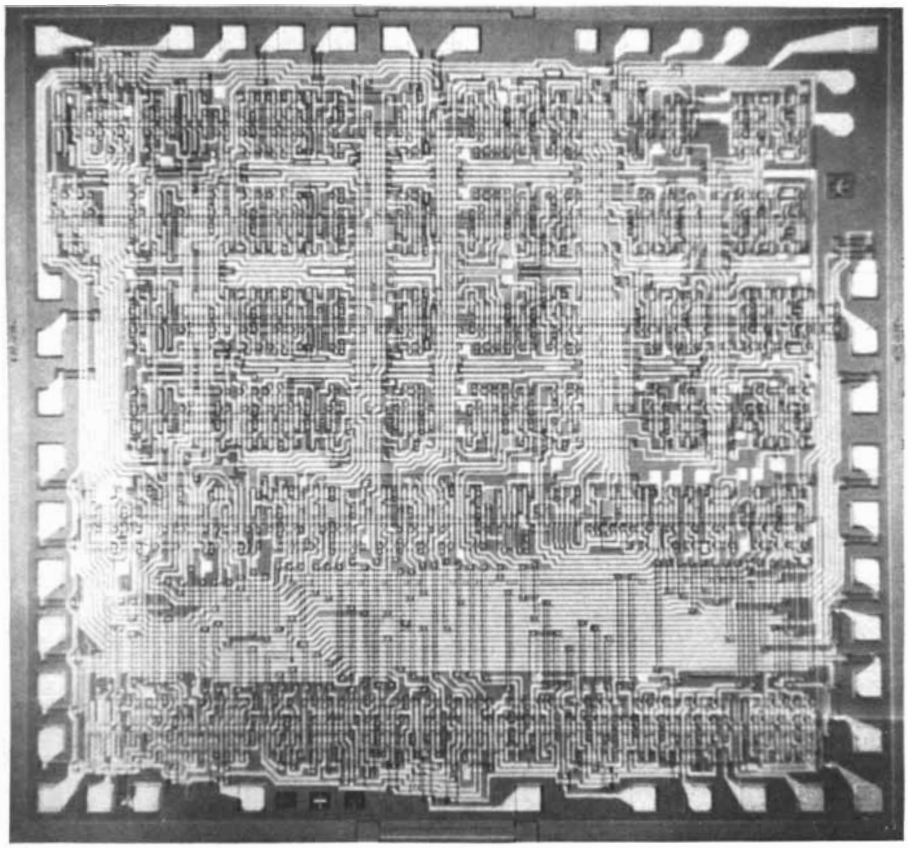
COMPUTER-AIDED DESIGN has become essential for arranging the devices and interconnections in LSI circuits. At the University of Manchester Institute of Science and Technology the author and his associates have worked out a series of computer programs that make the design of interconnections almost automatic. The circuit designer prepares a logic diagram of his needs and specifies the individual circuit elements required. This is punched on paper tape and fed into a computer. A program called PLACE examines the interconnections required and attempts to locate elements to give the simplest connection pattern. In the top diagram at the left the elements have been moved from their original arbitrary locations, represented by the numbers in the circles. (Thus element No. 1 had been the first element in the first row, and so on.) At this stage the connections are shown as straight black lines. For simplicity not all connections are shown. Program CROSSOVERS lists the places where a connection crosses an element and CROSSBOW bends the connections to one side (*gray lines with angles*). Program DUCK identifies certain crossings (*broken lines in color*) that can be avoided by routing the lines so as to pass under resistors (*solid lines in color*). After several more programs PACK examines the shape and size of the various elements and fits them into the smallest possible area, as shown in the bottom diagram. Gray regions denote unfilled spaces; the outlines of typical elements are in color. Finally, a program called LEE (named for its developer) fits in the actual wiring (*heavy black lines*).

Next a program called CROSSOVERS notes every place where straight connections cross over an element. CROSSBOW moves all these connections so that they no longer cross the element below. TWIST tries out each element in all orientations so that the wires out of each element are correctly positioned. DUCK takes any crossings that remain, identifies where a resistor is involved and routes the connection to pass below the resistor. The crossings that cannot be handled in this fashion are examined further by SEARCH, which seeks other ways to avoid a crossing. The final residue of crossovers is handled by CHEAT, which creates a minimum number of low-value resistors that can be placed under the surface and used as crossing devices.

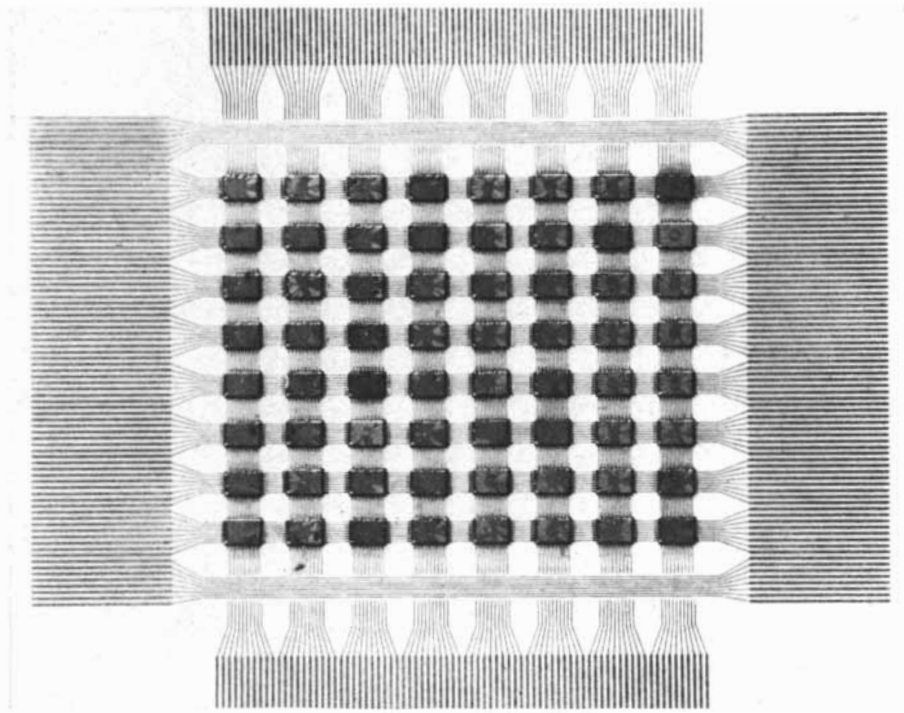
A program called PACK examines the dimensions of each element and fits all the elements into the smallest possible area without overlap. If there is not enough room between the elements for the connecting wires, STRETCH expands the layout as needed. Finally LEE (an algorithm developed by Chi-Yuan Lee of the Bell Telephone Laboratories) fits in the actual wiring, using the rules of the particular LSI technology being employed. Programs of this kind will undoubtedly be capable of increasingly complex tasks—the first gropings, perhaps, toward artificial intelligence. Stimulated by these exercises in automated circuit design, we are now examining techniques for organizing an entire factory on a logical basis, not necessarily with the goal of automating the operation but to simplify both man and machine functions in a manufacturing complex.

It must not be forgotten that semiconductor techniques can be applied not only to circuit-making but also to the production of such things as photoelectric cells and light sources. If 250,000 components can be put into a volume the size of a package of cigarettes, one could hope to duplicate an insect's eye by interconnecting thousands of tiny photocells with the LSI technique. A similar development could produce a flat, solid-state television picture screen.

Such is the potential for many new developments made possible by LSI: wristwatch television, robot toys a few inches high, a computer terminal for the home, electronically guided automobiles. One can predict that new markets of this kind will lead to a drastic reduction in the cost of LSI circuitry. The decade of the 1970's should be a boom time for microelectronics.



COMPUTER ON A CHIP has recently been developed by RCA for the National Aeronautics and Space Administration. The chip, which measures .146 by .155 inch, incorporates 780 MOS transistors and diodes (a density of 34,000 per square inch) linked into about 400 gates. The chip can perform all the arithmetical functions of a medium-size, medium-speed computer. Four such chips can be joined to provide a computer with a 16-bit word length.



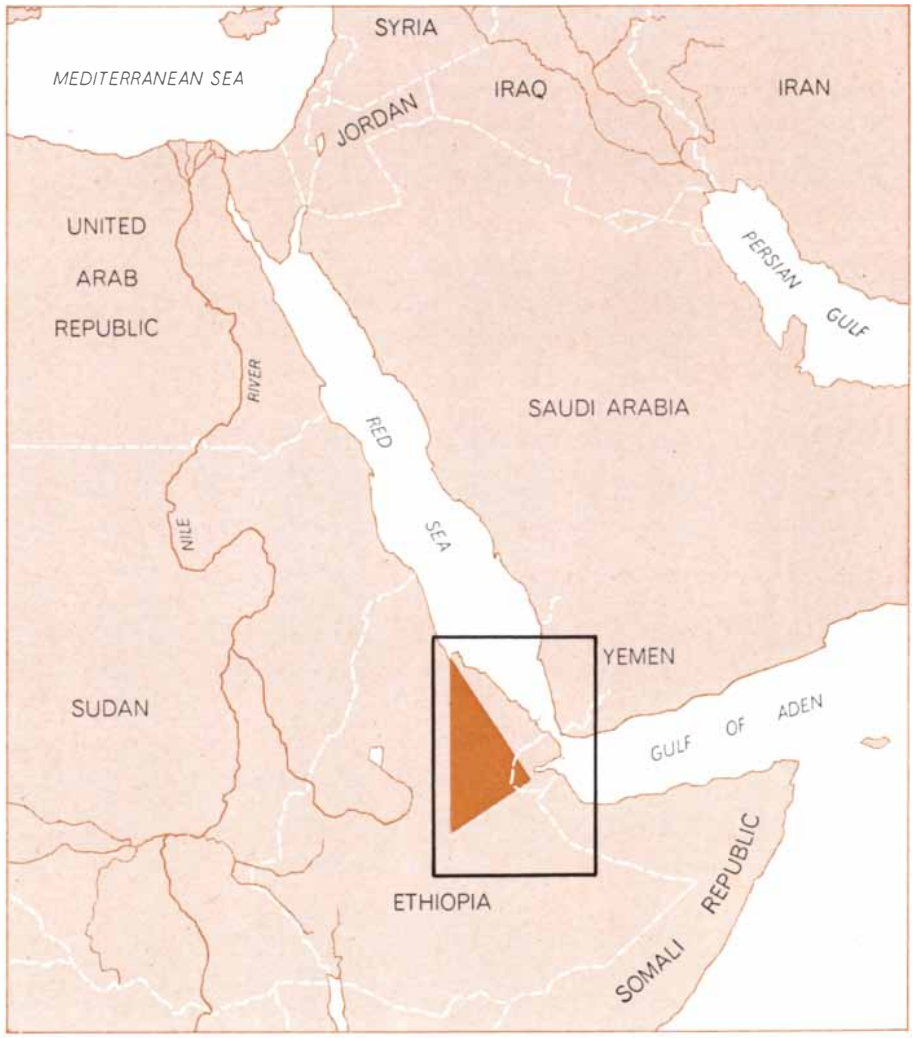
RIGHT-SCALE INTEGRATION, or RSI, is the way the Bell Telephone Laboratories describes a technology that permits the mixing of various kinds of circuits, such as bipolar and MOS, each at an appropriate state of development. In the photograph 64 bipolar memory chips, each .046 by .063 inch, are mounted on a ceramic wafer and connected by "beam leads" into a large memory array. The 64 chips fit within an area .6 by .75 inch and contain 40,960 transistors, diodes and resistors. This equals 90,000 devices per square inch.

THE AFAR TRIANGLE

A new ocean seems to be in the making where three great rift systems intersect near the junction of the Red Sea and the Gulf of Aden. The violence of the process has created a nightmarish desert landscape

by Haroun Tazieff

In the northeastern part of Ethiopia, at the juncture of the Red Sea and the Gulf of Aden, lies a region known as the Afar triangle. It is a wild and rugged country, featured by below-sea-level deserts, towering escarpments, fissures, volcanoes and craters. Few men have explored the region, and until recently it was terra incognita as far as its geology and even its exact geography were concerned. Now, however, the discovery of detailed evidence for the drift of continents and the growth of oceans has focused considerable interest on the Afar triangle [see "The Origin of the Oceans," by Sir Edward Bullard; SCIENTIFIC AMERICAN, September, 1969]. The triangle seems to be a focal point for new oceans in the making. What is more, whereas elsewhere the process that is producing continental separation is hidden in the depths of the ocean, here we can see it taking place in direct view on dry land.



AFAR TRIANGLE (*color*) is in northeastern Ethiopia where the Red Sea rift, the Carlsberg Ridge of the Indian Ocean and the Rift Valley system of East Africa meet. Its northern section was once submerged, and part is still below sea level (*see map on pages 34–35*).

The theory that the earth's present continents were once united in a great land mass and have gradually drifted apart is now generally accepted. Evidence collected over the past 10 years, mainly by exploration of the worldwide system of ridges running along the middle of the oceans, has outlined a convincing picture of how the continents were separated [see "The Confirmation of Continental Drift," by Patrick M. Hurley; SCIENTIFIC AMERICAN, April, 1968]. In brief, the process seems to be as follows. The material of the continents is a layer of comparatively light sialic rock, resting on a denser basaltic magma underneath. Stresses in the earth's crust may crack the sialic layer, producing faults and fissures that can be as much as 20 meters wide. Then molten magma wells up into the fissure, sometimes spilling out over the surface. The magma hardens into solid rock, thus holding apart the separated sialic blocks. Over long periods of time the same stresses create new fissures parallel to the old ones; these fissures too are filled with magma. Examination of the oceanic ridge has shown that it is composed of parallel strips of hardened magma, indicating that the crust was repeatedly fissured along the axis of the ridge and that the continental blocks thus moved farther and farther apart. The upwelled strips of basalt are distinguishable from one another by differences in the direction of their magnetic polarity, which

MASSIVE FAULT BLOCKS characterize the terrain of the Afar triangle. The aerial photograph above shows a region near 12 degrees north latitude, where faulting has caused huge segments of surface to subside below the level of the surrounding plateau. The depressed structures are whitened in places by salt or gypsum.

STAIRSTEP LANDSCAPE of the eastern shore of Lake Giulietti (*below*) is further evidence of the extensive downfaulting that has shaped much of the Afar triangle. Such long, depressed blocks, bordered by fault zones, are called graben structures by geologists; the graben structures here are among the world's most spectacular.

reflect changes in the earth's magnetic field with time.

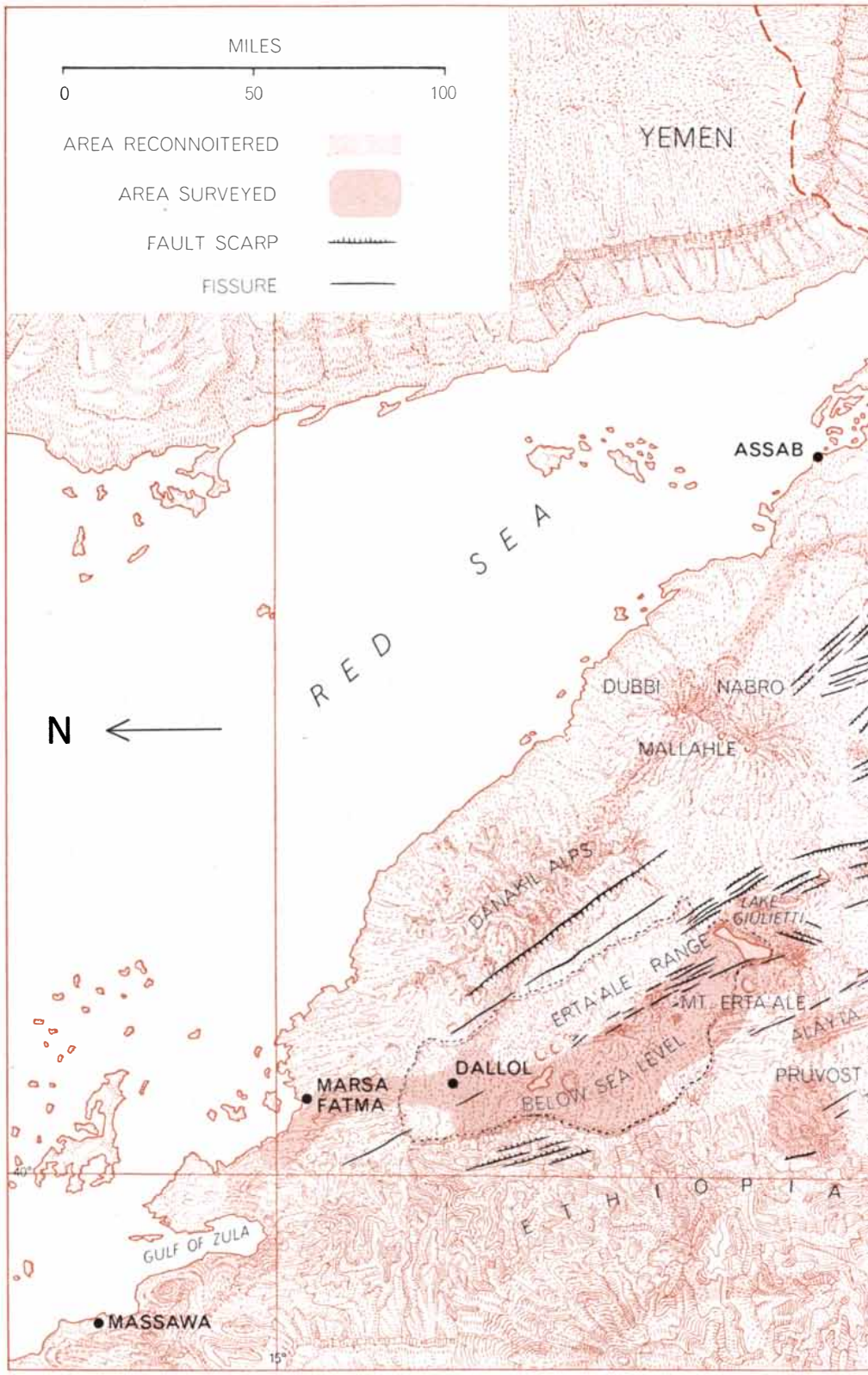
The overall conclusion from studies of the mid-oceanic ridges is that the continents have been moving apart at an average rate of a few centimeters per year. In the South Atlantic, for instance, it appears that the ocean has been widening at the rate of 2.5 centimeters per year, which indicates that the South American continent began to separate from Africa approximately 180 million to 200 million years ago.

Recent worldwide explorations of the ocean bottoms have shown that a rise running along the middle of the Indian Ocean, known as the Carlsberg Ridge, has a branch extending into the Gulf of Aden. The Red Sea bottom similarly has an axial ridge with physical properties like those of the oceanic ridges. The Gulf of Aden and Red Sea rifts, which are perpendicular to each other, meet in the Afar triangle. And the same region also lies at the northern end of the system of rift valleys that runs down the eastern side of the African continent. Once these facts were recognized, it was suddenly realized that the largely uncharted Afar triangle might offer an extraordinary opportunity for investigating the origin of new oceans.

The Afar triangle is one of the world's most forbidding regions. In addition to the fact that its terrain is all but impassable, the area is extremely hot; we were to find that the temperature rises to as high as 134 degrees Fahrenheit in the shade in summer and 123 degrees in winter. The region is inhabited only by nomadic tribes of fierce repute; the young warriors are said to mutilate male victims to offer trophies to their women, and they have been known to massacre armed parties for their weapons. Several exploring parties in the 19th century were slaughtered by the tribesmen.

Of the expeditions that had explored the Afar triangle before we began to survey it in 1967, the best-known was one carried out in the spring of 1928 by two Italians, Tullio Pastori and G. Rosina, a British mining engineer, L. M. Nesbitt, and half a dozen Ethiopians. The expedition's leader was Pastori, a hardy ore prospector who earlier had explored various parts of the region (and who, at the age of 60, in 1943 escaped from a British prisoner-of-war camp in Kenya and made his way on foot all the way to Alexandria on the Mediterranean coast). Nesbitt, who wrote a report on the 1928 expedition, vividly described the difficulties and dangers the expedition had encountered. It was apparently the first journey along the entire length of the Afar triangle, and Nesbitt's information provided a basis for the only detailed maps of the region that were available before our expeditions. The 1928 party was not equipped, however, to undertake a geological survey.

In 1967 we organized a team of specialists to study the geology of the Afar triangle with all possible thoroughness. Our group includes investigators from several universities in Italy, France and the U.S. It consists of three petrologists



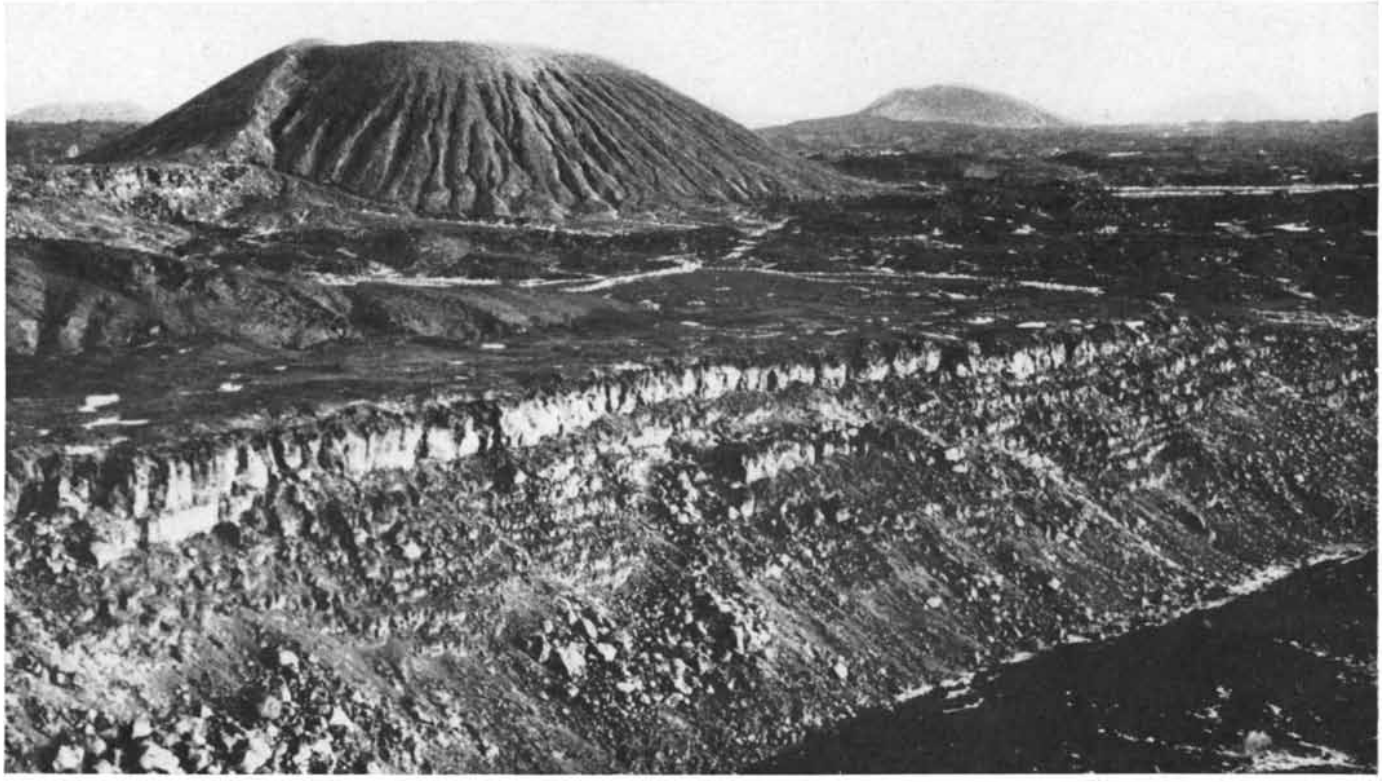
GEOLOGICAL SURVEY of the Afar triangle was conducted by the author and his associates beginning in 1967. In this map north is at the left and east at the top. The most inten-

(Giorgio Marinelli, Franco Barberi and Jacques Varet), four geochemists (Giorgio Ferrara, Sergio Borsi, J. L. Cheminée and Marino Martini), one tectonic geologist (Gaetano Giglia), two students of the geology of recent times (Hugues Faure and Colette Roubet), a geophysicist (Guy Bonnet), an oceanographer (Enrico Bonatti of the University of Miami) and a volcanologist (myself).

We have now completed three expeditions to the Afar triangle, all during the comparatively cool winter season (in 1967–1968, 1968–1969 and 1969–1970). Our party was unarmed and was not molested by the local people. For our explorations we have had the invaluable help of a helicopter, without which it would simply have been impossible to do serious, comprehensive fieldwork in that rugged country. So far we have

sive work was done in and near the area below sea level, between the Danakil Alps and the Ethiopian escarpment. In addition the group scouted widely by helicopter, landing more than 1,000 times to gather rock samples for later analysis and to study formations.

FLAT-TOPPED VOLCANO, Mount Asmara is composed of shards of volcanic glass such as are formed during underwater volcanic explosions. It resembles the numerous guyots, or submerged oceanic mountains, whose level summits are usually attributed to wave erosion. Because Mount Asmara was formed under water, it may be that a flat top is instead a feature common to all such volcanoes.



CINDER CONE near Lake Giulietti was built up at a point that overlies one of the innumerable fault lines found in the Afar triangle. A subsequent horizontal shift of one fault block has moved the far half of the cinder cone 100 meters ahead of the near half.

spent a total of 13 weeks in the field and have carefully mapped the geological structures and petrology of some 12,000 square miles in the northern half of the triangle. We have crisscrossed this entire area with the helicopter and have landed at more than 1,000 places to sample rocks and examine the tectonic structures on the ground.

On its northeast side the Afar triangle is separated from the Red Sea by a series of heights produced by deformations of the earth crust at faults and by volcanic action. Reading from north to south, these include a tectonic horst (upraised block) called the Danakil Alps, a mountain range formed by sedimentary and intrusive rocks, a volcanic massif composed of an active volcano and three volcanic piles crowned with calderas (craters of collapsed volcanoes) and, at the southern end, another mountainous horst. On the south side the triangle is bounded by the tall Somali scarp, from 4,900 to 6,500 feet high. On the west, the third side of the triangle, stands the huge Ethiopian escarpment, towering in some places to more than 13,000 feet. Here clifftops stand higher above the valley floor below them than anywhere else in the world. As for the floor of the triangle itself, it rises gently from about 400 feet below sea level near its northern end to more than 3,300 feet above sea level at the Somali end some 300 miles south.

What is one to make of this strange and spectacular landscape? Until very recently most geologists believed the Afar triangle was a funnel-shaped widening, produced in some unexplained manner, of the Great Rift Valley of East Africa. Our studies of the region's geology have led us to a completely different interpretation. The facts, as we have observed them on the scene, indicate that the floor of the triangle is actually a part of the Red Sea! In fact, the triangle from its northern apex down to the Ghubbet al Kharab at the western end of the Gulf of Aden and the Gulf of Tadjoura is a southwestern continuation of the central trough of the Red Sea that fades out close to 15 degrees south latitude. The tectonic trends of the Red Sea are evident and are geologically active throughout the area. There are none of the trans-rift structures or other formations that were once believed to account for the Afar triangle. It appears that as recently as some tens of thousands of years ago at least the northern half of this area was covered with seawater, with only the Danakil Alps and the high volcanoes standing above water as islands, and that most of the land has since been raised above sea level by tectonic uplifts through earthquakes, volcanic action and the rise of basaltic magma that filled the fissures.

The evidence that the Afar triangle is a part of the Red Sea floor, not some bizarre widening of the Ethiopian rift, can be seen on every hand. To begin with, we found that the observable facts contradicted other explanations of the region's topography. It had been suggested, for example, that the lofty escarpment on the west side of the triangle was produced by a downfolding of the high plateau, followed by erosion of the resulting hillside. Our observations turned up three important objections to this idea: (1) the blocks of faulted crust in the lower part of the escarpment are tilted westward—in the direction opposite to what would be expected in a downfold; (2) the supposed erosion should have deposited a vast amount of sediment in the triangle's closed basin, but almost none was found there; (3) the basin is filled with more than 3,000 feet of evaporites (salt formations deposited by the evaporation of seawater), and the basin's wall plunged down below this material at a steep angle, again indicating that the western boundary of the triangle was formed by slippage of the crust along a fault rather than by downwarping.

It had also been suggested that south of the Danakil Alps a belt of big calderas, apparently running north and south, was a continuation of the main Ethiopian rift and was a major active feature of the entire region. Field investigations show that no north-south belt exists, and that all the big calderas are located on a graben (a depressed section of crust) running north-northeast and south-southwest. This observation is an important one, because it again demonstrates that the Afar triangle is a part of the Red Sea and not an extension of the Ethiopian rift.

We found innumerable signs that the topography of the Afar triangle has been created by violent events that have occurred in very recent times, geologically speaking, and are still in progress. The entire northern half of the triangle shows clear evidence of extensive faulting of the crust and active crustal movement along the faults. North of latitude 13 degrees 10 minutes north all these faults are aligned along the axis of the triangle in the north-northwest to south-southeast direction [*see illustration on pages 34 and 35*]. South of 13 degrees 10 minutes north down to the Ghubbet al Kharab (11 degrees 30 minutes north) the same direction prevails, although there are also many faults and fissures running northwest-southeast and east-west. Along much of this part of the triangle the evidences of crustal movement are in plain view as wide-open fissures, horsts and grabens that form a classic graben structure of steps down the sides of a major depression. Even where the graben structure is now hidden under deposits of volcanic material and evaporites (but is still detectable by geomagnetic mapping), the fault axis is shown visibly by potash salt domes, explosion craters, boiling springs and other signs of volcanic activity below the surface. These eruptions follow the same line in the north-northwest to south-southeast direction.

This direction is precisely that of the Red Sea, so that the whole of the northern part of the Afar triangle can be regarded as part of the sea. All the evidence suggests that the waters of the Red Sea extended south-southeastward as far as the Somali scarp in the geologically recent past and that the present absence of water in the Afar triangle is only a temporary phase in the development of the ocean.

That the fissuring and displacements of the crust are going on actively at the present time is shown by several signs we were able to observe. Here and there we found fresh faults cutting through very young structures, such as alluvial fans and cones of active volcanoes. The volcano called Erta'Ale, the most active in all East Africa, has its main cone sliced by tectonic fissures that are parallel to the Red Sea axis. This is an exceptional phenomenon; volcanic fissures are usually not parallel but radial. We ourselves actually witnessed a significant event during our study: an earthquake in the middle of the depression on March 26, 1969, produced an appreciable slippage of the crust down a fault in the north-northwest to south-southeast direction.

Further evidence that the Afar triangle is actually a scene of oceans in the making came from the examination of the rocks themselves. Our samples gave every indication that the triangle's central trough contains no sialic (that is, continental) rock. The rocks, all very young, of the Erta'Ale volcanic range, which runs parallel to the Red Sea central trough, are preponderantly basaltic and typical of the rocks of oceanic ridges. From analysis of more than 100

BLACK RIBBONS of fresh basalt in the Erta'Ale mountains mark zones where molten rock has poured out of fissures in the floor of the Afar triangle. The basalt is chemically similar to the magmas that have welled up from the rifts in the earth's mid-oceanic ridges.

LOW VOLCANIC CONE that marks the northern end of the Erta'-Ale mountain range is further evidence that much of the area was submerged in the recent geologic past. The shards of glass that make up the cone are formed during an underwater eruption as lumps of hot lava turn the water about them into superheated steam. The steam explodes the lumps into hundreds of fragments.

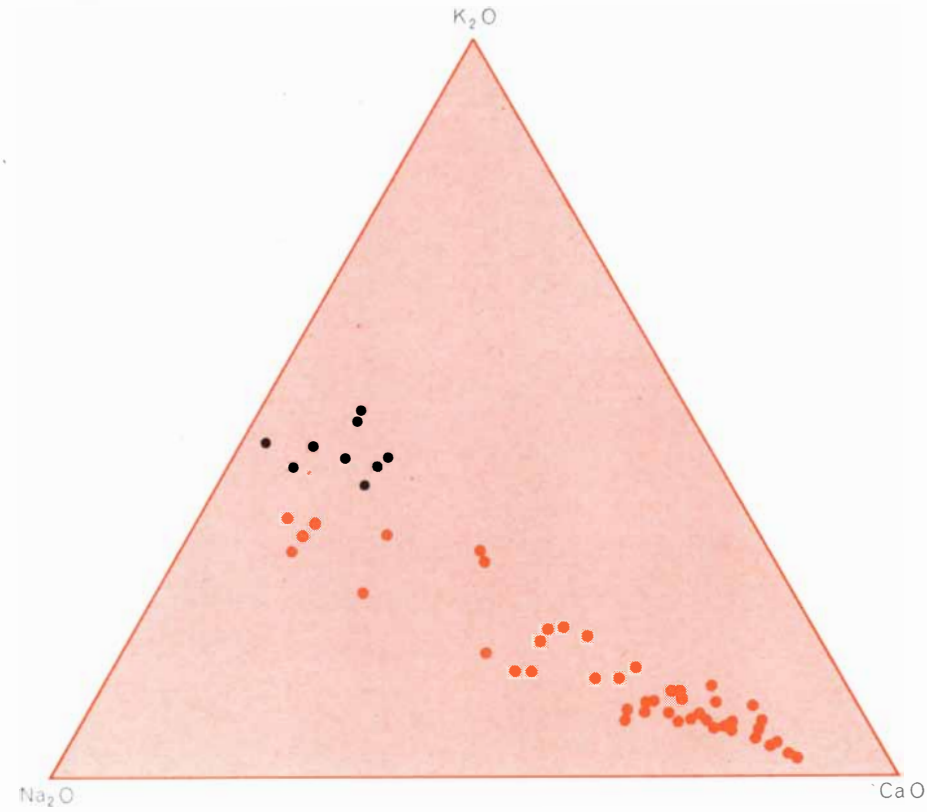
specimens from this range we estimate that its composition is more than 90 percent basalts, the rest consisting of varieties of volcanic rock: dark trachytes (8 percent) and rhyolites (.5 percent). Chemically these rocks all show an evolutionary relationship, forming a practically continuous series from olivine basalts to the dark trachytes and rhyolites. The relationship has been confirmed by analysis of their strontium; the ratio of the rare isotope strontium 87 to the common one, strontium 88, in all these rocks is uniform and about the same as that in oceanic basalts. Another index also shows clearly that they were derived from oceanic magmas. The differentiation into the rock varieties in the series apparently came about mainly through gravity separation of components as the original magmas evolved in a series of steps, marked by a distinct iron enrichment in the middle stages. The end products are glassy trachytes and rhyolites, giving evidence that they were produced in a highly fluid state.

We found that a parallel volcanic range in the triangle, the Alayta range, has the same character, structurally and petrographically, as Erta'Ale. To sum up, the petrology of both ranges seems to indicate that they were born as upwellings through fissures in the crust, that their parent material was basaltic magma such as is characteristic of ocean floors, and hence that there is no sialic crust immediately under these ranges. All of this suggests that in the northern part of the Afar triangle continental blocks have already been severed from each other. Evidently this area is a part of the Red Sea ocean-forming system that is separating Arabia from the African continent. Similarly, our survey of the region indicates that the Danakil Alps and two smaller horsts we have detected south of latitude 13 degrees (one close to the Ethiopian escarpment and the other in the middle of the Afar triangle) are continental structures in the process of being split off and separated from the Ethiopian plateau.

Many signs that the northern region of the Afar triangle was covered with seawater in quite recent times turned up in our on-the-ground explorations. On a terrace at the foot of the Ethiopian scarp Faure found a stone axe that was encrusted with seashells, indicating that the sea had covered it after it was abandoned. This axe is from the Acheulean period, not more than 200,000 years ago. We found coral reefs of the Quaternary period (geologically the most recent) in the lava fields of the region. Scattered about on the floor of the triangle are ash rings, resembling the one at Diamond Head in Hawaii, such as are known to be formed under water; these consist entirely of the shards of volcanic glass called hyaloclastites, which are typical of underwater basaltic eruptions. We even discovered a flat-topped cone, now standing on the dry beds of the triangle, that bears every resemblance to the famous guyots, or flat-topped seamounts, of ocean floors.

The ash rings were particularly interesting to me because I had previously witnessed the formation of two such structures from submarine eruptions, one in the Azores in 1957 and another south of Iceland in 1965. I found that the ash ring is formed as the result of secondary steam explosions from a volcanic eruption under water. The primary eruption tears the molten magma into pieces and hurls them into the water. Because of their large surface-to-volume ratio (a ratio much larger than it would be for a quiet lava flow) the lumps of hot lava transfer enough heat to the water immediately around them to turn it into superheated steam. This steam generates secondary explosions that shatter the lumps into tiny pieces of glass (hyaloclastites) and throw them high into the air—from half a kilometer to more than a kilometer above sea level (which is a great deal higher than material is tossed by the usual volcanic explosions of the Hawaiian or Strombolian type on land). The tiny fragments falling back around the volcano's vent form a large rim that is frequently horizontal and highly regular, because the fragments are deposited under water. We found that the Afar ash rings looked very fresh, and the most eroded one (presumably the oldest) was overlain with corals and shells of marine animals of the Pleistocene period, all of which adds to the evidence that the region was covered by the sea not long ago.

Our examination of the apparent guyot we found in the depression seems to cast a new light on the origin of seamounts. Hundreds of these flat-topped submarine mountains, with their tops in



DIFFERENTIATION DIAGRAM shows that the chemical composition of volcanic rock from Mount Erta'Ale (*colored dots*), midway between the Ethiopian escarpment and the Danakil Alps, is different from the composition of the rock from the Pierre Pruvost volcano (*black dots*), which lies close to the escarpment. The Pruvost lavas result either from a "contamination" of deep magmas by the sialic material in the earth's crust or from a melting of the crust itself. The lack of such contamination in the Erta'Ale lavas suggests that, as the Alps and the escarpment have drifted apart, they have split open the earth's crust along a vast rift zone, with the result that no crust remains below the Erta'Ale range.

some cases as much as 1,000 fathoms or more below the sea surface, have been discovered in the world ocean. To explain their flat tops, it is generally supposed that the peaks formerly stood above the surface of the water and were eroded flat by the waves, and that the tops are now submerged because the sea bottom sank or the ocean level rose. We found that the truncated cone resembling a seamount in the Afar triangle was built in a way that would account for its flat top simply by the method of its construction. This pile, called Mount Asmara, is about 1,200 feet high and tapers from a width of a mile and a quarter at the base to two-thirds of a mile at the top. It was apparently formed by a buildup of layer on layer of beautiful golden hyaloclastites, which consist of palagonitized olivine basalt and are clearly of submarine origin. Such a process, produced by successive eruptions from a volcanic vent, can account for Mount Asmara's flat top. I am wondering if many of the seamounts in the oceans may not have been built in the same way under water. Perhaps their tops never have in fact been above water but may someday rise out of the ocean as the building process goes on. At all events, it appears that Mount Asmara in the not distant past was totally submerged, with its base more than 1,600 feet below sea level.

If we suppose that the Afar triangle is a part of the Red Sea, the coast of Arabia matches very well the contour of the "coastline" of the part of the African continent from which it is assumed to be separating; the match is at least as good as that between Africa and South America on opposite sides of the Atlantic.

We still have to explain why the axis of the Afar rift is displaced somewhat westward from that of the central ridge in the Red Sea and why the two troughs are now separated. That question will have to await our further explorations in the southern half of the depression. It seems possible that the Gulf of Aden ridge and rift system, thrusting into the depression at right angles to the Red Sea axis, may be exerting a powerful influence that could account for the displacement.

Meanwhile the information obtained so far about the Afar triangle raises an interesting economic question. Because of the absence of sialic crust below the axes of active volcanic ranges of basaltic composition and the probable closeness of the hot mantle to the surface in the northern part of the triangle, a great deal of heat flows into the underground rock strata there. These strata are highly porous and absorb a vast amount of fresh water that drains into the floor of the triangle from the surrounding highlands in the rainy season. Consequently it seems likely that subterranean fields of superheated water and steam underlie parts of this desert region where impermeable strata prevent them from escaping into the atmosphere. If they could be tapped, they might supply millions of kilowatt-hours of cheap electricity per year. This reservoir could supply power to the nearby seaports (Assab, Massawa, Djibouti) to support large new industries (aluminum and other metallurgies, petrochemistry, fertilizers, canneries) in which electricity is the main cost factor. With ores and other raw materials shipped to these ports at low cost, the price of finished products would also be low, and the area could be expected to have a tremendous economic growth. This almost desert region might be an industrial megalopolis in the future—a future far less remote than the geologic one, when the Gulf of Aden and the Red Sea will have expanded into new oceans.

SALT PLAIN lies near the northern apex of the Afar triangle. Each year, when rainfall in the highlands to the east and west drains into this low area, the plain is covered by pools of brine. These are too shallow, however, to hinder the passage of salt caravans.

We want to be useful ...and even interesting

Kodak

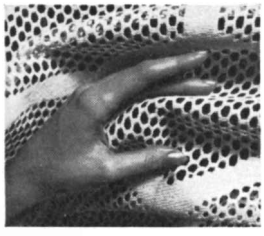
Wonder, fascination, accountants, economics

Our interest in oceanography has paid off in new friends—interesting, learned, even beautiful people, some of whom are encountered in such pleasant underwater environments as abound around St. Croix. How useful we can be to ocean science and technology remains to be seen.

It doesn't seem to take much film to accomplish what genuine working oceanographers—beautiful or not—have accomplished to date. Making lots and lots of dependable film is where we shine. A fairly direct proportionality connects the physical volume of film we make with the income that supports scholarly mathematical discourse *(see below)* as well as research toward film particularly suited for oceanography. As a matter of fact, little evidence has yet reached us that films we make for other purposes are not already well suited for oceanographic work.

Anybody who can see that we are missing a point here would do us a large favor indeed by dropping a note to S. Phillips, Special Applications, Eastman Kodak Company, Rochester, N.Y. 14650. As for illuminants that would permit aerial-photography-like surveys from a reasonable distance above the ocean bottom, we have thought of that.

Beauty and/or safety



You probably don't know the term "hand" unless you are in textiles, but you know "hand" when you feel it. Feel it, not see it. "Hand" means tactile beauty, as distinguished from visual beauty, beauty of sound, beauty of scent, etc. If textile men ever forgot what it means, life would grow drearier. If everybody agreed to forget about it, life might also be slightly safer.

For many years it has been known how to make fabrics nonflammable if you don't care how they feel, how easily they'll tear, how they discolor, how likely they are to keep their nonflammability through repeated cleanings. It has been found, however, that you do care.

This concerns us, since our spinnerettes happen to extrude a good deal of fiber for your favor.

In the case of our VEREL Modacrylic Fiber for draperies and elegant, sound-absorbing wall fabrics, the polymer itself is flame-resistant. (By official definition, at least 15% of the long-chain weight—but no more than 65%—is something other than $\left(\text{-CH}_2\text{-CH(CN)-}\right)$. That "something other" gives us our chance to retard flame.)

Now, through the intricate channels of trade that must be negotiated between fibermaker and ultimate shopper for clothes and home furnishings, word is filtering of our new ESTRON "FR" Flame Retardant Acetate. The news is that we put certain fire-quenching agents into the acetate solution before extrusion so that nothing is sacrificed of "hand," nothing of "esthetics." Since the consumer buys the fiber as cloth, fibers of higher flammability than ours might conceivably overwhelm ours in the finished product. Flame tests, once agreed upon, must tell.

"Esthetics" isn't the only problem. Cost has to be considered. Some mail-order houses have found that flame-retardant sleepwear is hard to move at premium prices.

Don't harass salespeople yet about ESTRON "FR" Acetate. It will get to you by and by.

Room to work

When a moderately well-informed person hears of lens aberrations, he thinks of defects in manufacture. Unwittingly imbued with Greek notions of perfection, he reasons that perfect spherical surfaces on perfectly homogeneous media should form perfect images.

There really is no reason why they should, and they don't. The bigger the aperture and angular field, the more they fail.

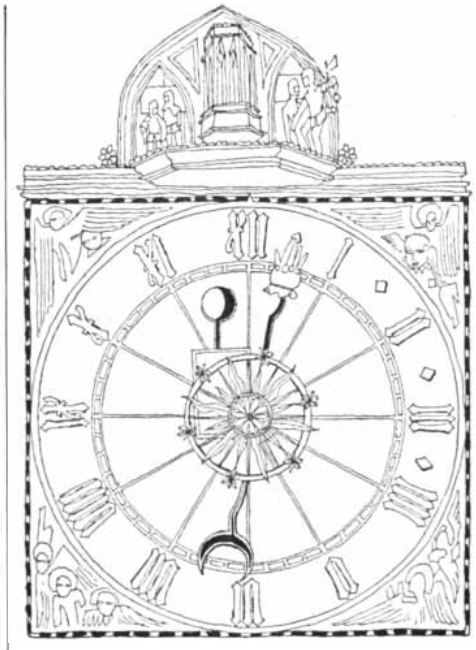
Though image perfection may remain forever unattainable even with perfect spheres and media, ever nearer approaches are made. One strategy employs numerous successive spherical surfaces separating numerous media of different refractive index. Each is calculated to undo some of the others' image errors.

In another strategy, sphericity is abandoned. Still no perfection.

A third way of bending the rays is now receiving consideration: make the index vary on a gradient. Planetary atmospheres bend light that way. How to produce such media in a factory is one question. How to fight aberrations with them is another question, a mathematical question. Mathematical weapons for the fight have been fabricated by the mathematician Erich W. Marchand of the Kodak Research Laboratories. His paper "Ray Tracing in Gradient-Index Media" in the January issue of the *Journal of the Optical Society of America* broadcasts them for use. In acclaiming his achievement, let us point out that the uncrowded fields of scholarly endeavor offer satisfactions comparable in their way with those of an uncrowded physical environment.

EASTMAN KODAK COMPANY An equal-opportunity employer

SCIENCE AND



The Roots of Violence

Violence in the U.S. has its roots in the nation's history and in failure to adequately attend to a number of social ills, according to the final report of the National Commission on the Causes and Prevention of Violence. "The time is upon us," the commission said, "for a reordering of national priorities and for a greater investment of resources in the fulfillment of two basic purposes of our Constitution—to establish justice and to ensure domestic tranquility." To that end the commission recommended "as a first step" that after the Vietnam war the Federal Government reverse the present relation between spending on defense and spending on the general welfare, so that (in terms of 1968 prices) the latter would receive about $81 billion per year and military outlays would be cut back to about $60 billion.

The commission, of which Milton S. Eisenhower was chairman, was established by President Johnson in 1968, shortly after the assassination of Robert F. Kennedy and two months after the assassination of Martin Luther King. It issued a series of reports over a period of several months. With its final report, issued at the end of 1969, the commission disbanded.

In its historical analysis the commission found that "the seeds of our contemporary discontent were to a large extent deeply embedded in those same ostensibly benevolent forces which had contributed to our uniqueness." One was that "the original dominant immigrant group, the so-called Anglo-Saxons, effectively preempted the crucial levers of economic and political power," so that later groups of immigrants have had to compete, often violently, for a share of power. A second historical factor was "America's prolonged encounter with the frontier," which necessarily gave rise to a tradition of vigilante justice. "Third," the commission said, "the revolutionary doctrine that our Declaration of Independence proudly proclaims is mistakenly cited as a model for legitimate violence by contemporary groups such as militant Negroes and radical students who confront a system of both public and private government that they regard as contemptuous of their consent." The industrial revolution, and in particular the violent struggle of organized labor for recognition and the explosive growth of cities, was also cited by the commission, as was the national prosperity, which generates frustration and often violence in those who perceive that they are not sharing in it.

Among the social conditions leading to violence the commission noted the pattern of life in ghetto slums, the lack of adequate education and job opportunities for the children of poor families and the inadequate consideration the society gives to the concerns of the young. "The way in which we can make the greatest progress toward reducing violence in America," the commission said, "is by taking the actions necessary to improve the conditions of family and community life for all who live in our cities, and especially for the poor who are concentrated in the ghetto slums.... To be a young, poor male; to be undereducated and without means of escape from an oppressive urban environment; to want what the society claims is available (but mostly to others); to see around oneself illegitimate and often violent methods being used to achieve material gain; and to observe others using these means with impunity—all this is to be burdened with an enormous set of influences that pull many toward crime and delinquency."

Introspection

The winter meeting of the American Association for the Advancement of Science mirrored the mood and the concerns of U.S. scientists. The mood was

one of self-examination. The members were concerned to a far greater degree than in previous years with the nature and failings of the scientific enterprise, the consequences of technological change and the proper uses of science in solving human problems. The topics of the principal symposiums give the tone of the meeting as a whole. They included power generation and the environment, military support of academic research, arms control and disarmament, the assessment of technology, hunger and malnutrition, the future of the space program, chemical and biological warfare, environmental design, optimum population levels and the effect of biological and medical intervention on "the identity and dignity of man." In a special program entitled "The Sorry State of Science" a group of graduate students criticized the entire scientific establishment for doing the work of industry and the military at the expense of the general welfare. At the end of the meeting the representative Council of the AAAS approved a report resolving that in the next decade the "main thrust" of the organization should be toward increasing the effectiveness of its work "on the chief contemporary problems concerning the mutual relations of science, technology and social change, including the uses of science and technology in the promotion of human welfare."

The growing sense of urgency with regard to issues involving science and the military was reflected by action on the use of herbicides in Vietnam. Last year the association suggested a study of the "risks and benefits" of defoliant applications but did not initiate one. This year the board of directors appointed Matthew S. Meselson of Harvard University to design a study of the ecological effects of defoliation. Then the council went further: by a 114-to-51 vote it urged an immediate end to the use of two defoliants, 2,4,5-T and 2,4-D, that have been reported to cause birth deformities in experimental animals. In the symposium on chemical and biological warfare there was general approval of President Nixon's decision to destroy U.S. stocks of bacteriological weapons. Some participants defended the continued use of tear gas in Vietnam; Meselson and others opposed it. There was dissatisfaction with the Administration's

position that toxins produced by bacteria are still permissible weapons even though their purpose is to produce disease and they can therefore be considered biological weapons.

The issue of military support of academic research brought sharp division. Noam Chomsky of the Massachusetts Institute of Technology called it a "symptom of the ongoing, and perhaps irreversible, militarization of society." Charles W. Schilling of George Washington University argued, however, that "to ensure freedom, national defense requires the advanced technology often pioneered by universities," and said that the "mutually beneficial" relation between the military and the universities has been "one of our greatest advances in science, without compromise to professional integrity." William M. Capron of Harvard said some military support had been worthwhile but that science could become "co-opted and corrupted by this kind of support."

The association took steps to broaden its membership by including more people concerned with social change and established a new 12-man panel of students as advisers to the board of directors. It also broke new ground by electing a woman as its president. Mina S. Rees of the City University of New York will be the head of the association in 1971.

Exothermic Laser

Laser beams have been produced by devices whose active material can be in almost any physical state: crystalline, liquid, gaseous or glassy. Normally an external source of energy is needed to "pump" an atomic or molecular species in the active material from the ground state to an excited state. When the excited species is stimulated to return to the ground state, energy is emitted in the form of radiation, hence the acronym "laser": light amplification by stimulated emission of radiation. The distinctive characteristic of laser radiation is that the waves are coherent, or all in step.

For several years there have been chemical lasers in which chemical reactions provide the pumping energy, but in every case the reactants themselves had to be activated by an external source of power before entering the reaction chamber. An obvious goal was to find exothermic chemical reactions that would release energy continuously in the precise form needed for pumping. This has now been achieved at Cornell University by Terrill A. Cool, Theodore J. Falk and Ronald R. Stephens, who report their work in a recent issue of *Applied Physics Letters.*

They have demonstrated a continuously operating carbon dioxide laser in which the carbon dioxide is pumped by vibrational energy released from chemical reactions that produce hydrogen fluoride in an excited state. A higher output results if deuterium (heavy hydrogen) is used in place of ordinary hydrogen. The emitted radiation has a wavelength of 10.6 microns, which is in the infrared region of the spectrum. A maximum output of eight watts has been achieved, with about 4 percent of the chemical energy being converted to radiation. Cool and his associates believe an efficiency of 15 percent may be attainable, which would make their chemical laser the most efficient known.

Side Effect

Para-chlorophenylalaline, a drug used in clinical research to treat a variety of conditions, including intestinal tumors and schizophrenia, may also be a powerful aphrodisiac, according to researchers at the National Heart Institute. Writing in *Science,* Alessandro Tagliamonte, Paola Tagliamonte, Gian L. Gessa and Bernard B. Brodie report that the drug (usually abbreviated PCPA) "induces long-lasting sexual excitation in male rats." Moreover, they note that when another drug, pargyline, is administered along with the PCPA, the sexually stimulating effect of the PCPA is enhanced. There is no evidence that pargyline used alone or with drugs other than PCPA acts as an aphrodisiac.

The discovery of the possible aphrodisiac effect of PCPA came in the course of a study of the role of serotonin (5-hydroxytryptamine) in controlling the estrous cycle and sexual behavior of female rats. It had been known for some years that PCPA is effective in reducing the level of serotonin produced by the pineal gland, a small organ located near the center of the mammalian brain. A "casual observation" that the administration of PCPA and pargyline to male rats produced sexual excitement prompted the Heart Institute group to study the influence of the selective inhibition of serotonin synthesis on sexual behavior. The study included both normal male rats and male rats whose pineal gland had been surgically removed. After treatment with either PCPA alone or with PCPA plus pargyline the rats were put in cages in groups of six and their sexual behavior was observed.

Of the 60 normal animals treated with PCPA alone 16 exhibited mounting behavior, coital movements and other signs of sexual excitement during the 12-hour observation period. The normal rats that were treated with PCPA plus pargyline showed far more sexual stimulation. A much larger percentage of these animals (58 out of 80) displayed compulsive sexual activity; moreover, the investigators point out, "the frequency of mounting was much greater. The sexual excitation lasted for several hours and usually reached a climax with all of the animals in one cage attempting to mount each other at the same time."

To decide whether the sexual excitation was related to a deficiency of serotonin in the rats' brains, a precursor of serotonin, the amino acid L-5-hydroxytryptophan, was injected into 10 of the animals treated with PCPA plus pargyline while they were exhibiting sexual excitation. Within 10 minutes all signs of sexual excitation disappeared.

Similar experiments were carried out with the pinealectomized animals; it was found that seven out of 12 pinealectomized rats treated with PCPA displayed sexual excitement at about the same frequency as the normal animals treated with PCPA and pargyline. This finding ruled out the possibility that the action of PCPA is mediated by the inhibition of pineal indole hormones derived from brain serotonin. The investigators conclude that the changes in sexual behavior produced by PCPA alone or by PCPA with pargyline result from the depletion of serotonin in the brain and from the secondary imbalance between serotonin and other substances in the brain. They add that "the sexual stimulation produced by PCPA alone and in combination with pargyline is not restricted to male rats. Rabbits injected with PCPA and pargyline also displayed compulsive sexual behavior that lasted up to three days."

Starquake

Not quite a year ago the Vela pulsar, which had been emitting sharp radio pulses almost precisely 11 times per second but which had been observed to be slowing down perceptibly, suddenly speeded up. A similar speedup was subsequently observed in the emission rate of the pulsar in the Crab nebula. Although seemingly tiny, these changes in pulse rate implied enormous changes in the physics of the emitters. What could have happened?

One hypothesis is that the pulsars experienced a "starquake." Pulsars are thought to be the remnants of supernovas: objects with about the mass of

the sun that as a result of gravitational collapse are perhaps only 10 miles in diameter. They are believed to consist of a metallic crust, which increases rapidly in density with depth, and a fluid core so dense that within it individual atoms can no longer exist. The crust may have a melting point of a billion degrees Kelvin. These ultradense objects are also spinning rapidly: from about 30 times per second, in the case of the Crab pulsar, to once every three or four seconds. The pulsed radio emissions are thought to coincide with the rotation rate.

In *Nature* Gordon Baym, Christopher Pethick and David Pines of the University of Illinois and Malvin Ruderman of Columbia University describe how a starquake might occur in a pulsar and what some of its implications would be. They visualize that the solid crust surrounds "three degenerate interacting quantum liquids": neutrons (the main constituent) and equal numbers of protons and electrons (amounting to a few percent of the number of neutrons). In ordinary matter only electrons are degenerate, meaning that no two can occupy the same quantum state. In the pulsar core neutrons and protons are also degenerate. They are said to be quantum liquids since, among other things, they behave as frictionless fluids.

Because of its high rotational speed the neutron star, or pulsar, is flattened at the poles. As it slows down slightly, stresses build up and rupture the crust. As a result the equatorial diameter of the pulsar shrinks slightly: by about one centimeter in the case of the Vela pulsar, and about 10 microns in the case of the faster-rotating Crab pulsar. To conserve angular momentum the velocity of the crust increases. This all happens in from .01 to .1 second. The speedup of the crust is then communicated to the degenerate protons and electrons in the core by the presence of a strong magnetic field. This may take hundreds of seconds. Finally, after a year or two the neutron superfluid "gets the message" and also speeds up. If the core contained ordinary neutrons it too would speed up in a matter of seconds.

The investigators conclude: "The sudden shift in the frequency of the Vela pulsar provides a unique probe of the structure of a neutron star, similar to the use of earthquakes in determining the nature of the earth's interior."

Self-assembly

The cell of a bacterium is a busy place in which at least 100 different enzymes, 10 percent of the total number

needed by the cell, are being completed at any one time. The large majority of these enzymes consist of from two to 12 separate subunits, each a peptide chain formed by linking together anywhere from 100 to several hundred amino acids. Synthesis of a single peptide chain takes about two minutes. Each chain is folded into a precise three-dimensional structure, and two or more of these structures must join together in a unique way to form an active enzyme. The question arises: With so many different subunits of several hundred enzymes floating around inside the cell, what prevents mismatched subunits from linking up and forming hybrid enzymes?

One can imagine three general possibilities. The subunits may be compartmentalized as they are made, so that they do not mix. The subunits may be segregated by time of manufacture, so that mixing does not occur. Or the binding sites may be so specific that mismatching can hardly occur even though subunits of hundreds of different enzymes are synthesized simultaneously and released into a common pool.

The last of these possibilities is what actually happens, according to experiments reported in *Proceedings of the National Academy of Sciences* by Robert A. Cook and D. E. Koshland, Jr., of the University of California at Berkeley. The two investigators dissociated a variety of pure enzymes into their component subunits and mixed the subunits in various combinations to see if hybrids would form when the subunits recombined. In some cases the enzyme subunits subjected to recombination were from the same source (for example rabbit cells); in other cases the subunits were from totally different sources (such as rabbit cells and yeast cells). In each experiment two different enzymes were mixed together and subjected to conditions known to dissociate the enzymes into their separate subunits. Conditions were then altered to favor reassembly of the subunits into active enzymes. Single enzymes were subjected to the same conditions to serve as controls.

When the activity of the enzyme mixtures was evaluated, it was found that the mixed subunits had sorted themselves out and joined with their appropriate partners to exhibit 80 percent of the activity of the controls in most cases and more than 50 percent of the activity in all cases. In a second series of experiments the conditions were made more extreme, so that individual peptide chains were unfolded after being separated from their partners. Even under these circumstances the enzymes could usually be reconstituted with activities exceeding 75 percent. Cook and Koshland conclude from their experiments that "correct association arises from evolutionary selection of highly specific intersubunit-binding interactions."

Red Plastic Snow

Accounting for the reddish color of Mars has provided planetary astronomers with a fascinating puzzle of no great moment. Presumably it will be solved in a few years when the first vehicles to land on Mars send back their findings. Meanwhile a new suggestion is advanced in a recent issue of *Science* by William T. Plummer and Robert K. Carson of the University of Massachusetts. They have studied the spectral reflectivity of polymers of carbon suboxide (C_3O_2) and find that one of them closely matches the reflectivity of Mars.

Perhaps the most popular hypothesis to explain the dull orange color of the planet is that the surface is lightly covered with one of the reddish iron-bearing minerals such as limonite. There are, however, important discrepancies between the reflectance of iron compounds and Mars. To get around them rather subtle assumptions have to be invoked.

When carbon suboxide is synthesized in the laboratory, it is a foul-smelling, clear liquid that boils at seven degrees Celsius. It is readily polymerized by ultraviolet radiation or by acidic catalysts. Depending on their molecular weight, the polymers range in color from pale yellow to orange to reddish-brown to violet and nearly black. The best match with the color of Mars was produced by a sample that was yellowish-orange.

Could carbon suboxide be produced and subsequently polymerized in the atmosphere of Mars, which is almost pure carbon dioxide? Plummer and Carson suggest that the only extra ingredient needed would be a trace of carbon monoxide, which might be released from time to time by volcanoes. In the presence of the ultraviolet radiation provided by sunlight, carbon dioxide and carbon monoxide should react to form carbon suboxide along with oxygen. The monomers of carbon suboxide would then be polymerized by the ultraviolet radiation and produce a colorful snowfall of plastic flakes. The authors also suggest that if enough polymer were produced at one time "it could account for the occasional presence of the strange yellow clouds of Mars which... are most commonly found in warm areas of the planet." They also suggest "that the principal difference between martian light and dark zones may be the degree of polymerization.... If the time scale for formation and polymerization of new carbon suboxide is sufficiently short, then the further polymerization of a freshly produced deposit might even account for some of the martian color changes, phenomena which appear quite difficult to explain if the surface is colored by the more stable iron oxides."

Adam and Ape

How long ago did the most progressive line of primate evolution divide into the lineages that led on the one hand to man and on the other to the anthropoid apes? The answer to this question is usually sought through interpretation of the fossil record, but two workers at the University of California at Berkeley have suggested another way. Their method is based on the extent of mutational change in such proteins as blood-serum albumin and hemoglobin. It suggests that the lineages of man and the apes of Africa may have separated much more recently than has been supposed.

Allan C. Wilson and Vincent M. Sarich report in *Proceedings of the National Academy of Sciences* that the rate of mutational change among the hemoglobin lineages of mammals evidently results in one replacement in the sequence of amino acids every 3.5 million years. The "mutational distance" separating the lineage of primates from the lineage of horses, for example, suggests that the two lines separated some 90 million years ago, early in Upper Cretaceous times. The estimate is within 15 percent of agreement with the estimate based on the fossil record.

Wilson and Sarich find that man is as closely related to the gorilla and chimpanzee in terms of the amino acid sequences of their hemoglobins as the donkey is to the horse. Moreover, the serum albumins of man and of the two African apes are some six times more different from the albumins of the macaque, a representative Old World monkey, than they are from one another. The lineage of Old World monkeys separated from the lineage of apes and men some 30 million to 45 million years ago; the separation of man and African ape must therefore have occurred only a sixth as long ago. Dating the separation on this basis places the event from five million to a little more than seven million years ago, in Upper Pliocene times. This is between seven million and 14 million years closer to the present than is suggested by the fossil record.

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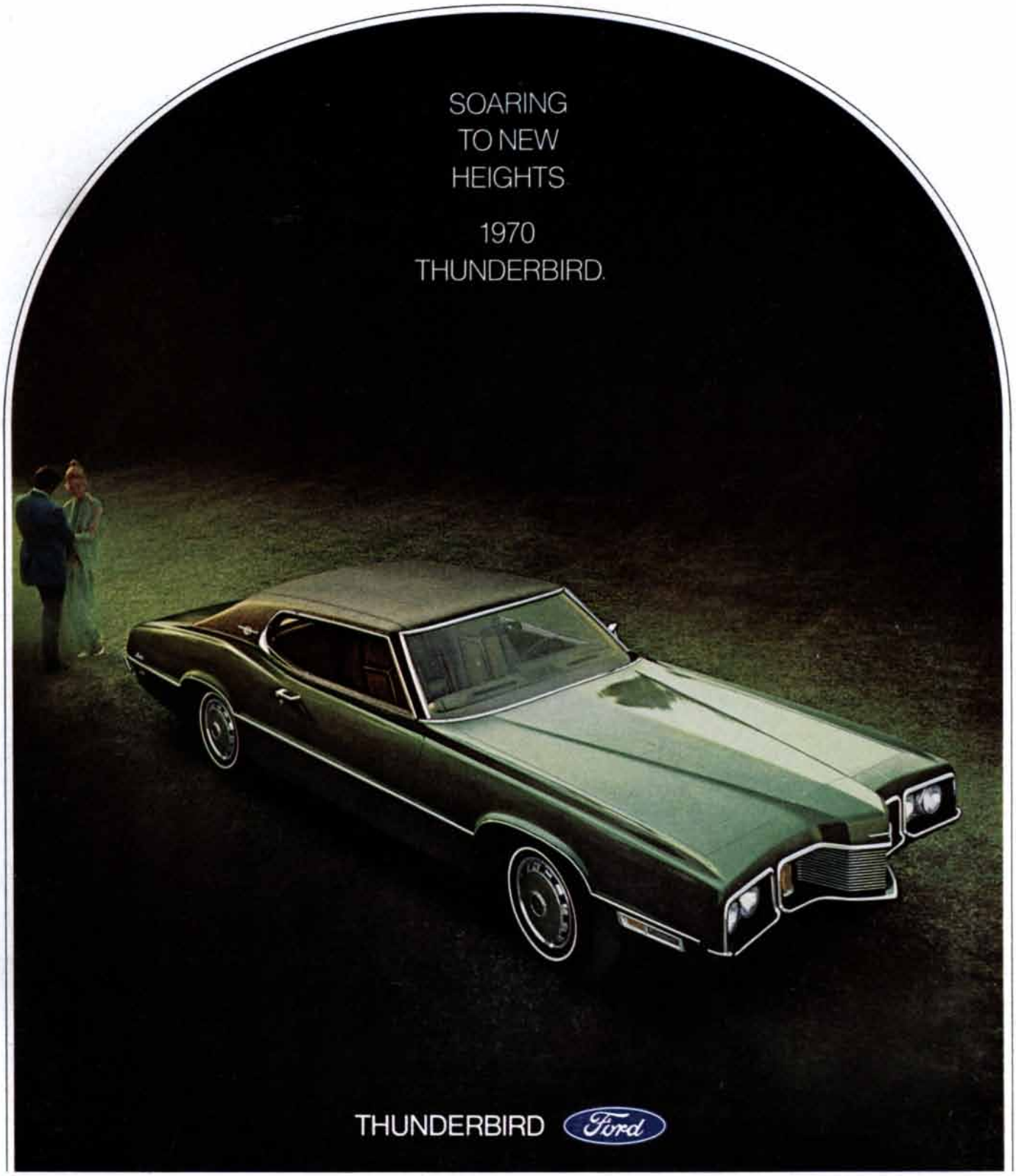

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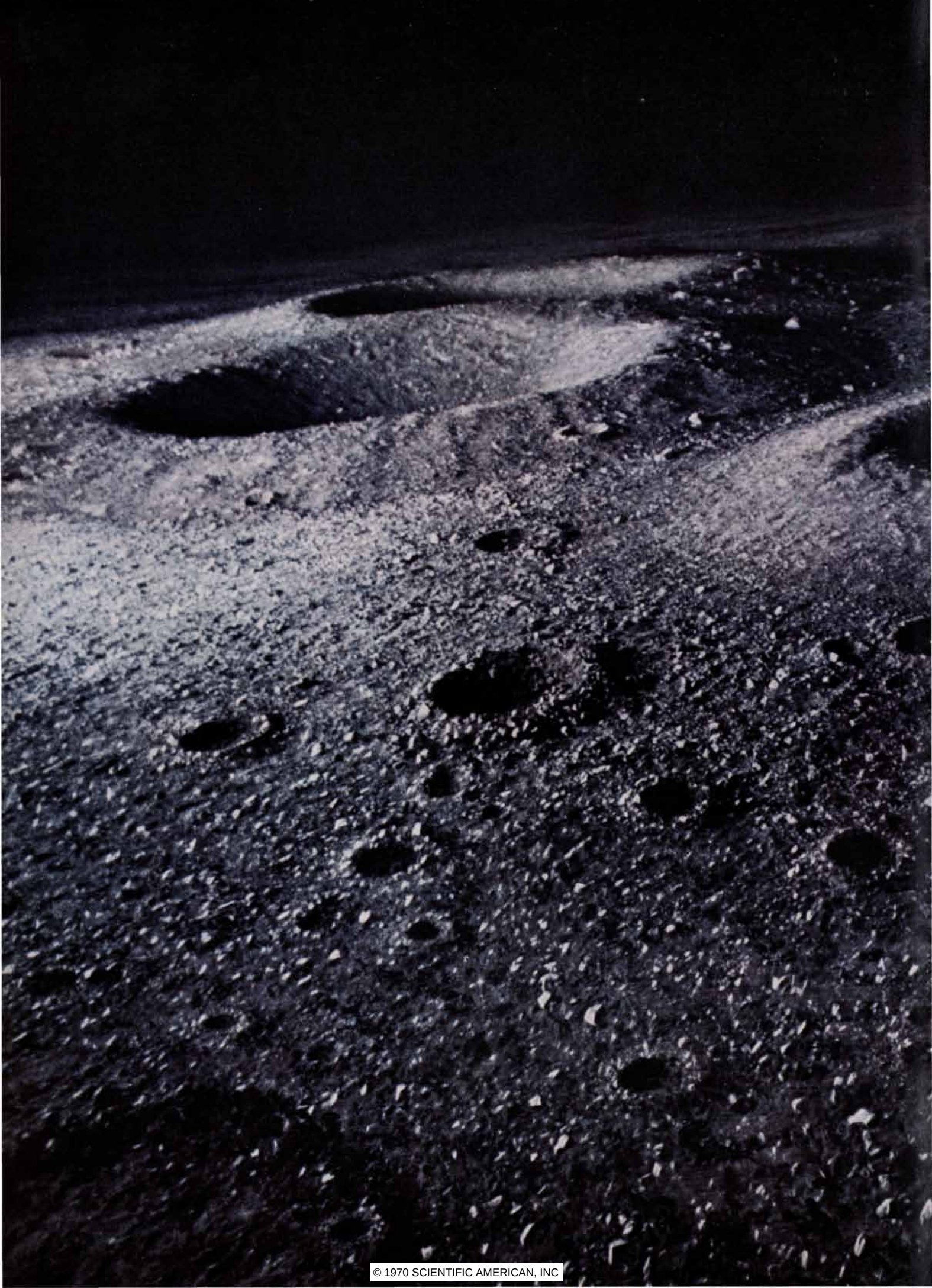

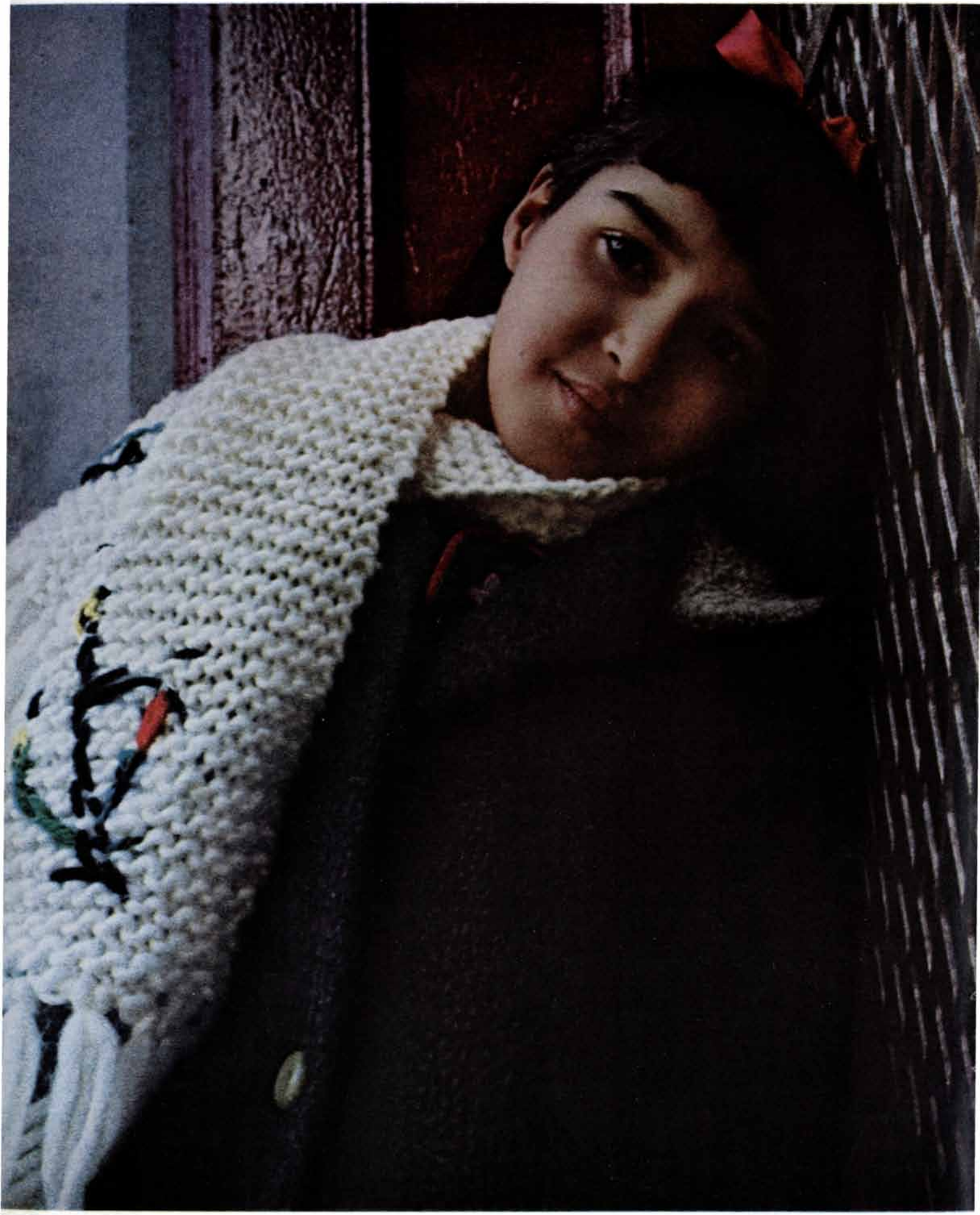

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UNION CARBIDE

THE DISCOVERY COMPANY

NUÑOA, at an altitude of 13,000 feet in the Andes Mountains of Peru, is the site of an experimental station operated by Pennsylvania State University for the study of human adaptation to high altitude. The native Indians herd llamas and alpacas, as shown here.

BARCROFT LABORATORY of the University of California is at an altitude of 12,500 feet in the White Mountains, a range just east of the Sierra Nevada in California. The environment appears uninhabitable but is the home of a number of small animal species.

THE PHYSIOLOGY OF HIGH ALTITUDE

To meet the stress of life at high altitude, notably lack of oxygen, a number of changes in body processes are required. What are these adaptations, and are they inborn or the result of acclimatization?

by Raymond J. Hock

At altitudes above 6,000 feet the human organism leaves its accustomed environment and begins to feel the stresses imposed by an insufficiency of oxygen. Yet 25 million people manage to live and work in the high Andes of South America and the Himalayan ranges of Asia. More than 10 million of them live at altitudes above 12,000 feet, and there are mountain dwellers in Peru who daily go to work in a mine at an elevation of 19,000 feet. How does the human physiology contrive to acclimatize itself to such conditions? Over the past half-century, ever since the British physiologist Joseph Barcroft led an expedition to study the physiology of the mountain natives of Peru in the early 1920's, a small host of fascinated investigators has been exploring this puzzle. We now know many of the details of the body's remarkable ability to accommodate itself to life in an oxygen-poor environment.

The study has an intrinsic lure, akin to the challenge of an Everest for a mountain climber, and in these days of man's travels beyond the earth's atmosphere the subject of oxygen's relation to life has taken on added interest. The problem also has its practical aspects on our own planet. Already more and more people each year have recourse to mountain heights for recreations such as camping and skiing; for example, in 1968 there were five million visitor-days in the Inyo National Forest of California, nearly all at elevations of 7,000 feet or higher. From studies of the physiology of adjustment to oxygen deprivation we can expect some beneficial dividends, not only for the problems of living or vacationing in the high mountains but also for medical problems in diseases involving hypoxia.

The native mountain dwellers of Peru and the Sherpa people of Tibet in the Himalayas have served as very helpful subjects for the investigation of acclimatization to high-altitude life. British expeditions led by L. G. C. E. Pugh have conducted several important studies of the Sherpas. In the Andes the research has been centered principally in the Institute of Andean Biology, a permanent station founded in 1928 as a division of the University of San Marcos by Carlos Monge with Alberto Hurtado as director of research [see "Life at High Altitudes," by George W. Gray; SCIENTIFIC AMERICAN, December, 1955]. Recently Pennsylvania State University established another station in Peru at Nuñoa under the supervision of Paul T. Baker and Elsworth R. Buskirk. In the U.S. the University of California has a major center for high-altitude research on White Mountain, with Nello Pace as director. I was associated with the White Mountain Research Station for several years as resident physiologist, working primarily with experimental animals. There are four laboratories in the complex: the Barcroft Laboratory at 12,500 feet and others at 14,250 feet, 10,150 and 4,000 feet. Investigators from the U.S. Army Laboratory of the Fitzsimons Hospital have also been active in human high-altitude research in the Rockies, principally on Pikes Peak.

The High-Altitude Environment

One may wonder why people choose to live in the hostile environment of mountain heights, as the Quechua Indians of Peru, for example, have done for centuries. Life on the mountains is made rigorous not only by hypoxia but also by cold. Even in the equatorial Andes the air temperature decreases by one degree Celsius with each 640 feet of altitude. The winters are long, snowy and windy; summers are short and cool. At the 12,500-foot station on White Mountain in California temperature records over a period of 10 years showed that the mean temperature is below freezing during eight months of the year, and even in some of the summer months the nighttime minimum averages below freezing. Plant life at high altitudes has an extremely short growing season, and few animals can breed successfully at these altitudes. The relatively strong ultraviolet radiation, ionization of the air and other harsh factors no doubt affect life there. There are a few compensating factors. The intense sunlight in the thin atmosphere heats the rocks and provides warm niches for life. The heavy winter snowfall lays down a greater store of moisture than may be available in the surrounding lowlands. For a few months the highlands offer grazing for herdsmen's flocks (which are brought down to lower altitudes when the summer season ends).

Most of the people in the highlands live on herding or agriculture, raising short-season crops such as potatoes or some grains. In the Andes mining also is an important factor in the economy. The highest inhabited settlement in the world is a mining camp at 17,500 feet in Peru. The residents there work in the mine at 19,000 feet that I have already mentioned. The miners daily climb the 1,500 feet from their camp to the mine. Significantly, they rebelled against living in a camp that was built for them at 18,500 feet, complaining that they had no appetite, lost weight and could not sleep. It seems, therefore, that 17,500 feet is the highest altitude at which even acclimatized man can live permanently.

Notwithstanding the rigors of life on the heights, the Peruvian Indians of the "altiplano" have thrived in their environment. It is said that the Incas had

QUECHUA INDIAN breathes from a device that records oxygen intake and carbon dioxide output while he exercises on a bicycle ergometer, which measures the work performed.

two separate armies, one for the lowlands and one for high-mountain duty. Monge and Hurtado believe the high-altitude natives have become a distinctive breed ("Andean man") superbly fitted for life on the heights but probably incapable of surviving long in the lowlands. This is open to doubt. It may be that at sea level the highlanders would succumb to diseases to which they have not been exposed in the mountains, but it has not yet been demonstrated that they would be unable to adjust physiologically to the conditions at low altitudes.

Nevertheless, it is incontestable that high-altitude man, in the Andes and the Himalayas, does indeed possess unusual physiological capabilities. They are evidenced in his responses to hypoxia (defined here as a deficient supply of oxygen in the air). To see his special attributes in perspective, let us first examine the usual reactions of an unacclimatized person to hypoxia.

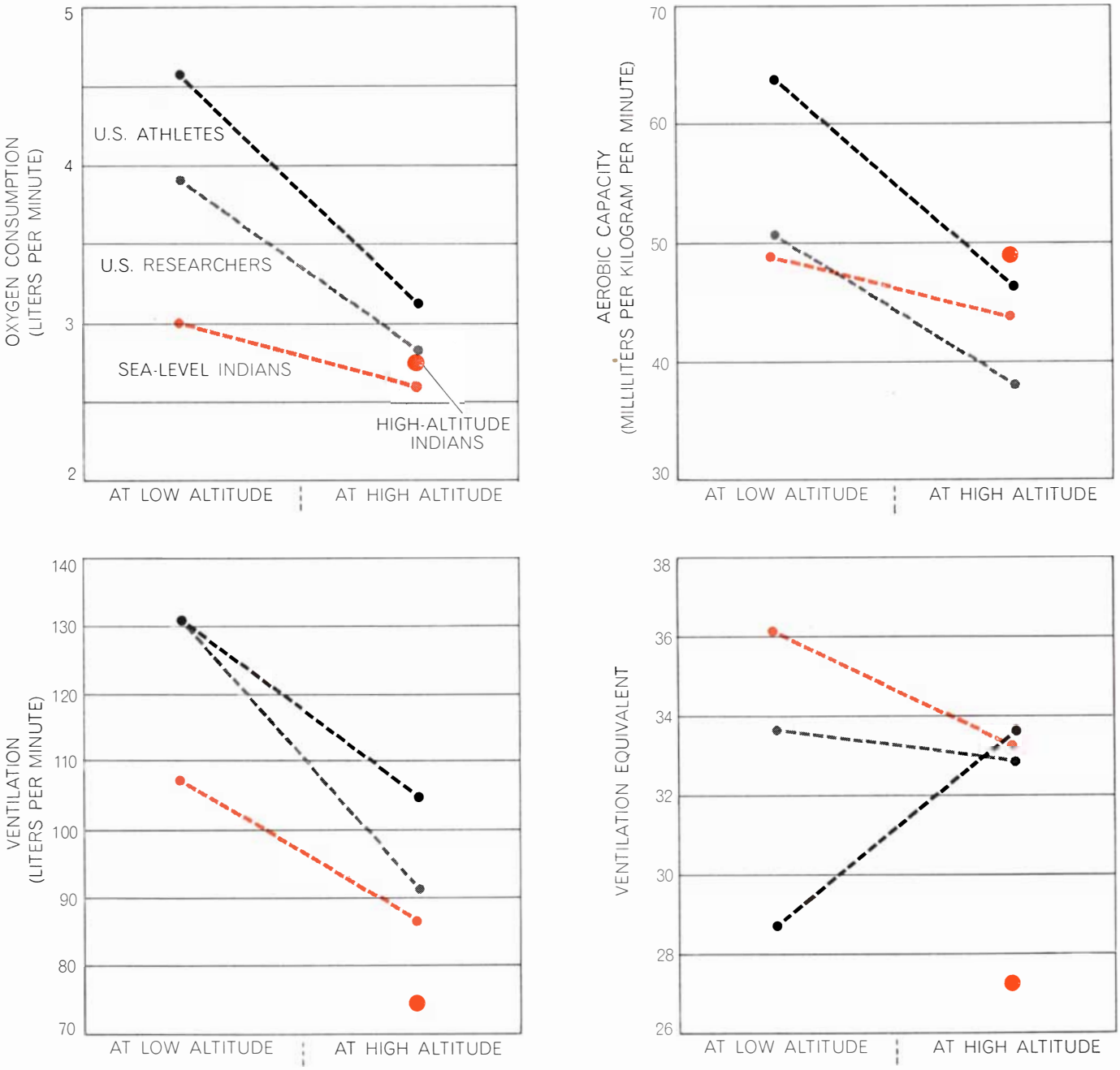
The Physiological Responses

The proportion of oxygen in the air is not reduced at high altitudes (it is constant at 21 percent throughout the atmosphere), but as the barometric pressure of the air as a whole declines with increasing altitude the partial pressure of the oxygen also declines correspondingly. Thus at 12,500 feet the barometric pressure drops to 480 millimeters of mercury (from 760 millimeters at sea level) and the partial pressure of oxygen is only 100 millimeters, as against 159 millimeters at sea level. That is to say, the number of oxygen and other molecules per cubic foot of air is reduced.

This decrease in oxygen tension, reducing the transfer of oxygen from inspired air to the blood in the lungs, calls forth several immediate reactions by the body. The breathing rate increases, in order to bring more air into the lungs. The heart rate and cardiac output increase, in order to enhance the flow of blood through the lung capillaries and the delivery of arterial blood to the body tissues. The body steps up its production of red blood cells and of hemoglobin to improve the blood's oxygen-carrying capacity. The hemoglobin molecule itself has a physicochemical property that enables it to take in and unload oxygen more readily when necessary at high altitudes. In a person who remains at high altitude these acclimatizing changes take place over a period of time. Investigators who measured them during a Himalayan expedition found that the hemoglobin content of the blood continued to in-

crease for two or three months and then leveled off. As the climbers moved up from 13,000 feet to 19,000 feet and beyond, the number of red cells in the blood increased continuously for as long as 38 weeks.

The adjustments I have just recounted are not sufficient to enable a newcomer to high altitude to expend normal physical effort. Because of the interest stimulated by the holding of the 1968 Olympic Games in Mexico City (at an altitude of 7,500 feet) much study has recently been given to the effects of high altitude on the capacity for exercise. It has been found that at 18,000 feet, for instance, a man's capacity for performing exercise without incurring an oxygen debt is only about 50 percent of that at sea level. The tolerance of such a debt, and of the accumulation of lactic acid in the muscles, also is reduced. This accounts for the fact that mountain climbers at extreme altitudes can take only a few tortured steps at a time and must rest for a considerable period before going on. The limits on the capacity for work are set, of course, by the limits of the body's possible physiological adjustments to the high-altitude conditions. These limits affect the rate of ventilation of the lungs, the heart rate, the cardiac output and the blood flow to the exercising muscles. The limit for hyperventilation, for example, is a flow of 120 liters of air per minute through the lungs. This maximum, invoked at an altitude of about 16,400 feet, supplies two liters of oxygen per minute to the blood. At extreme altitudes the heart can speed up its beat during moderate exercise, but under the stress of maximum exercise the limit for both the



OXYGEN CONSUMPTION of Quechua Indians who were natives of Nuñoa, at 13,000 feet in the Andes (*solid color*), was compared with that of sea-level Quechua (*light color*), U.S. athletes (*black*) and U.S. research workers (*gray*) in a study made by Paul T. Baker of Pennsylvania State University. The data were collected during a bicycle exercise test. (The low-altitude subjects had been at Nuñoa at least four weeks before their high-altitude tests.) Aerobic capacity relates oxygen consumption to an individual's weight and therefore measures the success of his oxygen-transport system. Ventilation is the total volume of air breathed by the individual. Ventilation equivalent is ventilation divided by oxygen consumption; the lower the value, the greater the oxygen-extracting efficiency.

heart rate and the cardiac output is lower than at sea level.

Mountain Natives' Physiology

Let us now turn to the mountain natives' extraordinary adjustments for living at high altitudes. To begin with, the Quechua Indians of the Andes and the Sherpas of the Himalayas have developed an exceptionally large chest and lung volume, enabling them to take in a greater volume of air with each breath. Their breathing rate also is higher than that of dwellers at sea level, but they do not need to hyperventilate as much as lowlanders do when the latter go to high altitudes. The mountain natives also have a high concentration of red cells and hemoglobin in their blood, and their hemoglobin is geared to unload oxygen readily to the tissues.

In the high-altitude native the lung capillaries are dilated, so that the pulmonary circulation carries an unusually large percentage of the body's total blood volume. Moreover, the blood pressure in the lungs is higher than in the rest of the circulatory system. The heart is unusually large, apparently because of the heightened pressure in the pulmonary arteries. The heartbeat is slower than in sea-level dwellers. The mountain dwellers' metabolism also appears to be affected by the hypoxic conditions. Their basal metabolic rate is slightly higher than it is in lowlanders, and when this is considered in terms of body mass, it turns out that the rate of oxygen consumption per unit of metabolizable tissue is unusually high. That is, the hypoxic conditions exact a cost in lowered efficiency in the use of oxygen.

The mountain natives show their superior acclimatization most markedly in their capacity for exercise at high altitude. Sherpas show a smaller increase in ventilation, similar oxygen consumption and a greater heart-rate increase when performing the same exercise as low-altitude subjects who have become thoroughly acclimatized to a high altitude. The ability of mountain natives to perform physical labor daily at altitudes where even acclimatized visitors are quickly exhausted by exercise is itself obvious evidence of the mountaineers' extraordinary physiology.

In general, the physiological adjustments of the permanent mountain dwellers are similar in kind to those developed by sojourners in the mountains after a year of residence there. Furthermore, even mountain natives sometimes lose their acclimatization to high altitude and incur *soroche* (chronic mountain sickness), which is characterized by extreme elevation of the relative number and mass of red cells in the blood, pulmonary hypertension, low peripheral blood pressure, enlargement of the right lobe of the heart and ultimately congestive heart failure if the victim remains at high altitude. In general, the differences between mountain natives and sea-level natives are most apparent in the mountaineers' superior capacity for exercise at high altitude and their ability to produce children in that habitat; newcomers to the mountains, even after extended acclimatization, are much less successful in reproduction. The Spanish conquistadors who settled in the high Andes, for example, found themselves afflicted with relative infertility and a high rate of infant mortality.

Does the special physiology of the mountain people arise from genetic adaptation or is it acquired during their lifelong exposure (from the womb onward) to high altitude? One approach to answering that question has been through investigations with experimental animals. The laboratory studies of animals have also explored the physiological aspects of acclimatization much more exhaustively than is possible in man. Much of this animal work has been done at the White Mountain Research Station.

Hypoxia and Rats

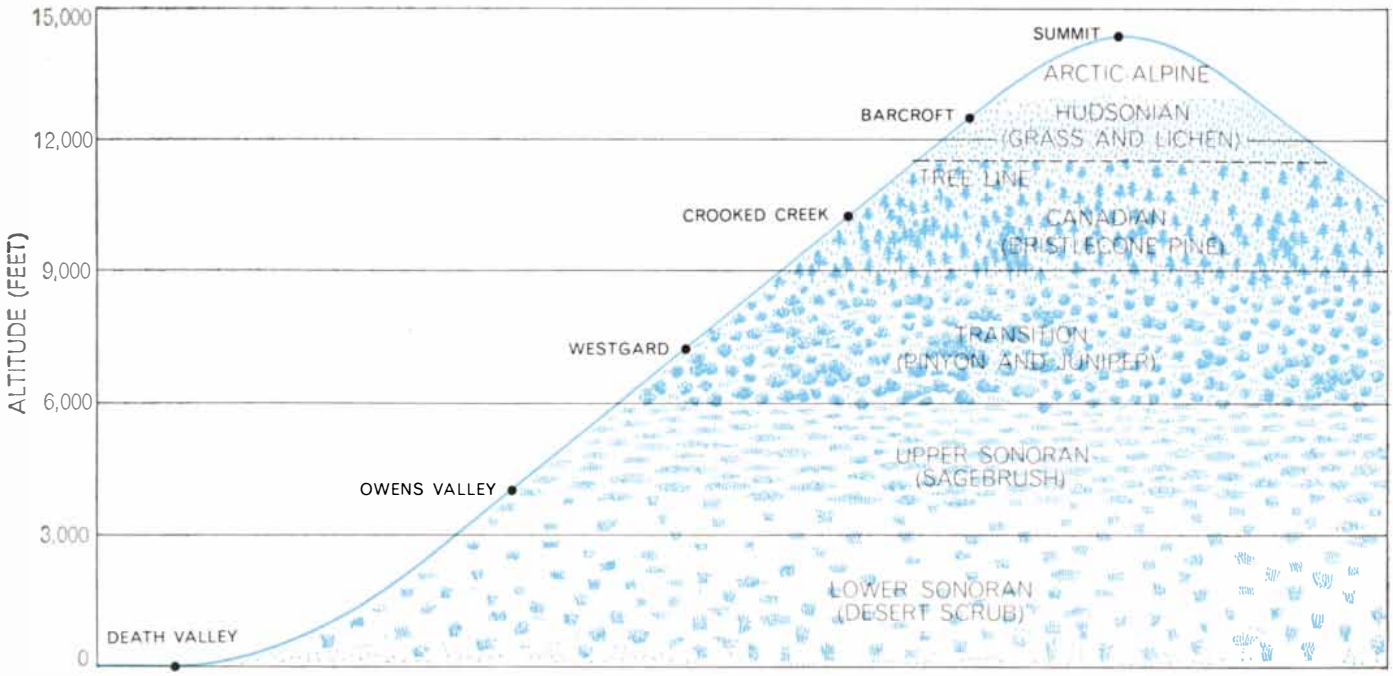
Pace and an associate, Paola S. Timiras, carried out a series of investigations on rats at the White Mountain Research Station. Rats that had been bred at sea level were brought to the Barcroft Laboratory (at 12,500 feet), and the investigators examined the responses to hypoxia in these animals and in the second generation of offspring produced at the high altitude. The development of the animals exposed to the high altitude was compared with that of a control group of rats kept at sea level.

The rats at the Barcroft Laboratory exhibited acclimatizing reactions like those of human newcomers to high altitude. There was a marked increase, for example, in their red cells and hemoglobin: in the imported animals the red-cell concentration rose to 54.6 percent of the blood volume, and in their second-generation offspring it was 66.7 percent, as against 47.5 percent in the control rats of the same age at sea level. The rats also developed an enlargement of the heart like that of human mountain natives. After 10 months at the high altitude they had a 20 percent higher ratio of heart weight to body weight than the sea-level controls did, and in the second-generation rats born at the Barcroft station the increase in heart-weight ratio was 90 percent. An increase in the relative weight of the adrenal glands was also observed in the rats exposed to the high altitude.

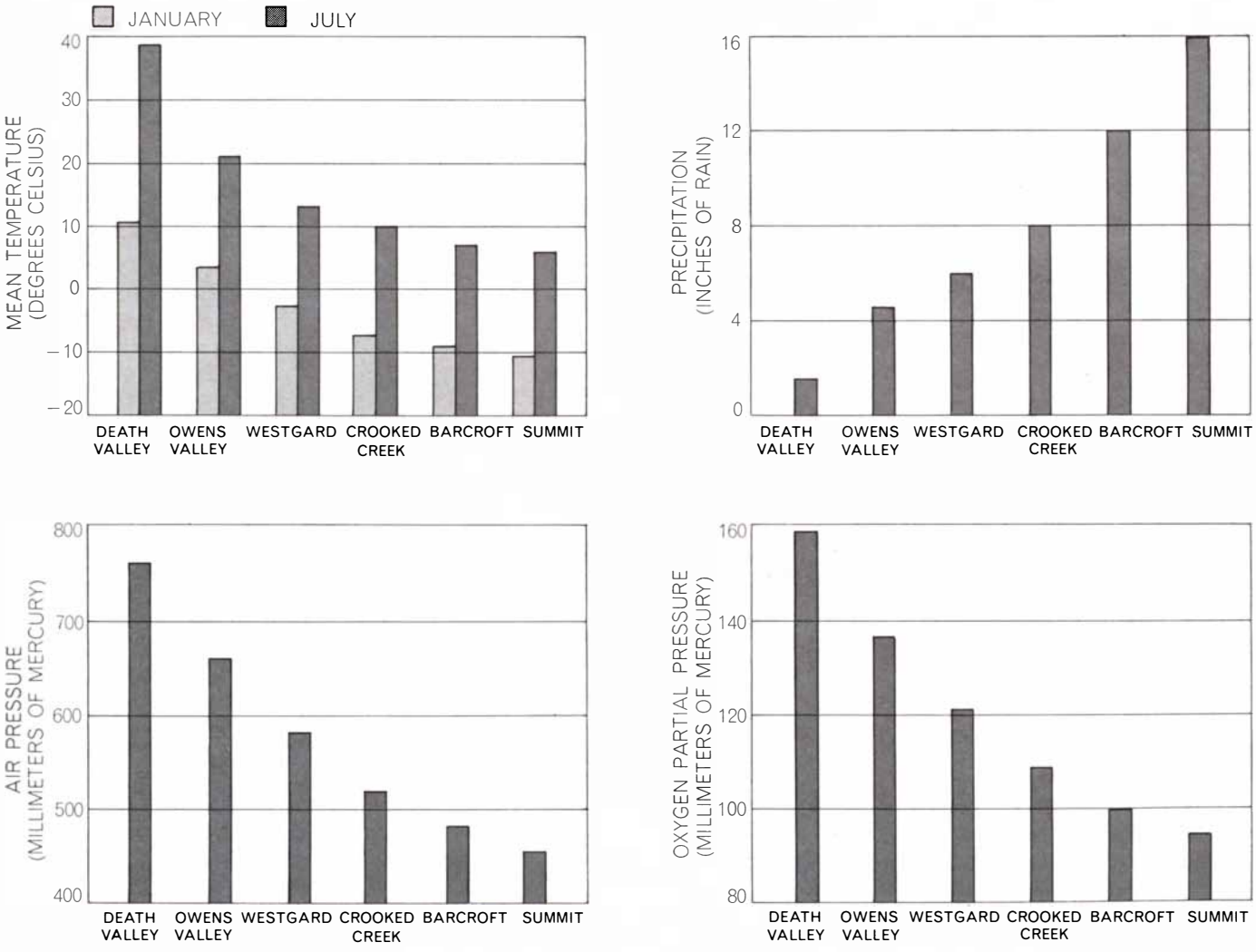
The exposure to hypoxia stunted the rats' growth. Up to the age of about 120 days the rats brought to Barcroft (at age 30 days) gained weight at the same rate as the rats left at sea level, but thereafter their growth slowed, and their maximum weight (at about 300 days) was significantly lower than that of the sea-level controls. The growth rate of the second-generation rats at high altitude was lower still: at 130 days they weighed only 250 grams, whereas their parents and the sea-level controls attained this weight in 84 days.

Fenton Kelley at the Barcroft Laboratory investigated the rats' reproduction and high-altitude effects on their young. The hypoxic conditions did not impair the ability to conceive in young, healthy rats: more than 85 percent of the females that were mated after 30 days of acclimatization became pregnant. Their fetuses, however, suffered considerable attrition: by the 15th day of pregnancy 25 percent of the females had abnormally stunted fetuses. Whether this is due to inadequacy of the oxygen supply to the fetus, disturbance of hormone production, neurological anomalies or metabolic disturbances has not yet been determined. At all events, the females bred at high altitude bore substantially smaller litters of live young than those bred at sea level.

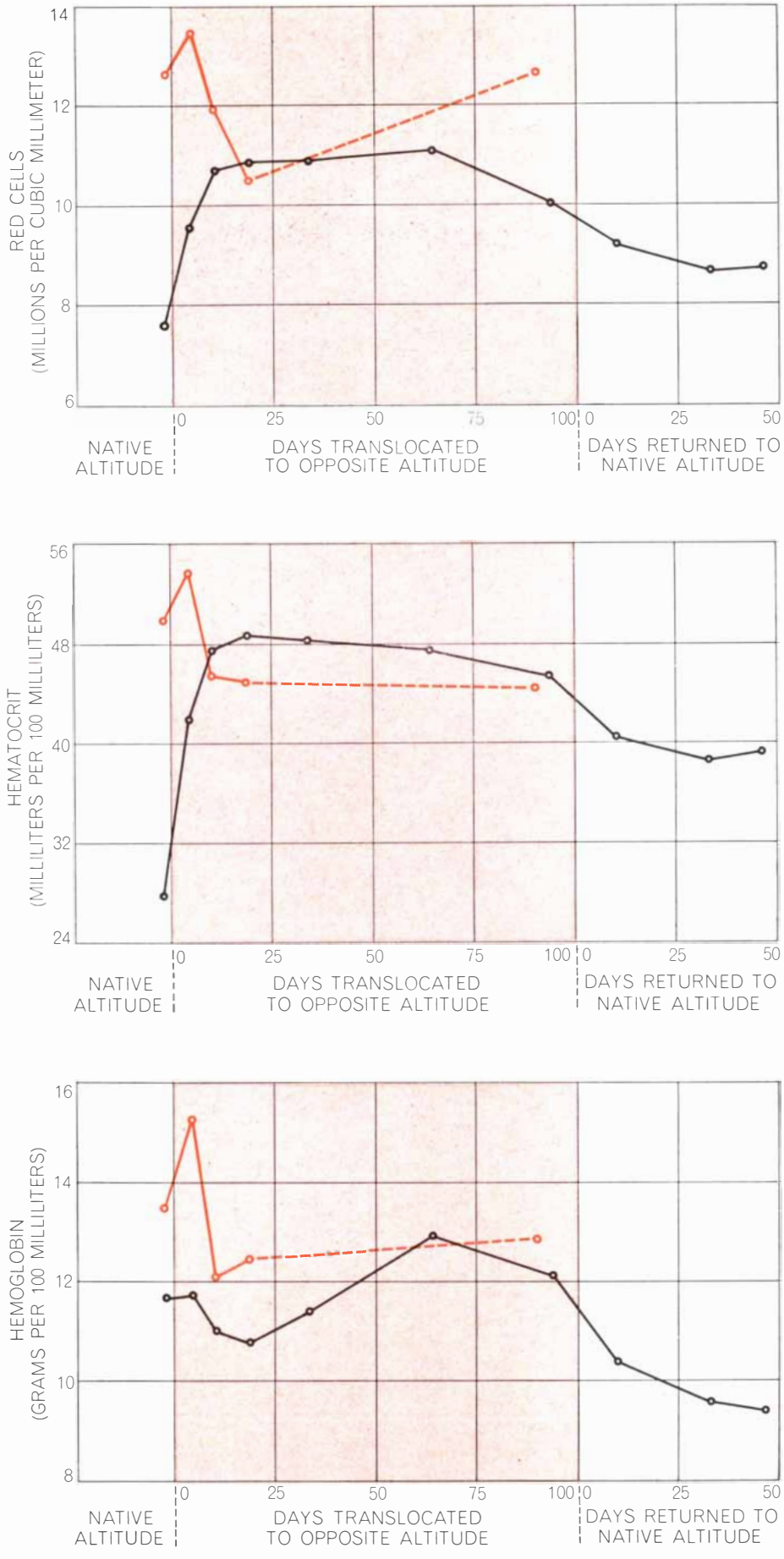
The offspring were generally normal in weight at birth, but by the age of 10 days their weight was 30 percent less than the sea-level norm. Their mortality rate in the first 10 days was about 20 percent, 10 times higher than in the sea-level control group. This was not attributable to lack of nursing ability in their mothers; in fact, the high-altitude infant rats had more milk in their stomachs than the sea-level young of the same age did. There were indications that the high-altitude young had metabolic defects that may account for their high mortality and for the slow rate of growth in those offspring that survived the postpartum period. The high-altitude young had a subnormal content of glycogen in the liver, apparently reflecting a defect in carbohydrate metabolism, and there is reason to believe the metabolism of fats and proteins also is affected by hypoxia. The dry atmosphere of high altitude may be another hazard for the newborn, affecting the



ALTITUDE RANGE of the deer mouse *Peromyscus maniculatus*, the animal the author studied, is remarkably large, extending from sea level to the summit of White Mountain in California. It encompasses six of the seven "life zones" described some years ago by the American naturalist C. Hart Merriam, which are indicated, with their characteristic vegetation, on this schematic diagram.



ENVIRONMENTAL DATA are given for the four laboratories of the White Mountain Research Station and two other places where the author worked, Death Valley and Westgard. Altitudes are indicated at the top of the page. (Summit precipitation is estimated.)



DEER MICE trapped at 12,500 feet (*color*) have more red blood cells, a higher hematocrit (red cells as a proportion of total blood volume) and more hemoglobin than mice trapped at sea level (*black*). As the curves indicate, these values increase in sea-level mice that are transported to the high altitude and decline again with their return to sea level. There is less long-term change, however, in high-altitude mice that are brought down to sea level.

body's water balance, temperature regulation, respiration and vulnerability to infection.

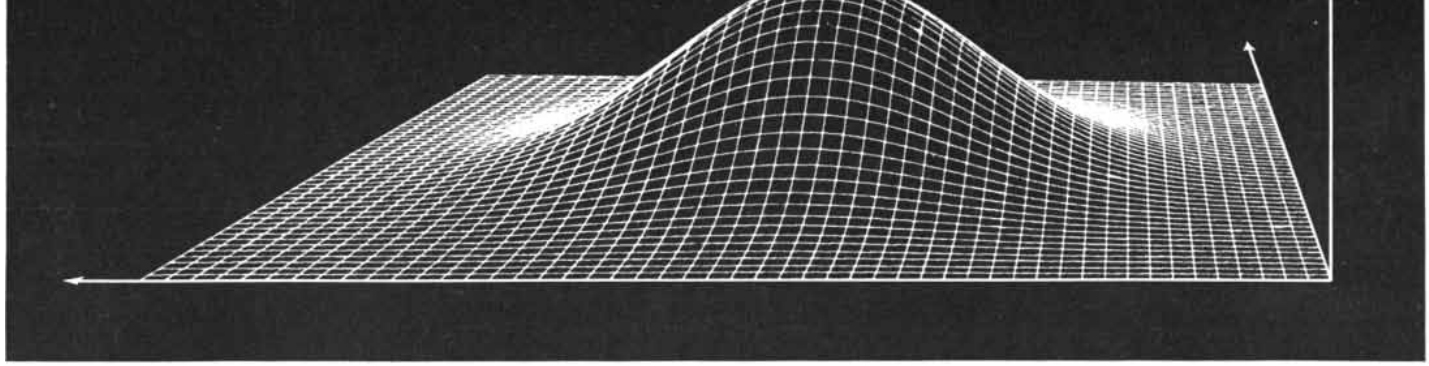
The Deer Mouse

My own investigations focused on the deer mouse (*Peromyscus maniculatus*), a small, white-footed species that is noted for its ubiquitous presence throughout North America and its ability to live in all climatic zones except extreme desert. Deer mice of various species are found inhabiting all altitudes from below sea level to about 15,000 feet. This one species is ideal for our studies not only because of its great variety of physiological responses to different conditions but also because a mouse spends its entire life in the same locality. A tiny deer mouse on White Mountain probably does not range more than a quarter of a mile from its birthplace during its lifetime; consequently we could be sure that a mouse trapped at 12,500 feet on White Mountain had been born at about that altitude (within 500 feet) and had been exposed to it throughout its life.

I trapped deer mice at seven different altitudes, ranging from below sea level to the 14,250-foot White Mountain summit, and for comparison of their native differences each population was examined at the altitude at which it was caught. It was apparent at once that the mice followed only in part the well-known rule that body size increases with exposure to cold: their body weight increased with increasing altitude up to a point. The heaviest weight was found at 10,150 feet; beyond that the oxygen scarcity apparently limits growth in deer mice as it was found to do in the experiments on rats.

There was also a clear progression, with increasing altitude, in the ratio of the heart size to the body weight. In the deer mice caught at 14,250 feet the relative heart weight was one and a half times greater than it was in mice living at an altitude of 4,000 feet. The relative number and mass of red cells and the amount of hemoglobin in the blood also increased with altitude in the deer mice as it does in rats and men. Contrary to what had been observed in rats, however, the mice's adrenal glands shrank with increasing altitude, both in absolute weight and in relation to body weight. Presumably this phenomenon in the mice reflects a different physiological response to the stresses of high altitude from that shown by the rats.

In an effort to determine whether the differences among the natives of various altitudes were genetic or simply the



Biometry

The Principles and Practice of Statistics in Biological Research

ROBERT R. SOKAL and
F. JAMES ROHLF
State University of New York
Stony Brook

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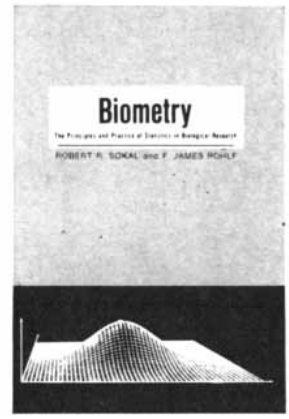
1969, 776 pages, 89 illustrations, (68-16819), $15.00



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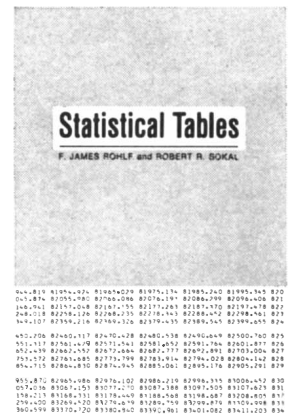

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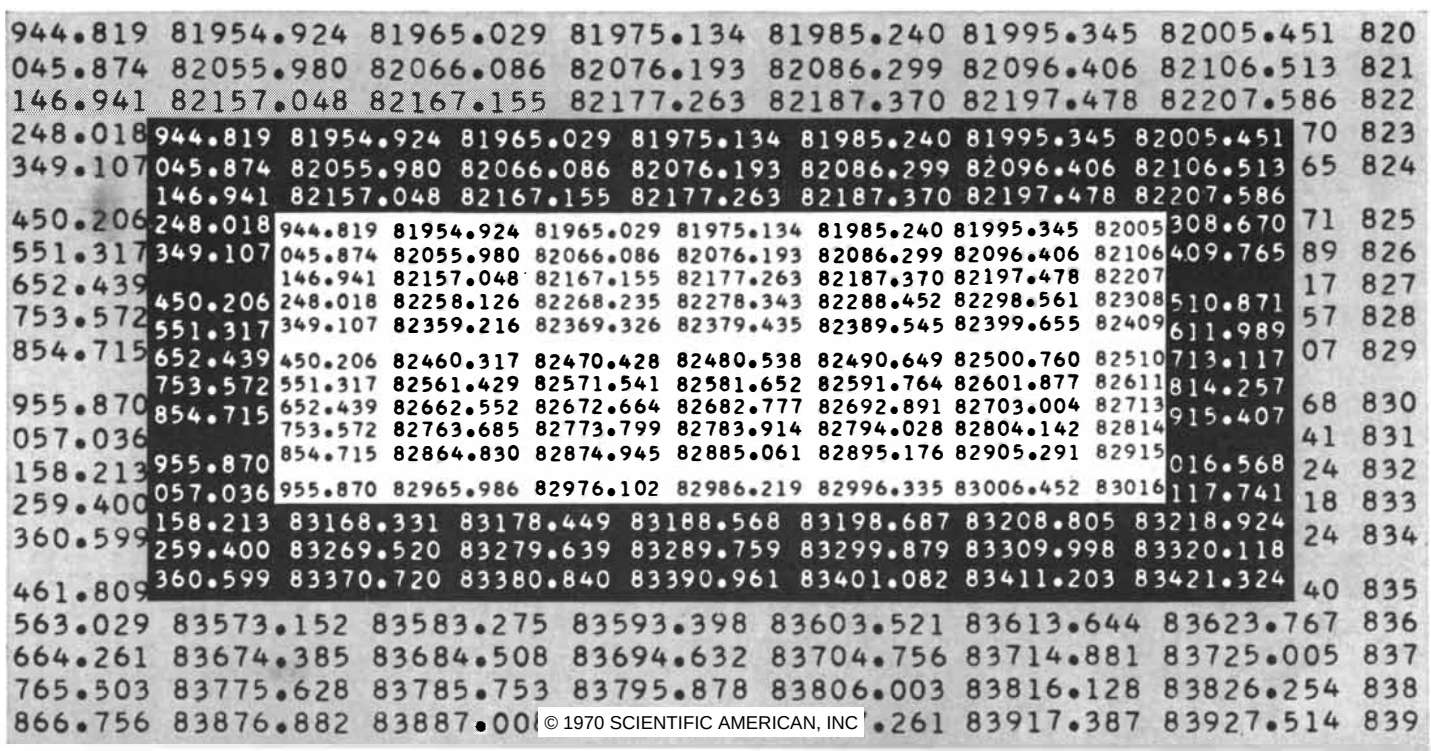
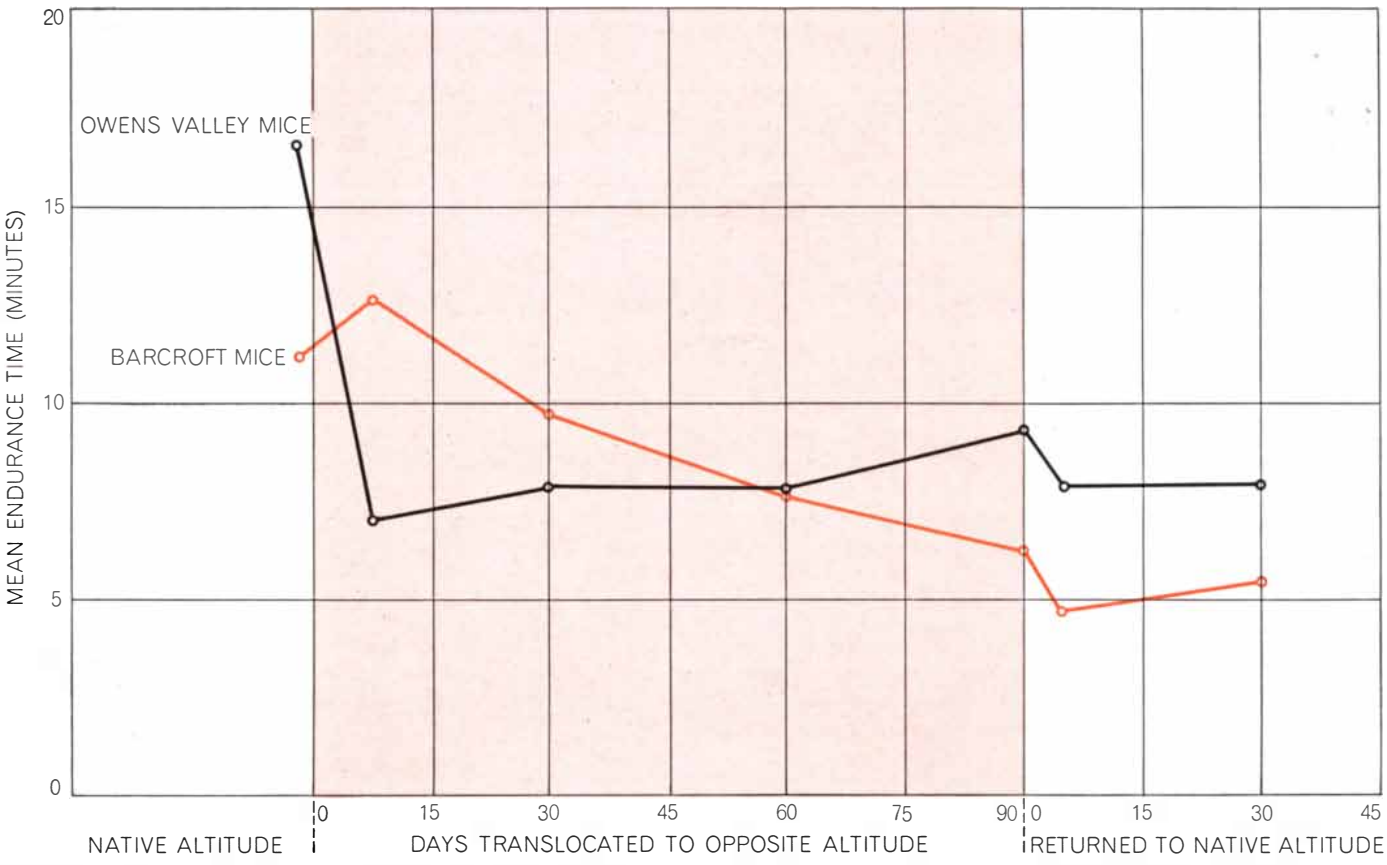
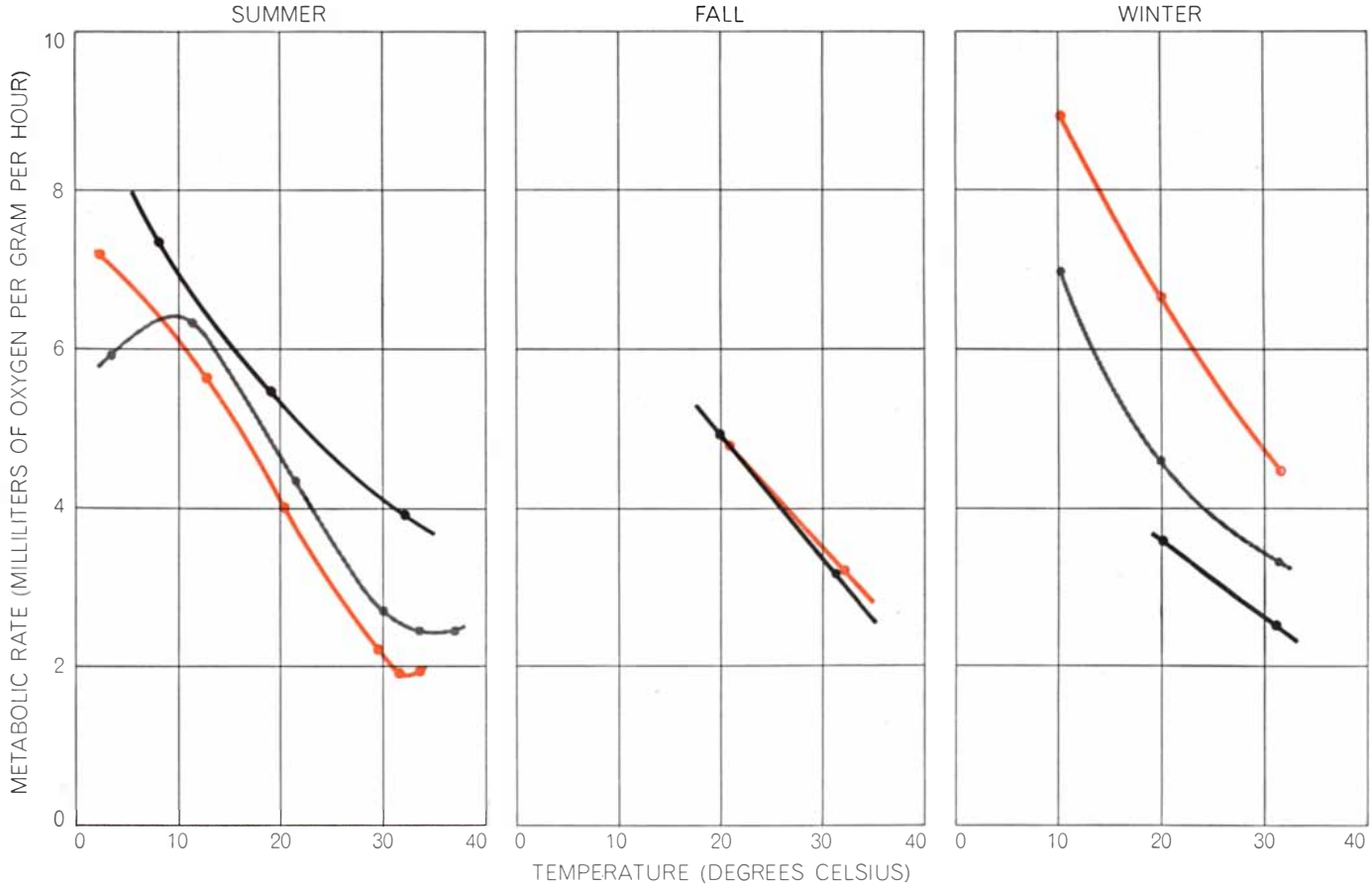




ENDURANCE of mice trapped at 4,000 feet (*black*) was greater than that of mice trapped at 12,500 feet (*color*) when both groups were in their home environments (*left*). The low-altitude mice showed a decided decrease in endurance when they were first taken to 12,500 feet but then improved somewhat. Surprisingly, the high-altitude natives did less well at 4,000 feet than at 12,500.

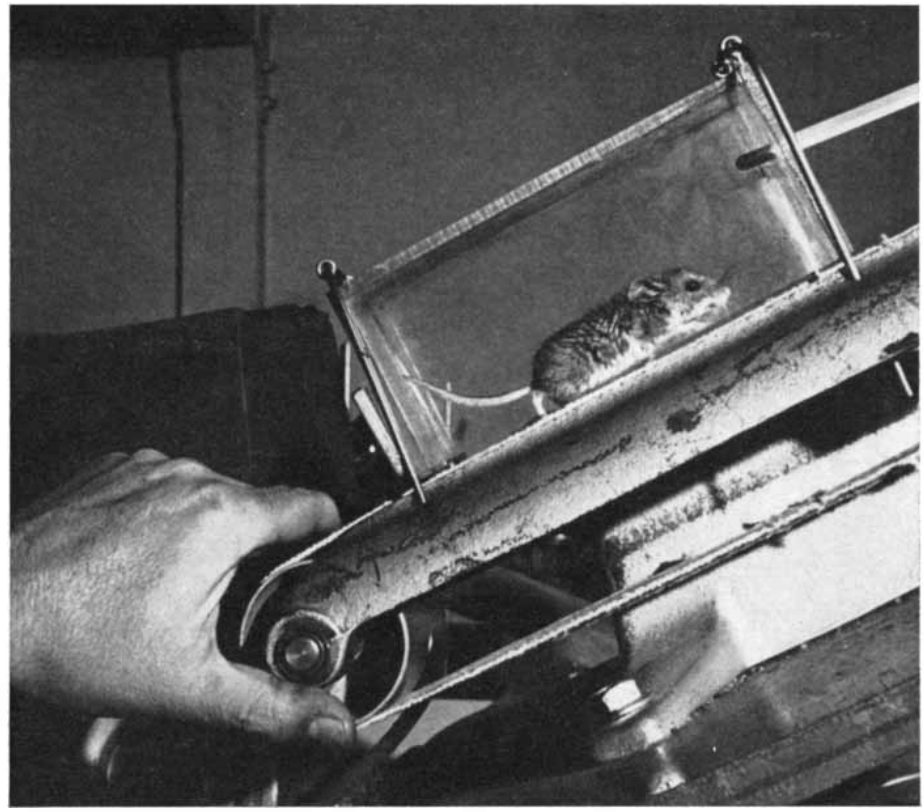


BASAL METABOLIC RATE (oxygen consumption at rest) of mice native to sea level (*black*), 4,000 feet (*gray*) and 12,500 feet (*color*) was measured at their native altitudes in the summer and winter over a wide range of ambient temperatures; two of the three groups were tested in the fall over a narrower temperature range. In the summer the sea-level mice had the highest rates and the 12,500-foot animals had the lowest rates; in the fall they were about equal, and in the winter the summertime findings were reversed (*see text*).

result of acclimatization from birth, I then began to transfer mice from one altitude to another for study of their responses to the change. When mice from the sea-level colony were transferred to our 12,500-foot laboratory, their relative heart weight did not increase. They showed definite signs of acclimatization, however, in other responses. The adrenal glands diminished in size. The weight of the spleen decreased and the lung weight increased, indicating that circulatory and respiratory adjustments were taking place. The red-cell mass and the hemoglobin content of the cells increased to about the same values as in native high-altitude mice. When the surviving mice were later returned to sea level, they soon reverted to their original sea-level condition: the adrenal glands gained in weight and the red-cell mass and hemoglobin fell back to sea-level norms. It appears, therefore, that most of the adaptive mechanisms found in native high-altitude mice are actually adjustments acquired in the course of their exposure to the conditions of their environment.

The reverse experiment—transferring high-altitude mice to sea level—produced a mixed picture. In these mice the relative heart weight decreased and the spleen weight increased, but the adrenals and the lungs showed no change in relative weight. After 90 days of acclimatization to the low altitude the number of red cells in the mice's blood remained unchanged from what it had been at high altitude. This seems to suggest that the high red-cell count in high-altitude mice may represent a genetic adaptation, but it might be explainable on the basis that the translocated animals simply retained their original high red-cell count because there was nothing in the change to low-altitude conditions that would foster destruction of the cells. The total mass of the red cells in proportion to the blood volume did decrease to sea-level values; this may have been due to an increase in the amount of plasma. The concentration of hemoglobin, however, changed only slightly if at all.

The high-altitude natives showed no inferiority to low-altitude mice in fertility; in fact, the average litter size at 10,000 feet or above was six, as against five for females living at 4,000 feet. The high-altitude young, however, had a poor survival rate: mortality among them by the 30th day after birth was 23 percent, whereas all the low-altitude young survived beyond that age. I found that the rate of growth for the young was about the same at all levels during the first 45 days of life, but thereafter it decreased with altitude. By the age of maturity (120 days) the average weight of mice born at 4,000 feet was 22.5 grams; of those born at 14,250 feet, 18.8 grams.



MINIATURE TREADMILL for testing the capacity of deer mice for strenuous exercise was improvised by mounting a linen belt on an old belt sander. The belt was moved at a speed of a mile and a half an hour. The mouse ran on it, restrained by the plastic barriers, until it was exhausted, and the length of time it ran was the measure of its endurance.

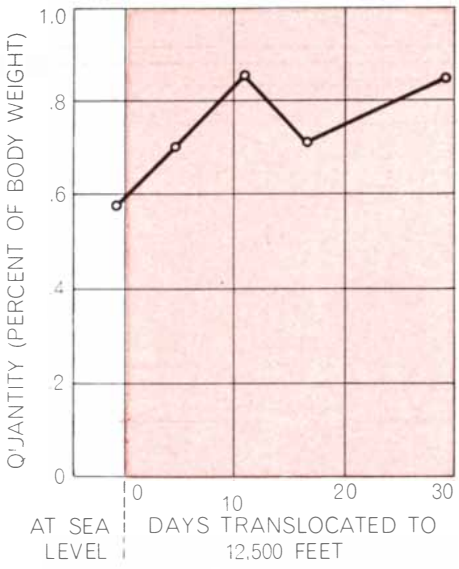
Exercise and Metabolism

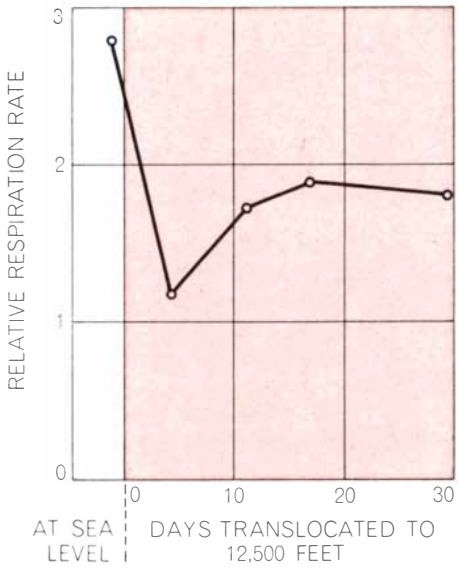
In order to test the capacity of the mice for strenuous exercise I developed a miniature treadmill that could be run at various speeds. As was to be expected, the natives at low altitudes showed more endurance than those at higher levels. The mean time before exhaustion on the treadmill in one series of tests, for example, was 16.7 minutes for natives at 4,000 feet and only 11.2 minutes for natives at 12,500 feet. Was the difference in performance due to the handicap of hypoxia at the higher altitude or to some innate physical or physiological difference in the mice themselves? I examined this question by switching the environment for the mice, testing the low-altitude natives at the high station and the high-altitude natives at the lower station.

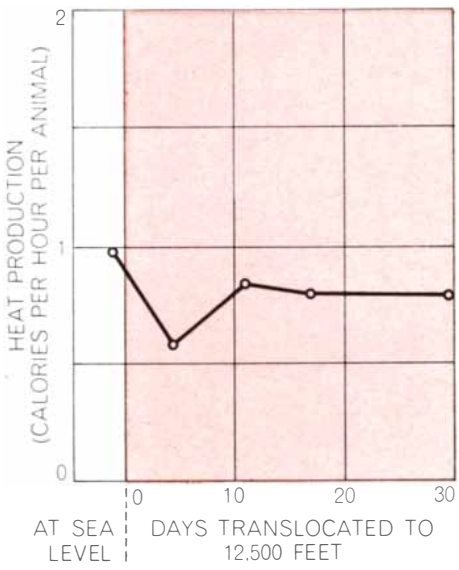
The 4,000-foot natives, when taken to the 12,500-foot level, at first showed a drop in endurance on the treadmill. Their performance slowly improved, however, as they became acclimatized over a period of 90 days. The transfer of 12,500-foot natives to tests at the 4,000-foot level, on the other hand, yielded a major surprise. Although they were now performing in an atmosphere richer in oxygen, their endurance on the treadmill declined instead of improving. At the end of 90 days of "acclimatization" they were able to run on the treadmill only half as long, before exhaustion, as they had done in their oxygen-poor native environment! The explanation may lie in abnormalities of the heart and certain other functions in the high-altitude mice and in the change to a new climate at the lower altitude.

In one study I compared low-altitude and high-altitude mice with regard to their consumption of oxygen during exercise. When sea-level natives were transferred to high altitude, they did not increase their oxygen consumption more while exercising than they had at sea level. High-altitude natives, on the other hand, showed a considerably greater increase in oxygen consumption during exercise than the low-altitude mice did, both at high and at low altitudes. In short, under both conditions the high-altitude mice paid a higher cost (that is, were less efficient) in the use of oxygen during exercise.

I measured the basal metabolic rate







BROWN FAT, a tissue that generates heat, increased in quantity in sea-level deer mice transported to 12,500 feet (*top*). The rate of respiration of the tissue decreased, however, because of the relative lack of oxygen (*middle*). As a result the animal's total heat production was somewhat reduced (*bottom*).

(as indicated by oxygen consumption at rest) of the mice at various altitudes under various temperature conditions. The stations used for comparison were at sea level, at 4,000 feet in the Owens Valley (which is hot in summer) and at 12,500 feet in the Barcroft Laboratory. The determinations were made during three different seasons and at temperatures ranging from near freezing to a maximum of about 99 degrees Fahrenheit. I found that in summer the high-altitude mice had the lowest metabolic rate, the 4,000-foot mice an intermediate rate and the sea-level mice the highest rate. (The highest temperature proved to be lethal for mice from the high altitude, and conversely lower-altitude mice tested at near-freezing temperatures became severely chilled.) In the fall (at temperatures between 68 and 90 degrees F.) the high-altitude mice and sea-level mice had about the same rate of metabolism. In winter (February) the situation was the reverse of the summer picture: now the high-altitude mice had the highest rate at all temperatures, the sea-level mice the lowest.

These observations could be interpreted as follows. At the high altitude the comparatively mild temperatures of summer enable the native mouse to adjust to the hypoxic environment by reducing oxygen consumption to the minimum required for nourishing the body tissues. Because of the mouse's small size it cannot grow a thick enough hair covering to insulate it effectively against the winter cold. Consequently the high-altitude mouse is forced to increase its metabolism in winter to maintain its body temperature. The sea-level mouse, on the other hand, is not subjected to extreme cold in winter. Hence it is adequately protected from the drop in the ambient temperature by a small increase in its furry insulation and by an adjustment in the form of "physiological insulation," that is, reduction of its body temperature, which cuts down heat loss by reducing the temperature difference between the body and the ambient air. (I found that the deep-body temperature of the sea-level mouse does indeed decrease in winter.) Moreover, the sea-level mouse in winter can afford to reduce its metabolic rate from the high rate associated with summer activities without stinting its tissues' needs for oxygen.

With two associates, Robert E. Smith and Jane C. Roberts, I looked into the metabolic response of mice at the cell and tissue levels. We found several marked differences in cell activities at low altitudes and at high altitudes. In most cases it was difficult to tell whether the observed differences were due to exposure to cold or to hypoxia. Studies of the brown fat in these animals, however, produced some significant findings.

Brown fat, found mainly between an animal's shoulder blades, is a heat-generating tissue [see "The Production of Heat by Fat," by Michael J. R. Dawkins and David Hull; SCIENTIFIC AMERICAN, August, 1965]. In response to exposure to cold there is an increase in both the mass of brown fat and its heat production, which may multiply severalfold in a few weeks. We found that the mass of brown fat could be increased in deer mice by exposure to cold or to hypoxia (which also lowers the body temperature). It turned out, however, that when sea-level mice were transferred to high altitude, the respiration of their brown fat decreased, so that its heat production was reduced in spite of a clear increase in its mass. On the other hand, when high-altitude natives were brought down to sea level, both the mass and the respiration of their brown fat increased, and its heat production apparently equaled that of sea-level mice that had been acclimated to cold. Evidently the transfer to the oxygen abundance at sea level had improved the tissue's respiration so that it increased its production of heat. From these findings we concluded that hypoxia, although it gives rise to the growth of brown fat, may suppress heat production by limiting the tissue's respiration.

Heredity or Environment?

The extensive investigations leave unsettled the question of whether men native to high altitude are a race apart or merely human beings with a normal heredity who have adjusted to the conditions over a lifetime of habituation beginning in the uterus. In some respects the mountain natives, both animals and men, do seem to show innate physiological differences from their kindred species at sea level. There is a serious objection to considering them a separate strain, however, namely the lack of genetic isolation. There has been no barrier in this case to the pooling of genes, either for the deer mouse or for man. We know that Andean man has intermarried freely with lowlanders. Indeed, many of the mountain miners came from the lowlands and many highlanders have come down to live in the lowlands. It seems likely that the highlanders have derived their special qualities from acclimatization—in short, that their response to their environment is phenotypic rather than genotypic.

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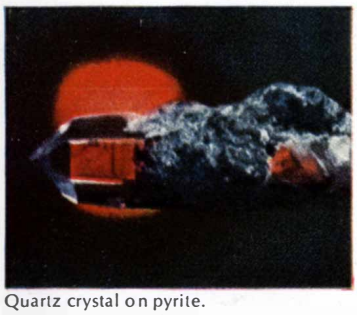
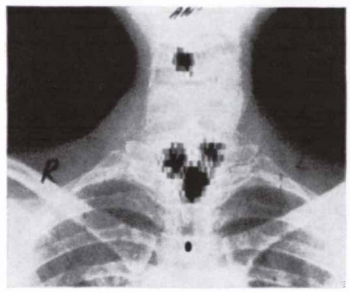
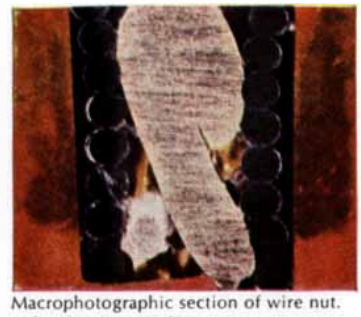


Quartz crystal on pyrite.
Polacolor Type 58 film.

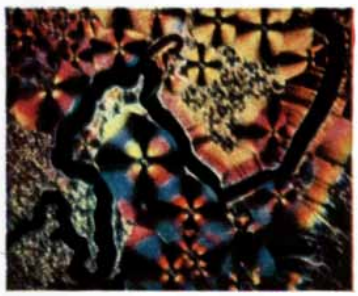


Copy of X-ray with isotope scan overlay.
Type 107, 3000-speed film.

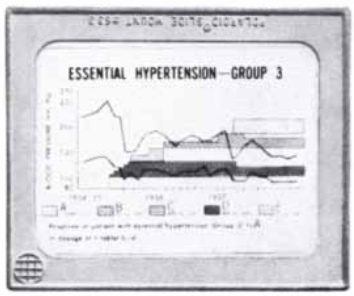
Macrophotograph, bacteria culture.
Polacolor Type 108 film.



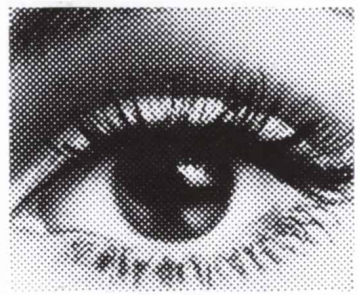
Macrophotographic section of wire nut.
Polacolor Type 58 film.



Photomicrograph, crystals under polarized light. Polacolor Type 58 film.

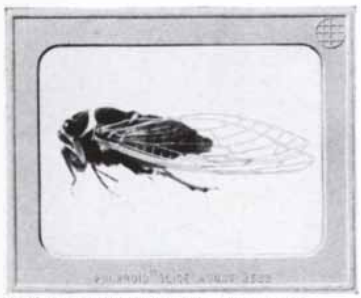


Slide for presentation, high contrast.
Type 146L projection film.



Instant screened print for printing reproduction. Type 51 high contrast film.

Coins, *circa* 100 A.D., catalog illustration.
Polacolor Type 108 film.



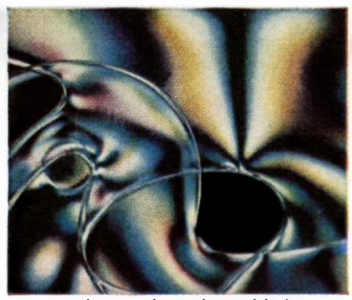
Biology study slide, continuous tone.
Type 46L projection film.

Handwriting study for legal investigation.
Polacolor Type 58 film.

Perforated ulcer of the stomach.
Polacolor Type 58 film.

Macrophotographic section of battery grid. Polacolor Type 58 film.

Copy of fingerprint record (negative).
Type 55 Positive/Negative film.



Stress analysis under polarized light.
Polacolor Type 58 film.

Diode fractures, for QC report.
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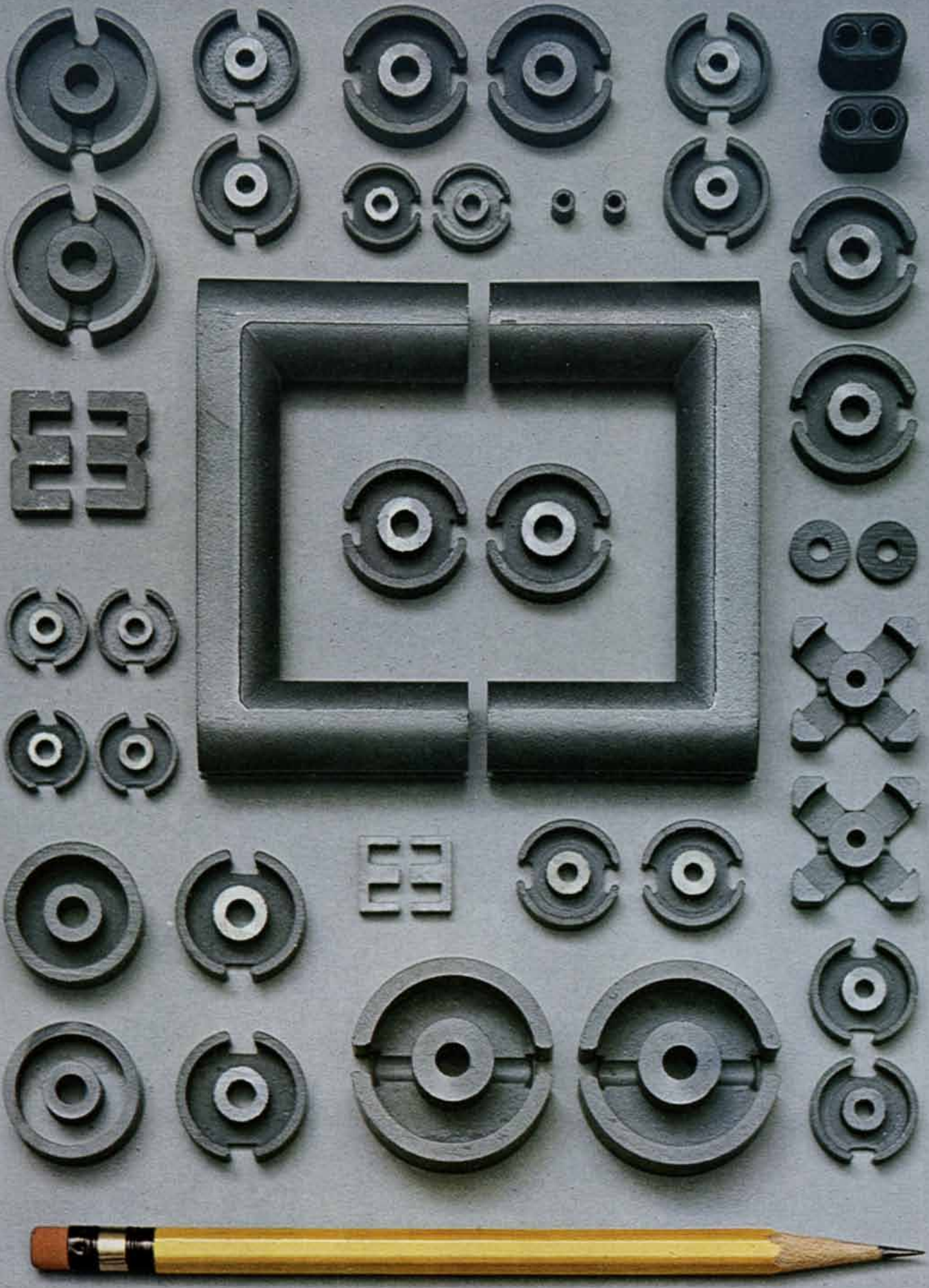

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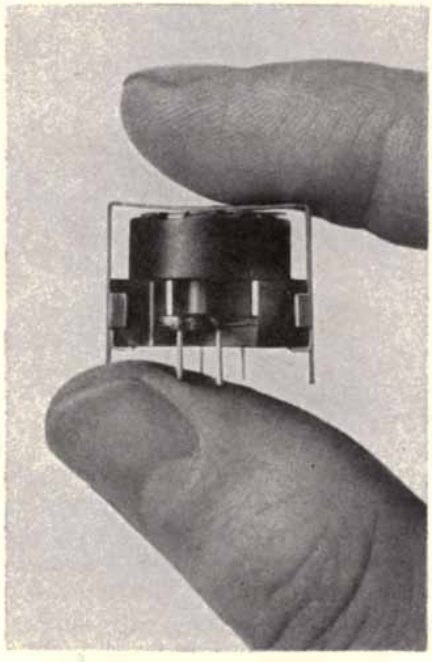

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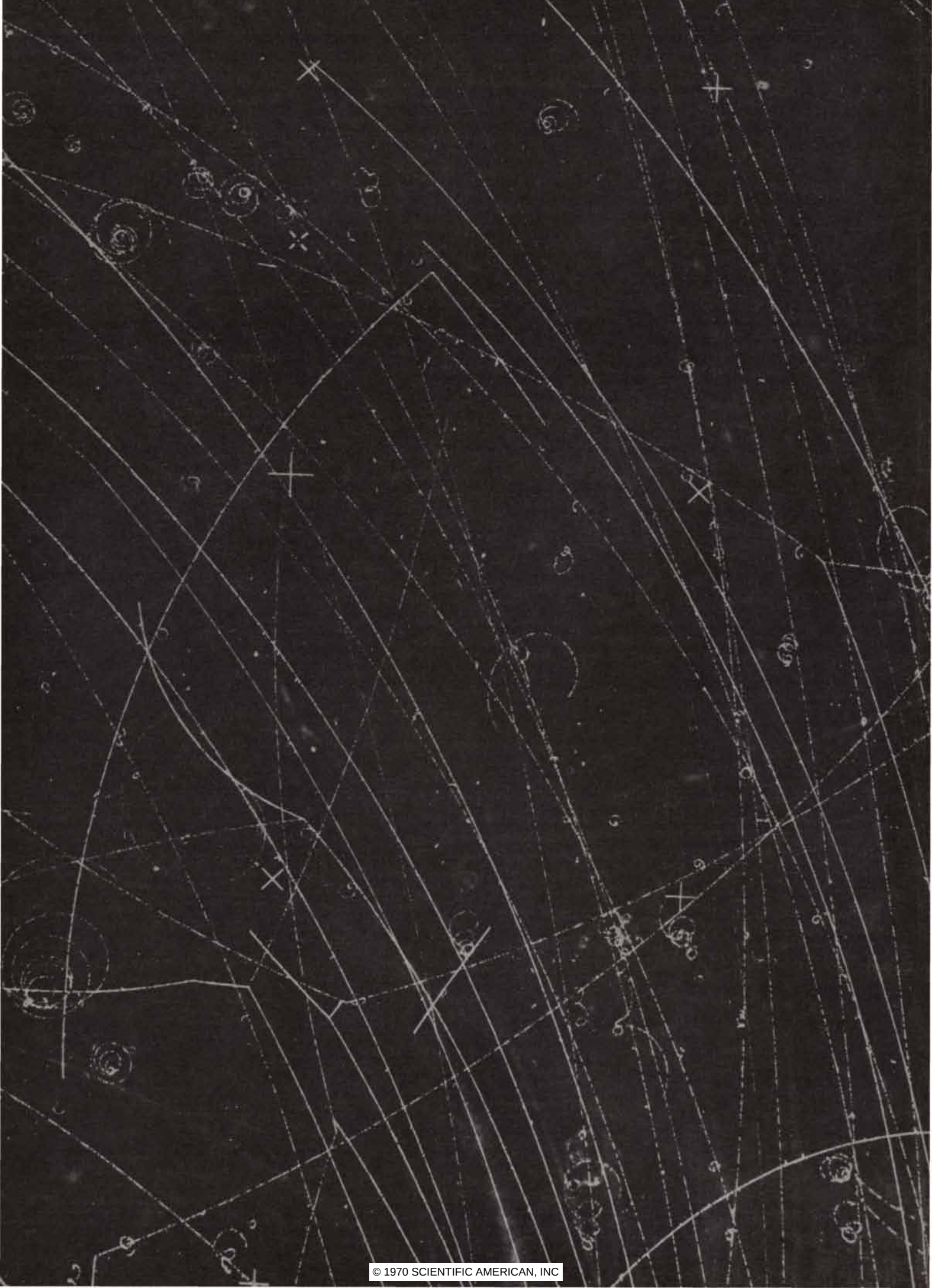


Particles That Go Faster than Light

Efforts to detect such particles, named tachyons, have yielded only negative results. Contrary to common belief, however, their existence would not be inconsistent with the theory of relativity

by Gerald Feinberg

Since the formulation of the special theory of relativity by Einstein in 1905 and its subsequent verification by innumerable experiments, physicists have generally believed that the speed of light in a vacuum (about 300,000 kilometers per second) is the maximum speed at which energy or information can travel through space. Indeed, Einstein's first article on relativity contains the statement that "velocities greater than that of light... have no possibility of existence."

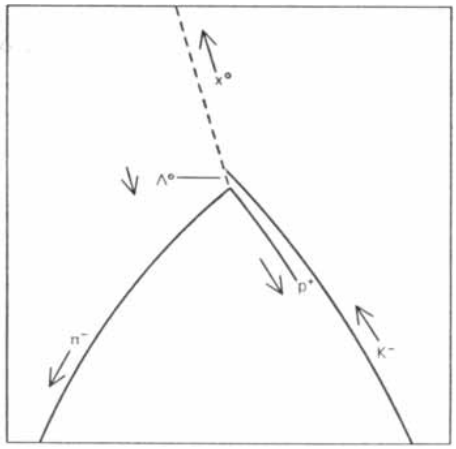
The basis of Einstein's conclusion was his discovery that the equations of relativity implied that the mass of an object increases as its speed increases, becoming infinite at the speed of light (which is usually denoted *c*). Since the mass of a body measures its resistance to a change of speed, when the mass becomes infinite the body cannot be made to go any faster. Stated somewhat differently, the relation between energy and speed implied by relativity is such that as the speed of a body approaches *c* its energy becomes infinite. Since this energy must be supplied by whatever is accelerating the body, an infinite source of energy would be needed to speed up a body to the speed of light from any lower speed. No such infinite energy source is available, and so it is impossible to make a body go from less than *c* to *c*.

Furthermore, if a body could somehow be made to go from a speed less than *c* to one greater than *c*, the same relativity equations imply that its energy and momentum would become imaginary numbers, that is, numbers containing a square root of a negative number. This situation does not seem to have any physical meaning. Objects with imaginary energy clearly cannot exchange energy with objects having real energy and hence cannot affect them. Accordingly, such objects could not be detected by real instruments, and can be said not to exist. Within the context in which Einstein worked, where the properties of objects varied continuously and where the creation of new objects was not considered, it therefore seemed a logical conclusion that no form of energy, and hence no matter, could travel faster than light.

With the development of subatomic physics, however, the context has changed considerably. We now know that the subatomic particles can easily be created or destroyed, and that in their mutual interactions their energies and other properties change discontinuously, rather than in the smooth way envisioned in classical physics. Therefore one can imagine the creation of particles already traveling faster than light, and so avoid the need for accelerating them through the "light barrier" with the attendant expenditure of infinite energy.

In addition, one can consistently require that such particles *always* travel at speeds greater than *c*, which obviously cannot be the case for known particles. If one assumes these conditions, there is no problem in satisfying the requirement that the particles carry real energy and momentum. This can be done mathematically by allowing a certain constant that appears in the relation between energy and speed to be an imaginary number, rather than a real number as it is for ordinary particles [*see top illustration on next two pages*]. This constant is usually known as the rest mass, because for ordinary objects, which can be slowed to rest, it gives the value of the object's mass when at rest.

For the hypothetical faster-than-light particles, which can never be brought to



SEARCH FOR TACHYONS led the author and his colleagues at Columbia University to scrutinize thousands of bubble-chamber photographs such as the one on the opposite page for indirect evidence of the occurrence of neutral tachyons among the by-products of certain subatomic interactions. The photographs, which were originally made at the Brookhaven National Laboratory for another experiment, were analyzed by means of the "missing mass" method. In this approach the energy and momentum of the charged particles in the reaction are measured directly from the configuration of the tracks they make in the bubble chamber. Although neutral particles are usually not observed directly, it is possible to tell from the values measured for the charged particles whether or not any neutral particles have been produced, and also what the missing mass of these particles is. In this case a negative *K* meson (K^-) was allowed to come to rest and be captured by a proton in the hydrogen bubble chamber (*see diagram at left*). One neutral particle, a lambda hyperon (Λ^0), was produced and was detected through its decay into two charged particles, a negative pion (π^-) and a proton (p^+). In order to conserve energy and momentum, another neutral particle (x^0) had to be produced in this reaction, but the experimenters were able to show that this particle was probably a neutral pion (π^0), not a neutral tachyon (t^0).

a $$E = \frac{mc^2}{\sqrt{1-(v^2/c^2)}}$$

b $$E_0 = mc^2$$

c $$E = \frac{\mu c^2}{\sqrt{(v^2/c^2)-1}}$$

EQUATIONS OF RELATIVITY pertinent to a discussion of the possible existence of tachyons are shown on these two pages. The relation between energy and speed that must be satisfied by any object obeying the special theory of relativity is given by equation *a*, where E is the energy of the object, v is its speed and c is the speed of light. The quantity m is known as the rest mass of the object and is related to the energy E_0 that the object has at rest by equation *b*. For a body traveling faster than light v^2/c^2 is greater than one; consequently the quantity under the square-root sign in equation *a* is negative, and the denominator of the quantity that is equal to E in the same equation is an imaginary number (that is, a number containing a square root of a negative number). In order to make E a real number one must choose m to be an imaginary number, say $m = \mu\sqrt{-1}$. As long as the object always travels at more than the speed of light, its energy, which can be written in the form shown in equation *c*, will then be real, because $(v^2/c^2) - 1$

rest, this constant is not directly measurable, and there is no need for it to be real. The square of the rest mass, however, can be expressed in terms of the measurable energy and momentum of an object and hence can be directly measured. For ordinary objects the rest mass squared is found to be a positive real number. For faster-than-light particles it would be a negative number; indeed, this fact is the basis of one attempt to detect such particles. It should be mentioned that there is a third class of particles, including photons (light quanta) and neutrinos, for which the rest mass is zero and which always travel at c.

The possibility therefore seems to exist that there is a new kind of natural object: one that always travels faster than light. The latter statement is invariant, in the sense that if a body travels faster than light with respect to one observer, it will do so with respect to any other observer himself traveling in relation to the first at less than the speed of light. These are the only observers of which we have any knowledge. It must be stressed that all the considerations given here and below are consistent with the special theory of relativity, and assume the validity of its equations for describing particles, even if the particles travel faster than light.

In anticipation of the possible discovery of faster-than-light particles, I named them tachyons, from the Greek word *tachys*, meaning swift. In order to show how physicists have gone about searching for tachyons, I shall describe some of the properties that would distinguish them from ordinary particles.

One such property follows directly from the relation between energy and speed given in the equations of relativity. We have seen that for ordinary particles, as their speed increases, their energy also increases. For tachyons, in contrast, an increase in speed results in a decrease in energy. Hence a tachyon that was losing energy by interacting with matter or by radiating light would speed up, whereas a tachyon that was gaining energy from some outside source would slow down, and its speed would approach c from above rather than below. Thus c acts as a limiting speed for tachyons also, but the limit is a lower limit, rather than the upper limit that it is for ordinary objects.

In the limiting case of a tachyon moving at infinite speed its total energy would be zero, although its momentum would remain finite. It should be emphasized that for a tachyon at infinite speed it is the total energy that is zero and not just the kinetic energy. For an ordinary particle with nonzero rest mass the total energy can never vanish.

The condition of infinite speed is, however, not invariant but depends on the observer. If a tachyon were moving at infinite speed as seen by one observer, its speed as measured by another observer in motion with respect to the first would not be infinite but rather some finite value between c and infinity. This is another way of phrasing Einstein's discovery that simultaneity for events at different points in space has only a relative and not an absolute meaning.

A second property of tachyons that substantially distinguishes them from ordinary particles comes about from the way measurements of energy and time change with the relative motion of observers. For ordinary particles the energy is a number whose value will change from observer to observer but that will always be positive. A tachyon whose energy is positive for one observer, however, might appear to be negative to other observers in motion with respect to the first. This can occur for tachyons because of the equation of relativity that states that the energy of a tachyon is always less than its momentum multiplied by c; this ambivalence does not apply to ordinary particles. If negative-energy tachyons were emitted by the unexcited atoms of ordinary matter, this would cause the emitting atoms to be unstable, and hence the existence of such tachyons would contradict the known stability of ordinary matter.

The change in the sign of the energy of a tachyon from observer to observer is connected to another peculiar property of tachyons. If an ordinary particle is seen by one observer to be emitted (say by an atom A) at one time and absorbed elsewhere (by atom B) at a later time, then any other observer in relative motion will see this process in the same way—as emission by atom A followed at a later time by absorption by atom B—although the time interval will vary from observer to observer. Tachyons, however, because they would travel faster than light, would move between points in "space time" whose time-ordering can vary from observer to observer. Therefore if one observer saw a tachyon emitted by atom A at one time t_1 and absorbed by atom B at a later time t_2, another observer could find that the time t_1' that he measures corresponding to t_1 is later than the time t_2' that he measures corresponding to t_2. If this occurs, the latter observer would naturally want to interpret what happens in the following way: The tachyon is emitted by atom B at the earlier time t_2' and absorbed by atom A at the later time t_1'.

It can be seen that this interchange of emission and absorption also removes the problem of negative-energy tachyons, since the reversal between observers of the sign of the energy occurs if and only if the reversal in time-ordering occurs. Since the emission of a negative-energy particle and the absorption of a positive-energy particle traveling in the

d $$p = \frac{mv}{\sqrt{1-(v^2/c^2)}}$$

e $$E^2 - p^2c^2 = m^2c^4$$

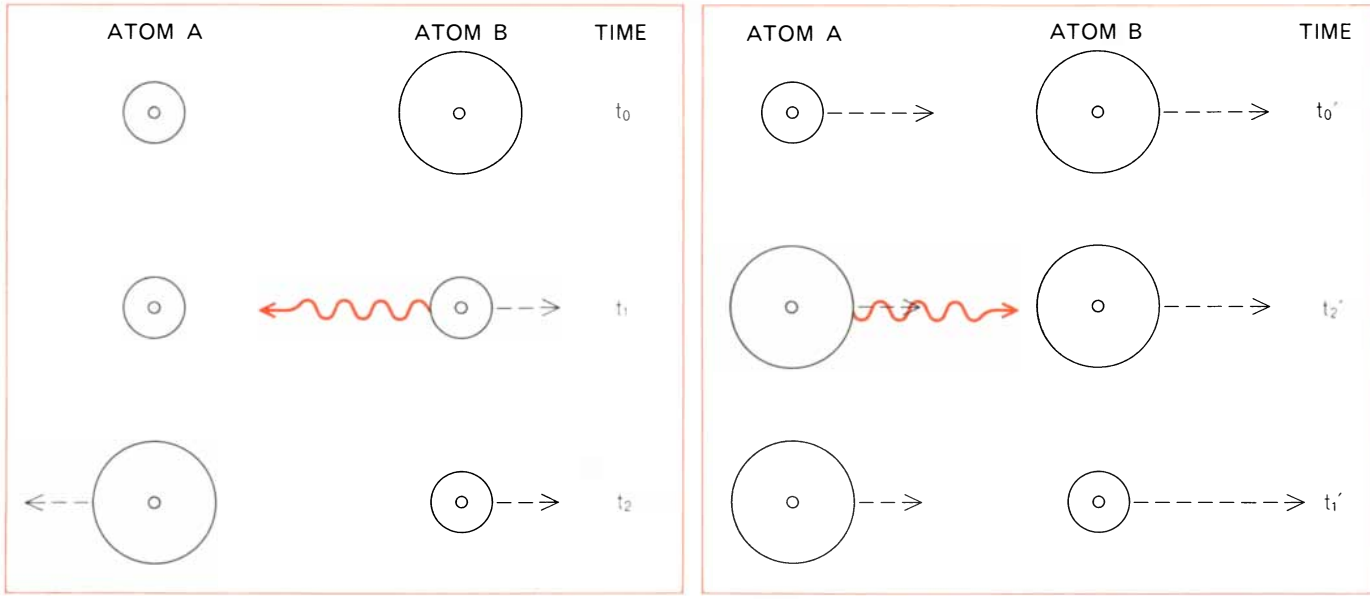
f $$\frac{v}{c} = \frac{pc}{E}$$

will in this case be a positive quantity. The momentum p of any body obeying the special theory of relativity can be expressed in terms of its speed by means of equation d, in which m is independent of v. It follows from a combination of this equation and equation a that the quantity represented by equation e does not depend on v and hence is the same for all observers. The quantity m^2 (called the rest mass squared) is then a constant for each object, even for bodies such as photons (light quanta) or tachyons, which are never at rest. One can also deduce from these relations equation f, which implies that if v/c is less than one (as it is for ordinary objects), then pc/E is less than one, $E^2 - p^2c^2$ is greater than zero and hence m^2 is positive. On the other hand, for objects that go faster than light v/c is greater than one, $E^2 - p^2c^2$ is less than zero and hence m^2 is negative. In either case the rest mass squared should always have the same value for a given object and can be measured by measuring the energy and momentum for the object.

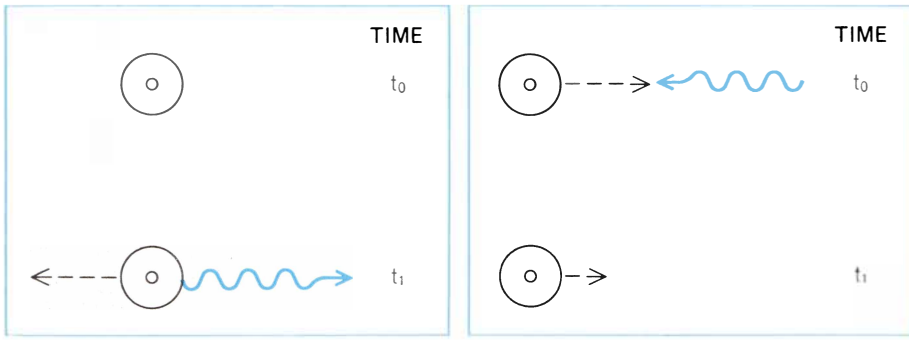
opposite direction produce the same effect on the energy of a system, it is always possible for any observer to insist that all tachyons have positive energy, and that emission and absorption take place in the familiar time-ordering, thus removing the instability problems that negative-energy tachyons would present. This interpretation of the negative-energy states of the tachyon was first proposed in 1962 by O. M. P. Bilaniuk, E. C. G. Sudarshan and V. K. Deshpande of the University of Rochester.

The description given above is in agreement with the principle of relativity requiring that any process that can be seen by one observer must also be a possible process for any other observer. The principle does not require, however, that different observers agree on the interpretation of any individual process. Hence there is no contradiction of the principle of relativity involved in the fact that one observer views as absorption what another views as emission, since both absorption and emission can be witnessed by either observer under suitable conditions. The novelty of tachyons is that emission and absorption must be converted into each other by a change in the observer's velocity, and this implies a closer connection between the two processes than exists for ordinary particles.

It also implies that the number of tachyons in some region of space must vary from observer to observer. Suppose one observer views the process of emission of a tachyon by an atom, with the subsequent escape of the tachyon to infinity. A second observer may view the same process as the tachyon's coming in from outer space and being absorbed by the atom. Hence the two observers will disagree on the number of tachyons present in the past and in the future. Again this situation differs from that for ordinary particles, where the number of particles present at any time is independent of the observer. A detailed theory of the interaction of tachyons with



PECULIAR PROPERTY OF TACHYONS arises from the fact that the time-ordering of points in "space time" between which a faster-than-light particle would move could vary from observer to observer. Thus a process that appears to one observer as emission of a tachyon by one atom followed by absorption of the tachyon by another atom could be reversed for another observer moving with respect to the first. In this schematic representation of such a phenomenon the first observer (*left*) sees atom A at rest in its ground state and atom B at rest in an excited state at time t_0. At t_1 atom B emits a tachyon (*color*), dropping to its ground state and recoiling (*broken arrow*). At t_2 this tachyon is absorbed by atom A, which jumps to an excited state and also recoils. In this situation the time-ordering would be t_0, t_1, t_2. To another observer (*right*), for whom emission and absorption have been exchanged, the same process would appear as follows: Atom A is now moving at time t_0' but is still in its ground state. It emits a tachyon at t_2' and jumps to an excited state, losing some of its translational energy. Atom B, which is moving and in an excited state at t_0', absorbs the tachyon at t_1', dropping to the ground state and gaining translational energy. For this observer the time sequence would be t_0', t_2', t_1'.



POPULATION OF TACHYONS in a region of space at any given time would also vary from observer to observer. One observer (*left*) would view the emission of a tachyon by an atom at rest, with the subsequent recoil to the atom and the escape of the tachyon to infinity. A second observer (*right*) would view the tachyon coming in from outer space and being absorbed by a moving atom, causing the atom to lose translational energy.

matter, which has not yet been worked out, would have to take these features into account.

Having convinced ourselves that the existence of faster-than-light particles does not imply any contradiction of relativity, we must nevertheless leave the determination of whether such objects really happen in nature to the experimental physicist. In the present state of theoretical physics there are few circumstances in which theories flatly predict that certain objects must exist. Instead these theories generally enable us to describe various hypothetical objects, and we must determine by experiment which objects exist in reality. For example, present theories allow for the description of particles with an electric charge equal to half the electron's charge and a mass six times the electron's mass, but we are fairly confident from experiments that no such objects are to be found in nature. We do not, however, know why this is so, and we may not know until we have more fundamental theories than we have now.

The situation with tachyons is similar; to settle the issue of their existence one turns to the experimentalist. This is not to say, however, that he must hope to stumble on them somewhere in the universe. One feature of all particle theories based on relativity is that they imply that if particles of some type exist at all, it must be possible to create them from other particles, provided that enough energy is available. For tachyons this condition of having enough energy is particularly easy to satisfy, because fast tachyons have very low energy. It is therefore easy to set up experimental conditions under which tachyons could be produced from other particles if tachyons indeed exist. The only unknown factor, apart from their existence, is the rate at which they would be produced. Among known particles the production rate varies by many orders of magnitude. Pions, for instance, are produced quite readily, whereas neutrinos are very difficult to produce. Therefore whereas an experiment with a positive result could establish the existence of tachyons, a negative result could at best establish an upper limit for the rate at which tachyons are produced from the particles involved. Only the demonstration that this rate, in all reactions studied, is much less than the rate of production of any other particles would lead to the conclusion that tachyons probably do not exist at all.

Two kinds of experimental attempt to produce and detect tachyons have been made so far. These experiments are sensitive to different types of tachyon and use very different methods, and so they will be discussed separately. The first experiment, which was done two years ago at Princeton University by Torsten Alväger and Michael N. Kreisler, was a search for electrically charged tachyons. It has been known for 35 years that electrically charged particles can be produced in pairs by the passage of high-energy gamma rays (photons) through matter. Many of the known types of charged elementary particle have been made in this way. It follows that if electrically charged tachyons exist, it should be possible to produce them from photons. As indicated above, the fact that tachyons can occur with zero total energy means that a pair of them can be produced by a photon of any energy, whereas a pair of ordinary particles can only be produced by a photon with an energy greater than twice the individual particle's rest energy.

Assuming that charged tachyons are produced, how can they be detected and distinguished from other charged particles that may be produced in the same way, such as an electron-positron pair? A convenient way to do this is to make use of the fact that charged tachyons would continuously radiate photons even when passing through empty space. This phenomenon, known as Cerenkov radiation after the Russian physicist who first observed it from electrons in 1937, occurs whenever a charged object moves through a substance at a speed higher than the speed of light in the substance. Thus an electron moving through glass at a speed greater than about .7 c will emit Cerenkov radiation, since the speed of light in glass is about .7 times its value in free space. Since the speed of a tachyon is greater than that of light in free space, one would expect the tachyon to emit Cerenkov radiation even in a vacuum, and a calculation confirms the expectation: The light would be emitted at a characteristic angle depending only on the speed of the tachyon [*see illustration on opposite page*]. Calculation also shows that a tachyon with the same charge as an electron would lose energy so quickly through Cerenkov radiation that even if it is produced with a very high energy, its energy will drop below one electron volt before it has traveled one millimeter. When this happens, the Cerenkov radiation will no longer include visible light, whose photons have energies of more than two electron volts. Instead the radiation will consist of infrared and longer wavelengths, which are a good deal harder to detect. In order to avoid this problem the Princeton experimenters used the ingenious scheme of allowing any tachyons produced to move through a region empty of matter but containing an electric field. The electric field would transfer energy to charged particles, but it would not cause ordinary particles to radiate detectable amounts of light. A tachyon passing through the region, on the other hand, would reach an equilibrium between gaining energy from the field and losing energy through radiation, and would therefore continue to radiate photons of about the equilibrium energy. By fixing the value of the field, the experimenters were able to make this equilibrium energy correspond to photons of visible light, thus making the radiation easy to detect.

In their experiment Alväger and Kreisler used gamma rays from a radioactive cesium source. These high-energy pho-

tons hit a lead shield that prevented them from reaching the detector directly. Beyond the shield was a high-vacuum region containing two parallel plates with an electric field between them [*see illustration on next page*]. Pairs of charged tachyons could be produced by the photons in passing through the lead, and some of these would escape (since they speed up while losing energy) into the region between the plates. A photomultiplier tube was used to detect any photons radiated by the tachyons passing through the region.

No positive indication of Cerenkov radiation, and hence no evidence for tachyon production, was found in this experiment. More precisely, the rate of production of tachyon pairs was found to be less than one ten-thousandth of the known rate for producing electron-positron pairs by photons of slightly higher energy. The mass-energy relation satisfied by tachyons makes it highly unlikely that this rate can depend very sensitively on either the photon energy or the tachyon mass. Therefore it seems, with one qualification to be discussed below, that tachyons with a charge approximately equal to the electron's charge simply do not exist. Tachyons with a charge differing from the electron's charge by more than a factor of two in the upward direction or .1 in the downward direction would probably not have been seen in the experiment. Of course, uncharged tachyons, which would not emit Cerenkov radiation, would not have been detected either.

The qualification that must be made to these conclusions is that it is uncertain whether or not tachyons might lose energy through processes other than Cerenkov radiation. One such possibility is that a single tachyon could decay into several tachyons, each of lower energy. If there were such other energy-loss mechanisms, the amount of Cerenkov radiation actually emitted might be smaller than the anticipated amount, and the value of the upper limit for the number of tachyons produced would be too low. For this reason, and because we are in general ignorant about possible interactions of tachyons with matter, it was thought desirable to search for tachyons in a manner independent of how they interact after being produced.

Such an experiment was performed recently by a group at Columbia University consisting of Charles Baltay, Ralph Linsker, Noel K. Yeh and myself. The method used was a well-known one for searching for new elementary particles; it is called the missing-mass method. In this approach a large number of reactions among elementary particles are examined in a detecting apparatus (in our case a bubble chamber) in which the momentum and energy of the charged particles in the reaction can be measured. In some fraction of the reactions a number of neutral particles will be produced in addition to the charged particles observed. These neutral particles are usually not observed directly, and it is often not even known how many of them are produced. By applying the laws of the conservation of energy and momentum, however, it is possible to tell from the values measured for the charged particles whether or not any neutral particles have been produced, and also what the momentum and energy carried away by these particles are. The latter quantities, defined as the difference between the energy or momentum of the particles observed going into the reaction and the energy or momentum of the particles observed emerging from the reaction, are known as the missing energy and momentum. If there are no missing energy and momentum in a given event, it suggests that no other particles have been produced.

From the missing energy and momentum in a specific event one can calculate a "missing mass squared" for the event. If exactly one missing neutral particle has been produced, the missing mass squared is the actual mass of the particle squared. A number of elementary particles, such as the neutral eta meson, have been detected in this way. The obvious advantage of the method is that nothing need be assumed about what the missing particle does after being produced. Its presence is indicated simply by the mass it represents, which is inferred from measurements made on known particles.

If a single neutral particle of a specific kind is produced, the missing mass will have the same value in each event, whereas if more than one particle is produced, the missing mass will not have a unique value but will vary from event to event, depending on the angle between the directions of the two neutral particles, among other things. Hence those events containing several neutral particles will in general show a distribution in the missing mass squared over a range of values. Since there is no way of knowing a priori whether a given event contains one or many neutral particles, the experimenter must combine all events to obtain an overall distribution of missing mass squared [*see illustration on page 77*]. The production of single particles will usually stand out as a peak at a specific value in the distribution of missing mass. If there is no such peak, it usually means that the production of a single neutral particle is improbable compared with the production of several neutral particles.

In using the missing-mass method to search for neutral tachyons, we note that if a single neutral tachyon is produced, the missing mass squared is a negative number. Furthermore, if two or more neutral tachyons are produced, the missing mass squared can be either positive or negative depending on the configuration. If the missing mass squared is observed to be negative for any events, then necessarily at least one tachyon must have been produced among the neutral particles. In other words, a collection of ordinary particles cannot have a negative mass squared. Hence in order to investigate neutral-tachyon production by means of specific incident particles, one makes a plot of the missing mass squared for all events and looks for any events with a negative missing mass squared. The production of single tachyons would give a peak in the missing-mass-squared distribution at some negative value, whereas the production of two neutral tachyons would give a broad

CERENKOV RADIATION would be emitted continuously by an electrically charged tachyon moving in a vacuum. The characteristic angle (θ) at which the photons (*black*) would be emitted would depend only on the speed of the tachyon: the faster the tachyon, the greater the angle. Ordinary charged particles, such as the electron, emit Cerenkov radiation only when they move through a substance faster than the speed of light in the substance.

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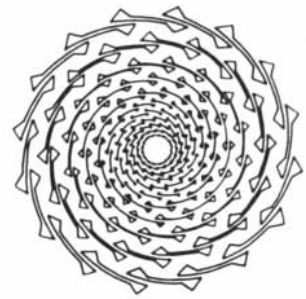

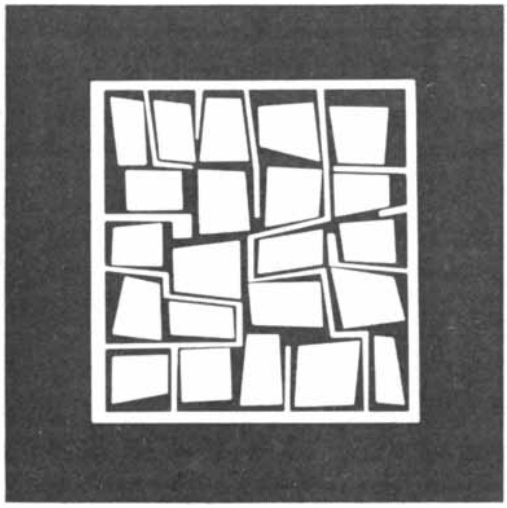

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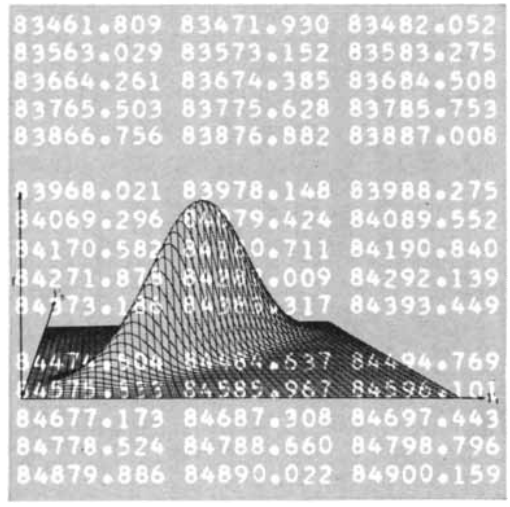

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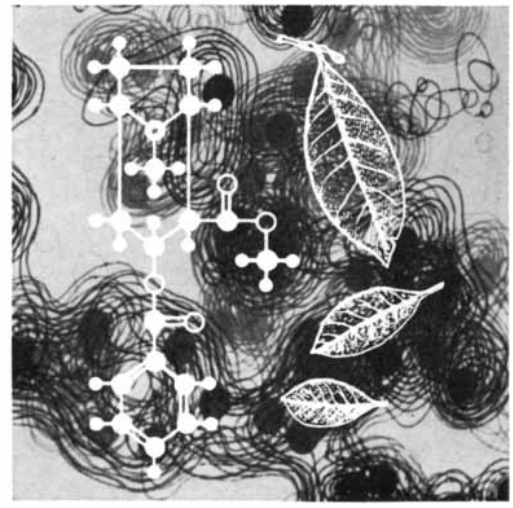

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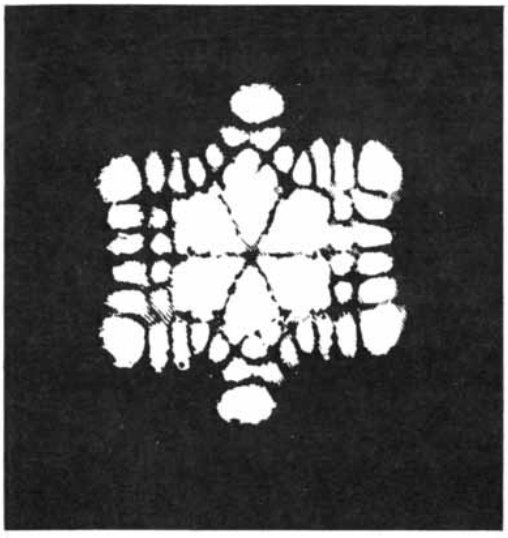

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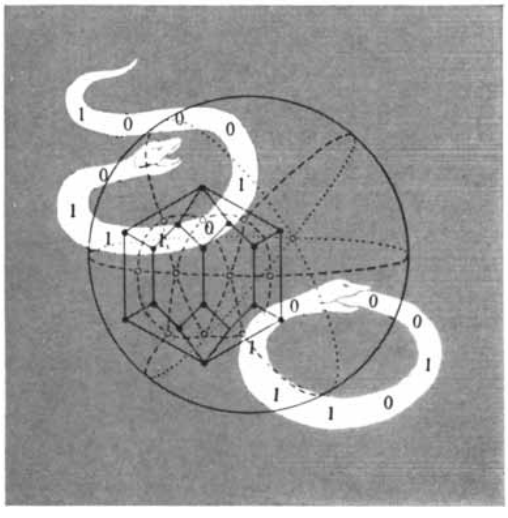

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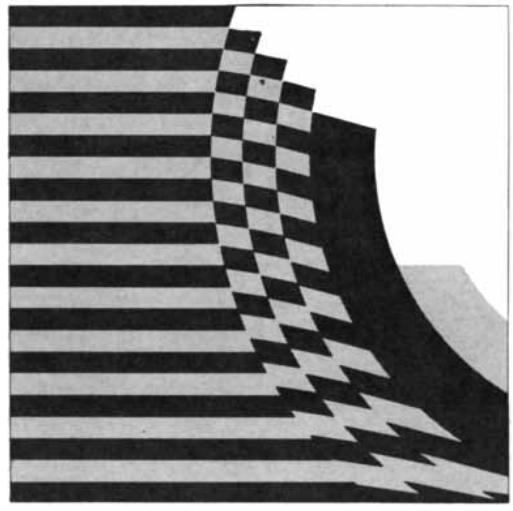

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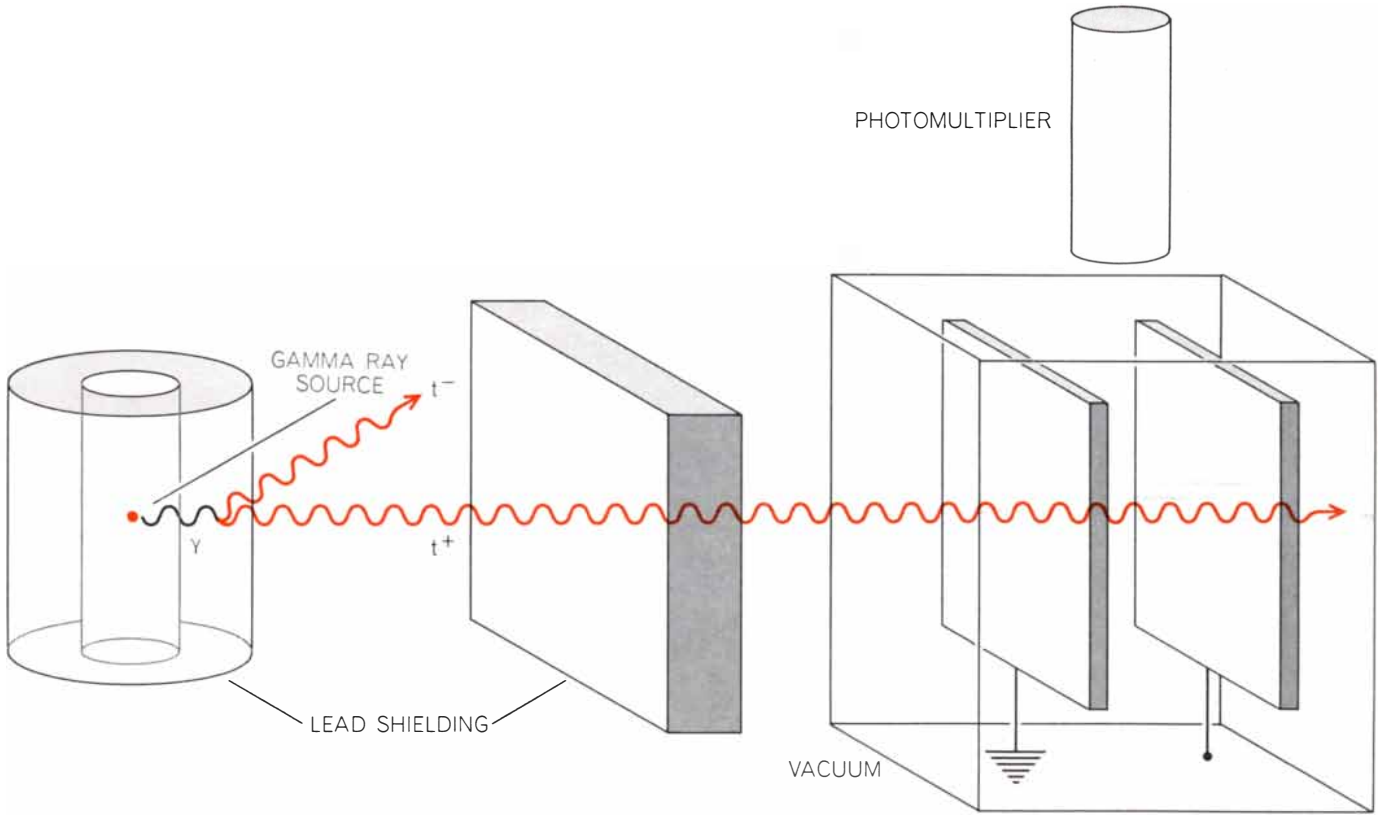
distribution of the total missing mass squared, over both positive and negative values, without any sharp peaks.

In our experiment two reactions were studied. In one, negative K mesons were allowed to come to rest and be captured by protons in a hydrogen bubble chamber. One neutral particle, a lambda hyperon, was produced and was detected through its decay in the bubble chamber into two charged particles. (The momentum and energy of the lambda particle can then be inferred from the measured values for the charged particles.) In order to conserve energy and momentum other neutral particles had to be produced. These were usually a single neutral pion, or sometimes a neutral pion and a photon. The events had all been analyzed previously for other purposes, so that the momentum and energy of the charges were already measured. A plot of the missing mass squared was made for some 6,000 events involving the capture of a negative K meson. It should be realized that in this case the missing energy and momentum are defined as the difference between the sum of the initial values for the K meson and the proton, and the values for the emerging lambda particle, which, as indicated above, can be inferred from its decay products, even though it is neutral. In our first set of measurements a number of events were found with a negative missing mass squared, which suggested tachyon production. Caution, however, suggested that various tests be made before this conclusion could be accepted.

One test involved making sure that the K mesons were really at rest when captured. If this were not the case, the missing mass squared would be incorrectly calculated for a given event, since in the calculation it was always assumed that the meson was at rest when captured. If the direction of the lambda particle were nearly the same as the actual direction of a K meson captured in flight, then the missing mass squared could be measured as negative when it was really positive. Accordingly all events in which the angle between the K meson and the lambda particle was less than 60 degrees were removed from the sample. For true tachyon-production events this should only reduce the number by the ratio of remaining events to total events, whereas it should eliminate all spurious negative-mass-squared events due to capture in flight. When this test was carried out, the number of events with negative missing mass squared was reduced to 23 from an original total of 101, indicating that most of the supposed tachyon events were actually captures in flight, producing ordinary particles.

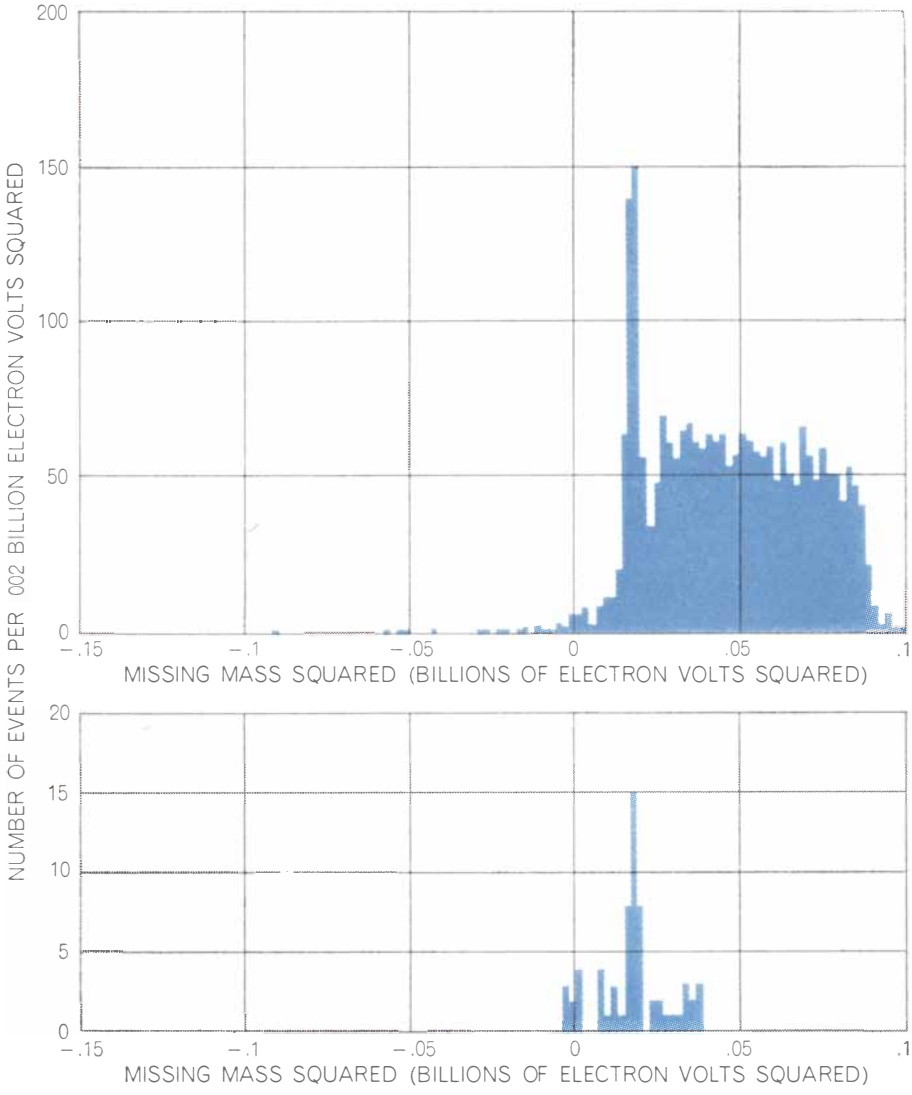
The remaining events were carefully remeasured to ensure that the missing mass squared had been correctly measured. It was found in each case that the true missing mass squared was positive or zero, within the precision of the measurements. Hence what was originally a substantial number of tachyon-candidate events was reduced, after careful study, to none at all. By comparing the limit on tachyon production (less than one) with the total number of events seen, most of which had a missing mass squared represented by a neutral pion, it can be inferred that the rate of tachyon production is less than one part in 400 of the



EXPERIMENT designed to detect charged tachyons by means of their Cerenkov radiation was carried out two years ago by Torsten Alväger and Michael N. Kreisler at Princeton University. They used a radioactive cesium source to provide high-energy gamma rays (γ), which were allowed to hit a lead shield that prevented them from reaching the detection apparatus directly. Pairs of charged tachyons could be produced by the gamma ray photons in passing through the lead, and some of these would escape into a high-vacuum region, which contained two parallel plates with an electric field between them. The purpose of the electric field was to transfer just enough energy to the tachyons to compensate for the energy they lost through radiation, thus enabling them to continue to radiate photons of visible light. A photomultiplier tube was used to detect any photons radiated by the tachyons passing through this region. No positive indication of Cerenkov radiation (and hence no evidence of tachyons) was found in this experiment.

pion production rate, which is typical of a strong production process. Of course, the tachyon production rate was also consistent with zero.

A similar search by the same group, carried out on the annihilation of antiprotons with protons, gave no examples of tachyon production and a similarly low limit for the rate of tachyon production in that reaction. In each of the experiments single tachyons could be produced only if their mass squared was within a specific range of values, and hence the experiment tested single-tachyon production only for particles in that mass range. There are reasons to believe, however, that single-tachyon production is forbidden anyway, just as single production of electrons without other similar particles is forbidden. Nonetheless, production of two tachyons, or of tachyon-antitachyon pairs, is not so forbidden. Such two-particle production could occur in either experiment no matter what the squared mass of the individual tachyons was, and so the experiments actually put rather sharp limits on the production of tachyons of any mass, except for values so near zero that they are within the experimental error of being positive.



RESULTS of the analysis by the author and his colleagues at Columbia of some 6,000 bubble-chamber events involving the capture of a negative *K* meson are presented here in the form of two curves representing the overall distribution of missing mass squared for all events in terms of its energy equivalent in billions of electron volts squared. The highest peak in each case corresponds to the production of single neutral pions. The production of single neutral tachyons would result in a similar peak at some negative value of missing mass squared, whereas the production of two neutral tachyons would give a broad distribution of the total missing mass squared over both positive and negative values without any sharp peaks. In an early set of measurements (*top*) a number of events were found with a negative missing mass squared, which suggested tachyon production. In a subsequent test (*bottom*), which involved rechecking some of the measurements, the number of events with negative missing mass squared was reduced to essentially zero, indicating that most of the supposed tachyon events were actually errors in the first set of measurements.

Both of the direct experimental searches for tachyons that have been carried out have therefore yielded negative results. Indirect arguments have also tended to restrict still further the possible interactions of tachyons. According to one of these arguments, if charged tachyons exist, the photon would not be a stable object but instead would decay within some time period into a pair of charged tachyons. We know that photons can travel for billions of years across intergalactic space without so decaying. This implies that if charged tachyons exist at all, then either their charge is many orders of magnitude smaller than that of the electron, which means that they interact very weakly with photons, or else their mass squared is very close to zero, which makes them difficult to distinguish from ordinary particles. Similar conclusions can be drawn from indirect arguments about the very small interactions of neutral tachyons.

The possibility that tachyons exist but do not interact at all with ordinary particles need not concern us, because if they do not interact with the objects that compose our measuring instruments, we have no possible way to detect them, and for our purposes it is the same as if they do not exist at all.

If we plausibly interpret the above results to conclude that tachyons cannot be produced at all from ordinary particles, we seem to be left with two possibilities. One remote possibility is that tachyons do interact with ordinary particles and can exchange energy with them but cannot be produced from them. This situation would strongly contradict all our experience with relativistic quantum theories of particles, and so it is improbable but perhaps not impossible. The hypothesis could be tested by searching for tachyons in natural phenomena, such as cosmic rays. A difficulty in carrying out such a search is that tachyons should lose energy rapidly and become hard to detect. The second possibility is that tachyons simply do not exist, and that nature has not filled the niche that is allowed by the theory of relativity. If this is the case, as now seems probable, we may not understand why it should be so until we reach a much deeper understanding of the nature of elementary particles than now exists.

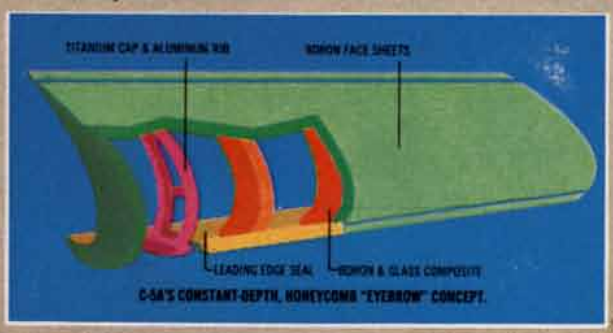
Lockheed is inventing some unexpected composites.

Boron-composite wing slats fly on the C-5A. • New techniques cut boron-aluminum fabrication costs. • Filament-reinforced aluminum doubles in weight, quintuples in strength. • Graphite-wound struts help fuel tanks keep cool.

Research scientists are changing the name of the game in composites. Their aim: to free aerospace designers and engineers from being locked into specifying only those materials that now exist. The future credo will hopefully be to design freely in terms of the need—lighter, stronger, more heat-resistant—and let the scientists invent unique materials to meet the specs. Some of Lockheed's advanced techniques and applications in this direction are described briefly here.

Putting composite "broadgoods" to the test. Just how well large structural parts made of boron laminate composites will hold up is now being determined under actual test on the U.S. Air Force's giant C-5A transport. For wing leading-edge slats, Lockheed engineers formulated sandwich-type panels more than 12 feet long and 4 feet wide. A honeycomb core is bonded between laminated skins of boron/epoxy composite which are cured by autoclaving in contoured fixtures.

To achieve maximum strength/weight advantages, the slat's variable loadings and stresses were computer-analyzed by matrix algebra methods. This permitted making optimum use of one of the best filamentary composite features: the capability of being tailored exactly for meeting point-to-point structural requirements. As a result, layers of boron filaments are added or



C-5A'S CONSTANT-DEPTH, HONEYCOMB "EYEBROW" CONCEPT.

deleted throughout the slat skins so that the material works at top capacity without being excessively thick.

Where the strong filaments must be pierced by holes for mechanical fasteners, a compound technique is used. Thin titanium sheeting is interlaminated with the boron plies to develop excellent joint strength at those points.

The C-5A slats face harsh trials: erosive effects of rain

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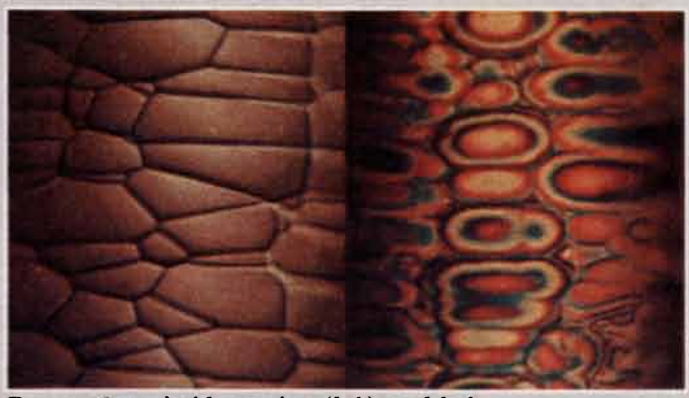
and dust, large variable loads, and acoustic and maneuvering loading that can cause structural fatigue. But, so far, both ground and flight test evaluations show the slats to be well up to their task.

Moving B/Al closer to market. Stepped-up activity in atmospheric, space and undersea environments has widened the demand for light, tough materials with high thermal stability. One answer is boron-reinforced aluminum, a material that can yield from 25% to 40% structural weight savings over conventional aluminum and titanium alloys. But a problem has been price, and how to lower it.

Lockheed scientists, therefore, have developed a truly economical fabrication method. They start by coating boron filaments with a submicron boron-nitride protective film. The "nitrided" filaments are then mated into aluminum-base matrices through a continuous liquid-infiltration process; and the resulting rods or tapes may contain as many as 40 nitrided boron filaments. A secondary continuous casting process joins the basic rods and tapes into larger bodies.

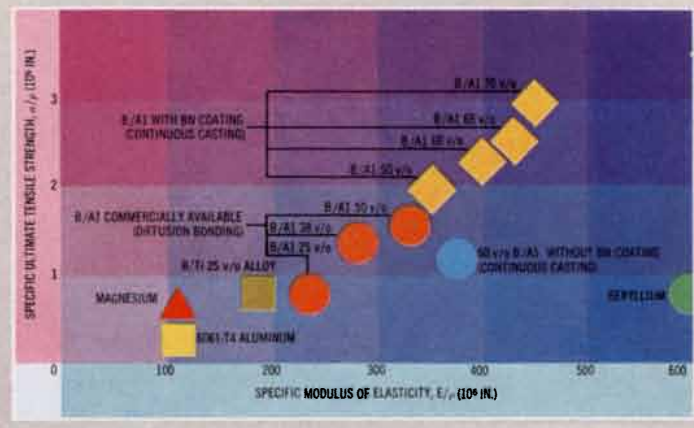


Boron after nitride coating (left) and before.

At maximum fiber content of 65% to 70% of volume, the material has Young's modulus of 38 to 44 million psi. Ultimate tensile strengths are 231,000 to 259,000 psi in the as-fabricated condition; 233,000 to 276,000 psi after 1 hr. of heat treatment in air at 1,050°F. Density is slightly less than 0.1 lb/cu. in.; and strength- and stiffness-to-weight ratios, respectively, have measured 2.9 x 10^6 in. and 4.5 x 10^8 in.

As for thermal stability, the composite shows no strength loss after 100-hr. and 1,000-hr. heat treatments in 600°F air. During tensile tests at up to 1,000°F, longitudinal strengths were slightly higher than room-temperature values. The nitride coating technique clearly promises to push service temperatures for boron-aluminum composites close to the aluminum matrix limit of 800°F.

But perhaps even more important is that the Lockheed developments make possible a reduction in cost of boron-aluminum composites to a point nearing $100 a pound, the cost-effective target for most supersonic aircraft applications in the 1970s.



Improving the weight-to-strength factor. Blending the benefits of metallic structures with those of filamentary composites can produce tubular frame members far lighter and stronger than those now in use. In one instance, Lockheed engineers used an 0.020″-wall, 6061-T6 aluminum tube as a substrate, then bonded high-modulus, high-strength boron filamentary tape to the tube.

Because the substrate is metal, the resulting member can still be joined easily to adjacent structures. The change in weight-to-strength relationship, however, becomes dramatic. Without reinforcement, the tube weighed 0.125 lb. and carried a maximum load of 4,500 lbs. Reinforced with 4 boron plies, the composite tube doubled in weight—0.268 lb.—but carried more than 5 times the load: 22,500 lbs.

Blocking thermal leaks. Aluminum alloy struts supporting a fuel tank were forming an unwanted thermal path, permitting absorption of more BTUs than service requirements allowed. The solution was a nonmetallic strut of high-modulus graphite-filament composite, continuously wound over permanent titanium end members. The result was a threefold improvement: (1) the composite strut's tensile strength exceeds that of 7075-T6 aluminum—100 x 10^3 psi versus 83 x 10^3 psi; (2) strut weight is reduced by 52%; and (3) elastic modulus of the composite exceeds that of the aluminum by 54%. In a similar application for cryogenic tanks, struts formed of fiberglass composite showed a conductivity reduction by a factor of 10 over titanium struts.

The developments mentioned here are only a few of Lockheed's projects in composites technology. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.

Only Marantz Has a Built-in

What's a Marantz?

Any audio engineer or stereo hobbyist will tell you Marantz builds the world's finest high-fidelity components. And has for fifteen years.

This message, therefore, is not to engineers but to professional musicians, serious music-lovers, and beginning stereo hobbyists. We'd like to introduce you to Marantz.

Never Heard Of Marantz?

Until this year, the least-expensive Marantz stereo component you could buy cost $300.00. And our FM tuner alone cost $750.00! To own a Marantz, you either had to be moderately wealthy or willing to put beans on the table for awhile. But it was worth it. And a lot of experts thought so, too, because the word soon got around, and the products sold themselves.

What The Competition Said

The chief design engineer of a major competitor once said that no one even tries to compete with many of Marantz' sophisticated features; it would be just too expensive. Marantz designs its circuits the same way the aerospace industry designs missiles and jet planes—for utmost performance and reliability.

Built-In Oscilloscope

The unique features of a Marantz component are there for only one purpose: to make possible the highest level of listening enjoyment.

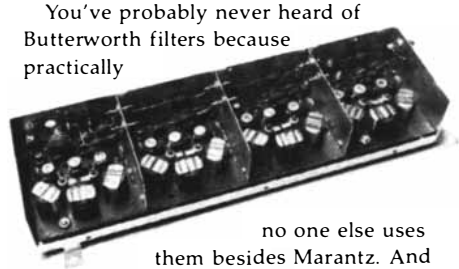
That's why we put an oscilloscope in our best components.

An oscilloscope is kind of a TV tube. But instead of the "Wednesday Night Movie," it shows you a green wavy line. An electronic picture of the incoming FM radio signal, telling you exactly how to rotate your antenna for minimum multipath distortion (ghost signals) and maximum signal strength (clarity) even from the weakest stations.

The "scope" also shows correct stereo phasing: that is, whether the broadcasting transmitter or your equipment is out of phase. And it lets you set up optimum stereo performance and reception to create a solid "wall" of sound.

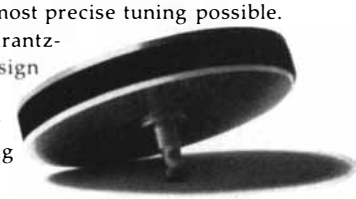
Features, Not Gimmicks

You've probably never heard of Butterworth filters because practically



no one else uses them besides Marantz. And the U.S. Military. Other manufacturers feel they can get by without them. And they can. Because their standards don't have to measure up to Marantz'. Butterworth filters let you hear music more clearly, with less distortion, and, unlike conventional I.F. coils or filters, they never need realignment. They help pull in distant FM stations and separate those right next to each other on the dial. Although Butterworths cost more, Marantz designed not one but four of them into our Model 18 receiver.

Marantz also offers a different tuning experience because you rotate the actual tuning flywheel. This results in the smoothest, most precise tuning possible. And this Marantz-exclusive design requires considerably fewer moving parts than conventional systems used by other manufacturers. The benefits: reduced friction, wear, and service problems. We call this patented feature "Gyro- Touch tuning."



Built To Last

Marantz stereo components aren't built in the ordinary way. For example, instead of just soldering connections together with a soldering iron, Marantz uses a highly sophisticated waveflow soldering machine—the type demanded by the Military. The result: perfect, failproof

Oscilloscope!

connections every time.

Even our printed circuit boards are a special type—glass epoxy—built to rigid

military specifications, ensuring ruggedness and dependability.

Marantz Power Ratings Are True

When someone tells you he has a "100-watt amplifier," ask him how the power was rated. Chances are his 100 watts will shrink to about 75 or 50 or perhaps even as few as 25. The reason is that most manufacturers of stereo amplifiers measure power by an inflated "peak power," or "IHF music/dynamic power."

Marantz states its power as "RMS continuous power" because Marantz believes this is the only method of measurement that is a true, absolute, scientific indication of how much power your amplifier can put out continuously over the entire audible frequency range.

But if Marantz *were* to use the unscientific conventional method, our Model Sixteen 100-RMS-100 power amplifier could be rated as high as 300 watts

Moreover, you can depend on Marantz to perform. For example, the Marantz Model 16 can be run all day at its full power rating without distortion (except for neighbors pounding on your wall). That's power. And that's Marantz.

Marantz Speaks Louder Than Words

In a way, it's a shame we have to get even semitechnical to explain in words what is best described in the medium of sound. For, after all, Marantz is for the listener. No matter what your choice in music, you want to hear it as closely as possible to the way it was performed.

In spite of what the ads say, you can't really "bring the concert hall into your home." For one thing, your listening room is too small. Its acoustics are different. And a true concert-hall sound level (in decibels) at home would deafen you.

What Marantz does, however, is create components that most closely recreate the sounds exactly as they were played by the musical performers. Components that consistently represent "where it's at" in stereo design. And no one gives you as much—in any price range—as Marantz.

Every Marantz Is Built The Same Way

Every Marantz component, regardless of price, is built with the same painstaking craftsmanship and quality materials. That's why Marantz guarantees every instrument for three full years, parts and labor.

Now In All Price Ranges

Today, there is a demand for Marantz quality in other than very-high price ranges. A demand made by music-lovers who want the very best, no matter what their budgets. True, you can still invest more than $2,000.00 in Marantz components, but now we have units starting as low as $209. Though these lower-priced models do not have every unique Marantz feature, the quality of *all* models is the same. Marantz quality.

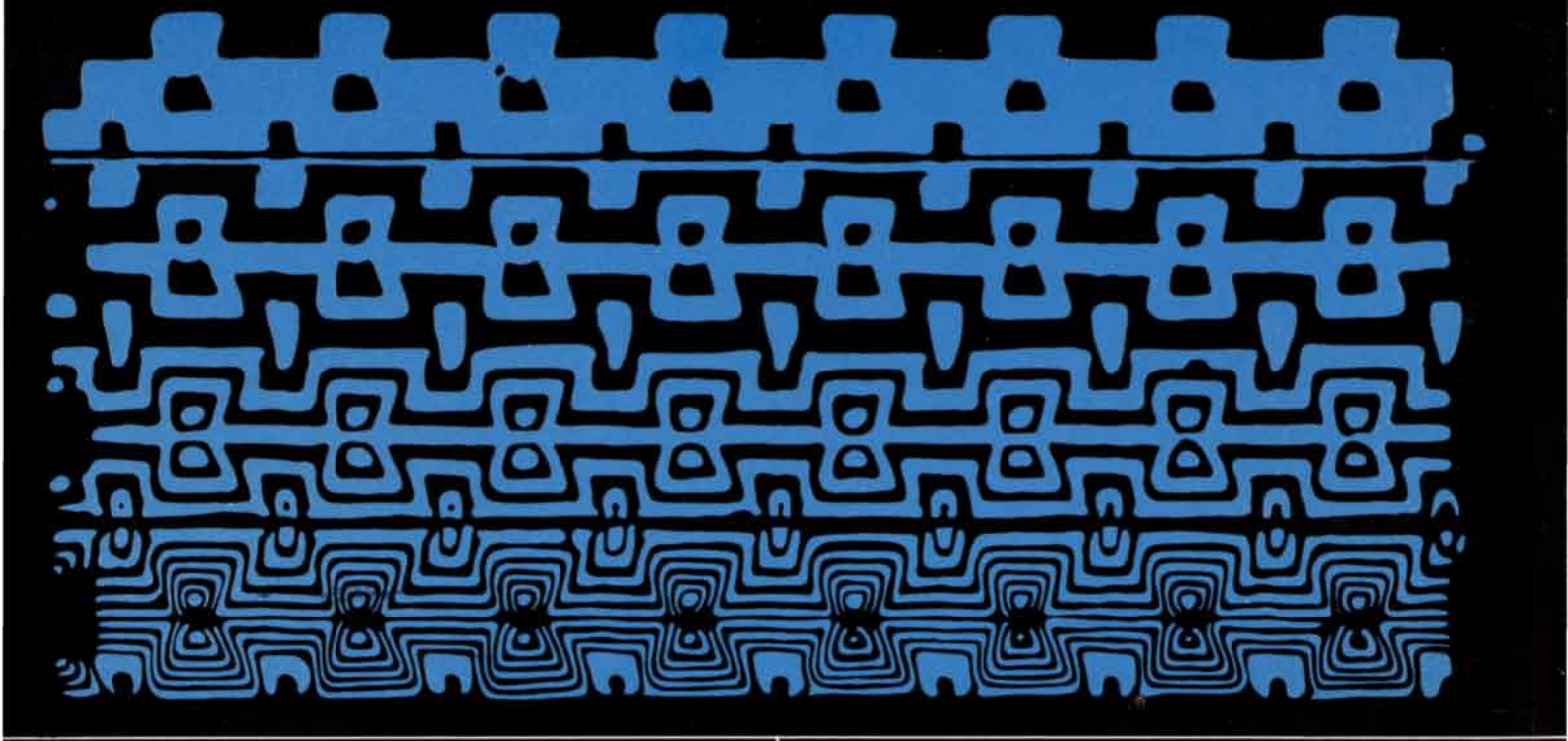
And quality is what Marantz is all about.

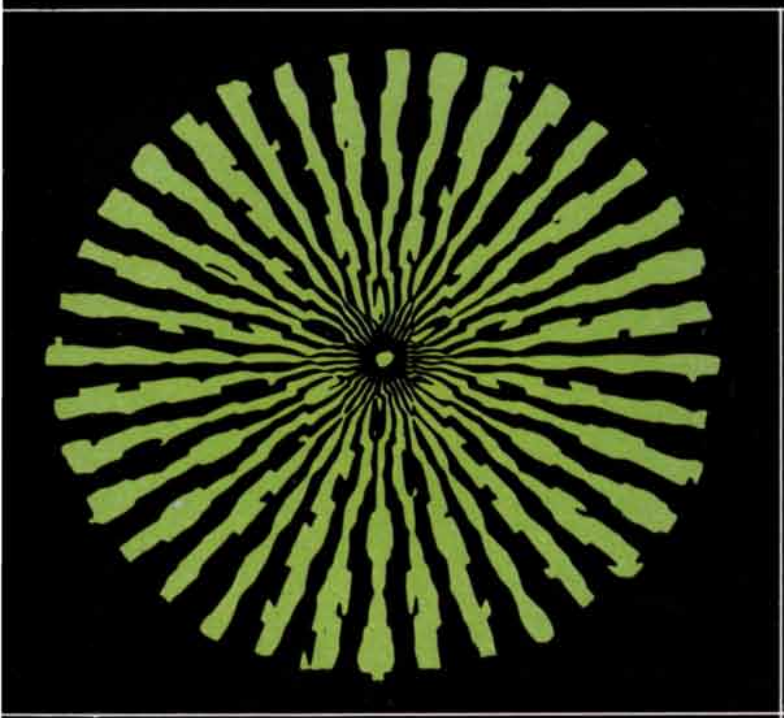
Hear For Yourself

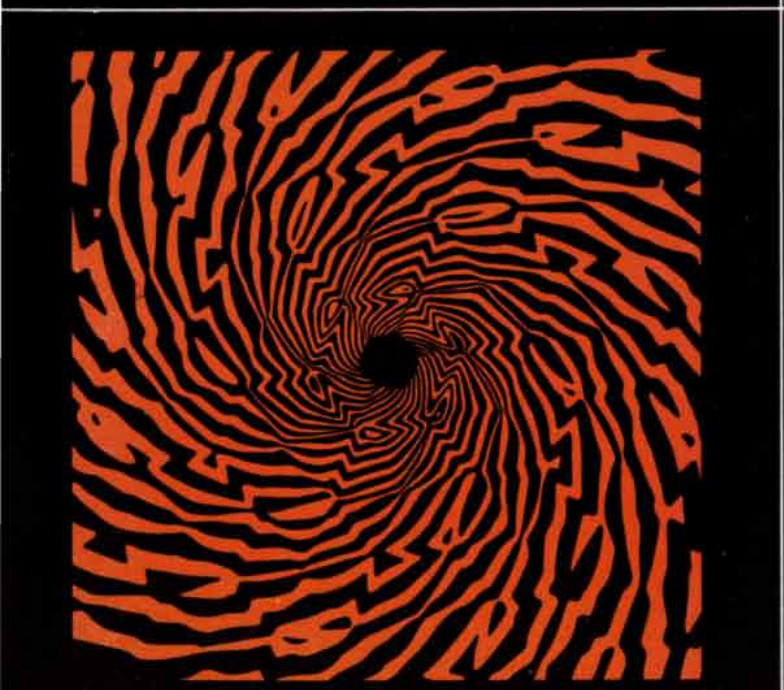
So now that you *know* what makes a Marantz a Marantz, *hear* for yourself. Your local dealer will be pleased to give you a demonstration. Then let your ears make up your mind.

marantz®

Components • Speaker Systems • Receivers







PHOSPHENES

"Seeing stars" is seeing phosphenes, subjective images generated within the eye and brain rather than by light from outside. They presumably reflect the neural organization of the visual pathway

by Gerald Oster

The eye is a sense organ that can readily be turned off. One can exclude optical inputs by entering a totally dark room or wearing a light-tight blindfold. Yet visual perception does not end; one does not have an impression of total blackness. As the eyes become adapted to darkness, and particularly if one relaxes, the visual field lights up: wispy clouds and moving specks of light appear, generally in pastel shades of blue, green, orange and yellow. Pressing the eyes evokes still other figures. These subjective images resulting from the self-illumination, as it were, of the visual sense are called phosphenes (from the Greek *phos*, light, and *phainein*, to show). Because phosphenes originate within the eye and the brain they are a perceptual phenomenon common to all mankind, and they are extremely interesting from a psychological and aesthetic standpoint. Because their patterns must be intimately related to the geometry of the eye, the visual pathway and the visual cortex, they provide a means of studying the exquisite functional organization of the brain.

Phosphenes can arise spontaneously, and they can also be provoked in a number of ways. They appear spontaneously only when the usual visual stimuli are lacking and particularly when the viewer is subjected to prolonged visual deprivation. Phosphenes may account for the "illuminations," the visions or the experience of "seeing the light" reported by religious mystics meditating in the dark; they are the "prisoner's cinema" experienced by people in dark dungeons; they may well constitute the fact behind reports of phantoms and ghosts. Darkness is not a requirement; only the absence of external visual stimuli is needed. Phosphenes are a hazard to the long-haul truck driver peering for hours into a snowstorm. Airplane pilots often experience phosphenes, especially when they are flying alone at high altitudes, where the sky is cloudless and empty of the usual depth cues. (One wonders what future astronauts will see on trips to Mars as they peer into the void for several months.)

It is instructive for an adult to ask an articulate child what he sees when he closes his eyes at bedtime. Children have an ability, which diminishes with adolescence, to evoke phosphenes quite easily. Phosphenes may indeed be an important part of the child's real environment, since he may not readily distinguish this internal phenomenon from those of the external world. The developmental significance of phosphenes is suggested by a study, conducted by Rhoda Kellogg at the Golden Gate Nursery School in San Francisco, of some 300,000 scribblings made by young children of different ethnic origins. Children between the ages of two and four, capable of manipulating a pencil but not of making naturalistic pictures, draw figures that have a distinct phosphene character [*see illustration on page 86*]. Were phosphenes also part of the subject matter of art in the childhood of the human species? Phosphene-like figures appear in prehistoric cave drawings and in folk art and more sophisticated works from many cultures and different periods [*see top illustration on page 87*]. Art historians, it seems to me, might well consider the possible effects of phosphenes as an "intrinsic" source of inspiration for men of many different societies when they are speculating on relations and cross influences among primitive cultures.

"Seeing stars" is seeing phosphenes, an experience that can be induced by a blow on the head or by other mechanical means. A less violent procedure is to apply pressure to the eyeballs with the fingers. If, with the eyes closed, one gently touches the lid with the tip of a finger, a phosphene appears: a glowing circle or part of a circle, apparently about a quarter of an inch in diameter [*see upper illustration on next page*]. The phosphene's location in the visual field is opposite the point the finger touches: at the outer edge of the field when the eyelid is touched near the nose, low in the field when the center of the upper lid is touched.

Increasing the pressure on the eyeball produces more dramatic phosphenes. One procedure is to apply the index fingers at the inner edge of the eyeballs and press in and toward the temples [*see lower illustration on next page*]. The visual field lights up and then, as pressure is maintained for a few seconds, a scintillating design appears—a kind of checkerboard or shifting field of glowing dots, sometimes with elaborate substructures arrayed around a luminous center. When the pressure is released, the checkerboard fades away, sometimes leaving the central luminosity. If the pressure is then renewed, a pattern of bright, irregular lines appears that resembles a system of blood vessels. When the pressure is again released, a fine filigree image appears and remains for some time. The checkerboard design is probably some manifestation of the orderliness of the

PAINTINGS made by the author are attempts to capture the subjective impression of phosphene shapes and colors. The paintings were done with an oil suspension of phosphorescent pigments that glow in the dark and then diminish in intensity as phosphenes do.

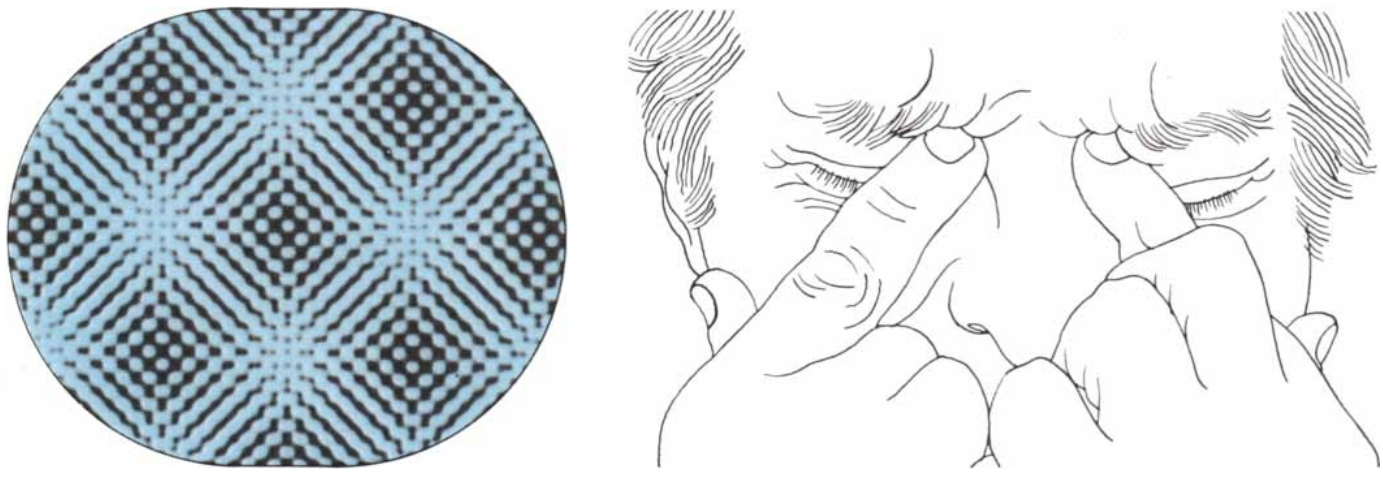
neural network of the retina; it shifts in the visual field as the gaze is shifted. The filigree, on the other hand, may be generated farther along the visual pathway, since it remains stationary regardless of where one looks. As the reader will discover when he and others try these experiments, individual sensitivity varies widely. I know one woman who, if she inadvertently rubs her eyes with a towel in the morning, provokes such intense phosphenes that they are superposed on her normal vision for hours afterward.

Pressure phosphenes act like external light in that they influence afterimages [see "Afterimages," by G. S. Brindley; SCIENTIFIC AMERICAN, October, 1963]. An afterimage is the image perceived when one closes one's eyes after having stared at a bright source of light for about 10 seconds. If one turns from the bright source to gaze at a dimly lighted white wall, the afterimage is dark—a negative image. The afterimage also appears as a negative if, instead of staring at a white wall after looking at the bright source, one closes one's eyes and superposes a pressure phosphene; the "light" from the phosphene serves as the luminous background. Pressure phosphenes have their own negatives. A phosphene produced by touching the eyelid gently appears as a dark circle if the eye is kept partly open and fixed on a well-lighted surface.

A different kind of mechanically induced phosphene results when one suddenly moves one's eyes after having been in the dark for some time. The best occasion for this is on waking up while the room is still dark. The characteristic pattern is a fan-shaped burst of yellow arcs that are clearly defined at first but that become fuzzy when one tries to generate the phosphene again [*see illustration on opposite page*]. The late Bernard Nebel of the Argonne National Laboratory studied these eye-movement phosphenes in detail. He suggested that they may be produced by inertial drag exerted on the retina by the vitreous humor, the clear gel that fills the eyeball.

Phosphenes are also induced by a wide variety of chemical agents. Alcohol is one; a person with delirium tremens may see a field of bright, moving specks that he may interpret as insects crawling on the wall. Toxins such as those associated with scarlet fever may evoke similar phosphenes. Hallucinogenic drugs such as mescaline, psilocybin and LSD often evoke phosphenes of abstract design. Indeed, phosphenes appear to be a significant feature of psychedelic intoxication. Some years ago I took a small dose of LSD (75 micrograms) in the course of an experiment in visual psychology. Long after the other effects of the drug had worn off—for six months, as a matter of fact—I saw magnificent phosphenes at bedtime. For the most part they were variations of rather simple geometric forms in pastel shades of yellow, orange and green. (Psilocybin,

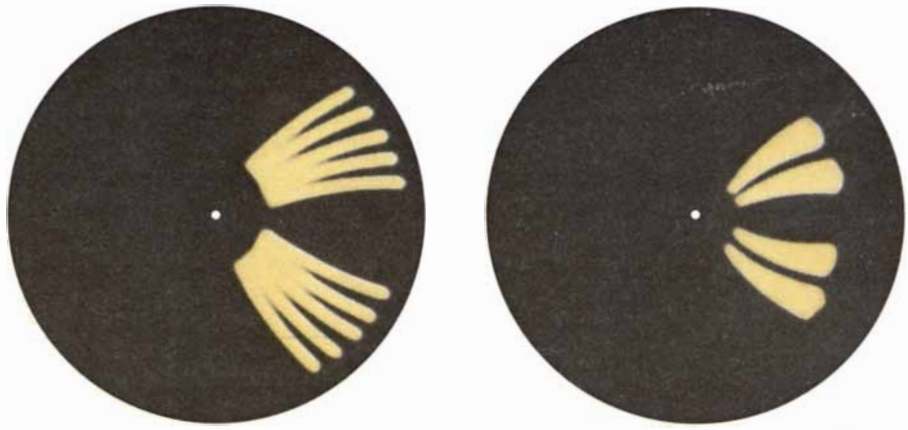
LIGHT TOUCH on the eyelid (*right*) produces phosphenes that are circular in form: disks or concentric circles or arcs (*left*). The phosphenes induced by gentle pressure tend to appear at the side of the visual field opposite the point at which the pressure is applied.



STRONG PRESSURE on the eyeballs (*right*) produces a phosphene that resembles a checkerboard or a field of lights in motion (*left*). The effect has been simulated here with a moiré pattern but the dynamic quality of such a phosphene is hard to reproduce.

according to other investigators, tends to produce phosphenes in disquieting colors—deep blue and dark green.)

Pronounced phosphenes are associated with a number of disorders. A person suffering from migraine headache may see a checkerboard or "fortification" pattern [*see top figure in illustration on page 82*], usually in the half of the visual field that is opposite the side of the head where the ache is localized. Ophthalmologists recognize a pronounced phosphene that regularly accompanies movement of the eye as a symptom of a detached retina. Disturbing phosphenes may also arise from pressure on the optic nerve or on the visual regions of the brain, caused by a tumor or by some vascular disorder within the cranium.



EYE-MOVEMENT PHOSPHENE is produced by a flick of the eye, particularly on arising from sleep in a dark room. It first appears (*left*) as an array of arcs originating near the fovea (*dot*); an attempt to repeat it yields a softer image (*right*) on the fatigued retina.

A convenient way to produce phosphenes for experimental purposes is with electrical impulses. The electrical induction of phosphenes was discovered in the 18th century, when it was considered entertaining for a group of people to join hands in a circle and receive a shock from a high-voltage electrostatic generator. Benjamin Franklin, participating in one of these diversions in Paris, noticed that along with the shock came a flash of light that could be seen with the eyes closed. Alessandro Volta spent much time investigating this phenomenon. He discovered that the flashes appeared only at the making or breaking of the circuit, not during current flow, and that phosphenes were most easily induced by electrodes placed at the temples. In 1819 the Bohemian physiologist Johannes Purkinje published the most detailed early account of phosphenes. He applied one electrode to his forehead and the other to his mouth, and by rapidly making and breaking the current with a string of metal beads he was able to induce stabilized phosphene images.

The most extensive investigation of electrically induced phosphenes was carried out by the late Max Knoll and his colleagues at the Technische Hochschule in Munich. (Knoll is better known as the builder, with E. A. F. Ruska in 1932, of the first electron microscope.) The contemporary way to produce repetitive on-off changes in voltage is to use a square-wave generator. Knoll applied low-voltage square-wave pulses (about one volt, with only a milliampere of current) to the temples, wrapping the electrodes in felt soaked in a salt solution in order to make good electrical contact. He found that pulses in the same frequency range as brain waves (from five cycles per second to about 40) were most effective in producing phosphenes. He tested more than 1,000 people and found that all of them, after becoming dark-adapted, saw at least a flickering light; by concentrating carefully about half of the subjects also saw geometric figures.

As Knoll varied the frequency of the pulses the patterns changed, and by altering the frequency Knoll's group identified 15 classes of figures [*see bottom illustration on page 87*] and a number of variations within each class. For each person tested the spectrum of phosphenes (the kind of pattern at each frequency) was repeatable, even after six months. The frequency dependence of phosphene form is suggestive of some kind of resonance phenomenon, with different groups of nerve cells acting together when they are driven electrically at a certain rate. The Munich group found, incidentally, that electrically induced phosphenes were considerably more elaborate for subjects who had been given a very small dose of a hallucinogenic drug, say 10 micrograms of LSD.

The formless, flickering phosphenes that are apparently induced in all subjects by electrical pulses have been the subject of a number of investigations. I find that the flickering does not seem to wander with the gaze, suggesting that it arises deeper than at the retina. Probing the eyelid with a small electrode produces flickering in the same part of the visual field as the electrode; this is in contrast to the phosphenes produced by slight pressure, which appear on the side of the field opposite the pressure.

In my laboratory at the Mount Sinai School of Medicine in New York we have explored the relation between the flickering field and frequency. Mordecai Shlank and I found that there is a maximum frequency above which the flickering light disappears. Ordinarily light above a certain frequency (the critical fusion frequency) seems steady. (A tungsten lamp flickers in the New York City subway, where the current alternates at 30 cycles per second, but it appears steady on a 60-cycle home circuit.) With electrically induced phosphenes, however, as the frequency is increased the flickering does not smooth out; instead the field goes black above about 40 cycles. The effect is eerie: as the frequency is increased past the critical point the phosphenes suddenly disappear, leaving one with a feeling of being left alone in space. Apart from its emotional effect, this phenomenon may be worth studying in order to separate the purely neurological aspects of vision from those originating with the external light stimulus.

Using two electrically independent generators and four electrodes, we have applied pulses of two different frequencies at the same time. Each is just above the critical point and would therefore produce no phosphenes by itself. Together they generate beats, which are seen as undulating phosphenes that move slowly across the field of view. It would appear that some neural mechanism "mixes" the two signals, which interact periodically to produce a beat, just as the auditory system mixes tones of two different frequencies when they are applied simultaneously, one to each ear.

When flickering phosphenes are combined with normal vision, the phosphenes begin to take on a form. If one stares at a brightly lighted white surface while rather high-frequency pulses (100 cycles per second) are applied, fig-

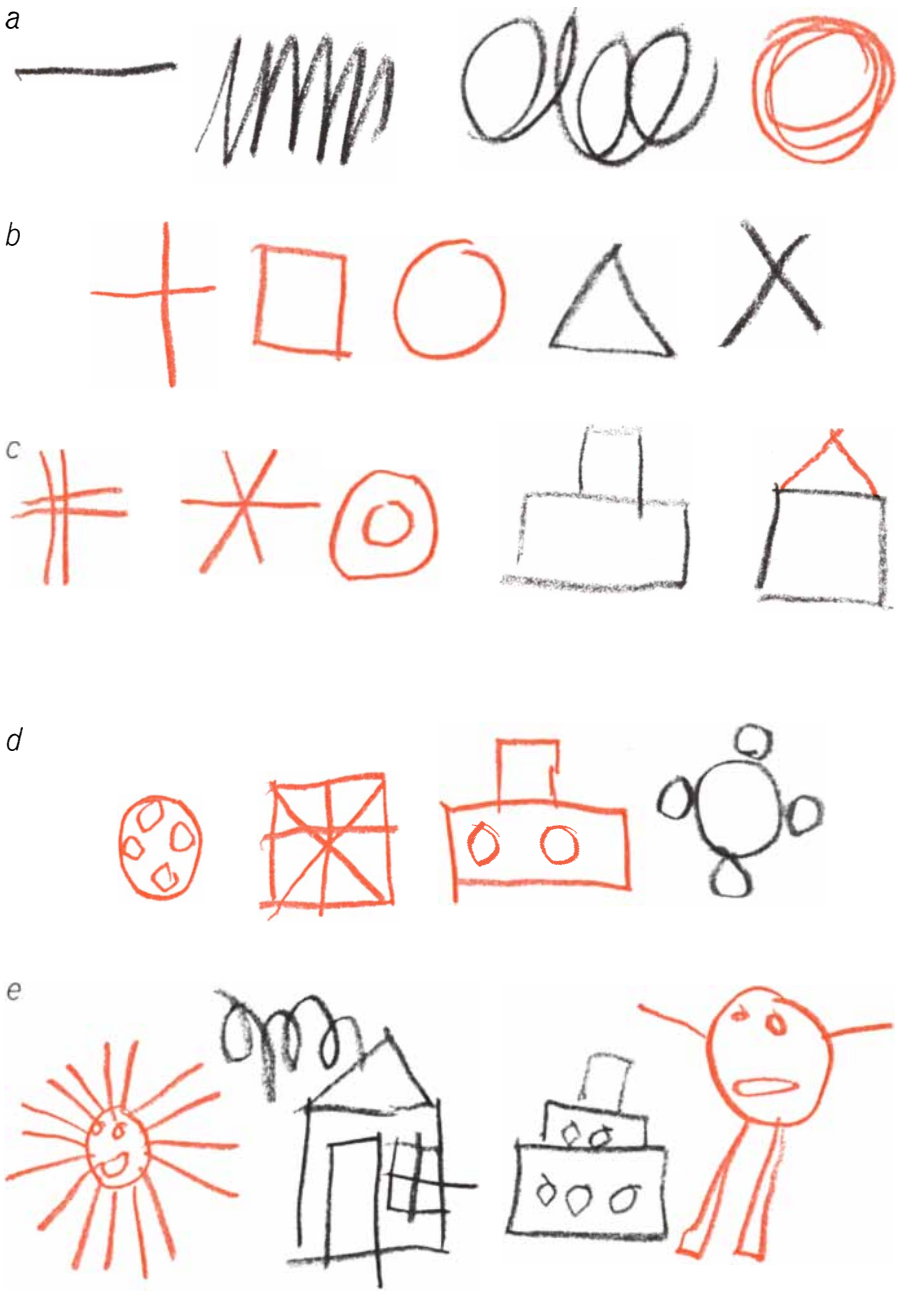
ures resembling a contour map appear. If the light is periodically interrupted by a shutter rotating at about the same frequency as the voltage being applied, the contour phosphenes slowly wax and wane in intensity. This is another beat phenomenon, with the frequency of the beat determined by the relative frequencies of the electrical and the light stimuli. G. S. Brindley of the University of Cambridge found that when the frequency of the light is an exactly integral multiple of the electrical pulses, the appearance of the beat is quite sensitive to the phase relations of the two stimuli. He also found, interestingly enough, that beats could be seen even when the frequency of the interrupted light far exceeded the critical fusion frequency; evidently information about frequency was somehow getting through the visual apparatus even though the light alone would have seemed steady in the absence of the electrical signal. That nerves should distinguish among high frequencies is of course not surprising; the auditory nerves do, after all.

As I have mentioned, phosphenes seem to originate at different points along the visual pathway. The visual areas of the brain can be stimulated directly to produce phosphenes. This has been demonstrated by a number of investigators, usually in the course of brain operations during which the patient is conscious under local anesthesia. In 1928 a German neurosurgeon, Otfrid Foerster, noticed that when he electrically stimulated the surface of the occipital lobe at the back of the brain, the patient experienced the sensation of light.

The technique of electrical stimulation of the surface of the brain (the cerebral cortex) has been highly developed in recent years by Wilder Penfield and his colleagues at the Montreal Neurological Institute. They apply an alternating current to two closely spaced electrodes in contact with various areas on the surface of the brain. Stimulating the visual cortex at the extreme rear of the brain interrupts the patient's normal vision and causes him to see specks of light. When the electrodes are moved to the adjacent region, the visual associative area, the patient reports seeing phosphenes of geometric design. When the electrodes are moved farther forward, the patient frequently reports a visual scene of some past experience that is so vivid as to seem to be current. Penfield's experiments do not establish just where in the brain the phosphenes are being produced. It could be at the site where the electrodes are applied, or conceivably at some other locus in the visual pathway to which the electrical impulses may be transmitted. In any case there is apparently some relation to eye motion, since the phosphenes produced by stimulation of the visual cortex move in the direction in which the patient gazes.

The human brain is notable for its large area devoted to vision. The region of the visual cortex devoted to fine visual detail alone is some 10,000 times as large in area as the fovea, the central region of the retina whose closely packed cone cells discriminate fine detail. Because the visual cortex is the most convoluted portion of the brain, much of it is not available to Penfield's surface electrodes, and so other techniques are required in order to stimulate it selectively.

One reason for pursuing research into such methods is the possibility of developing a visual prosthesis for people blinded by injury to the eyes or the optic nerve. The cortex of such a patient may be subject to electrical stimulation even though he may not have received visual inputs for several years. At Cambridge, Brindley and W. S. Lewin estimated on the basis of the topology of the visual cortex that if 50 closely spaced centers



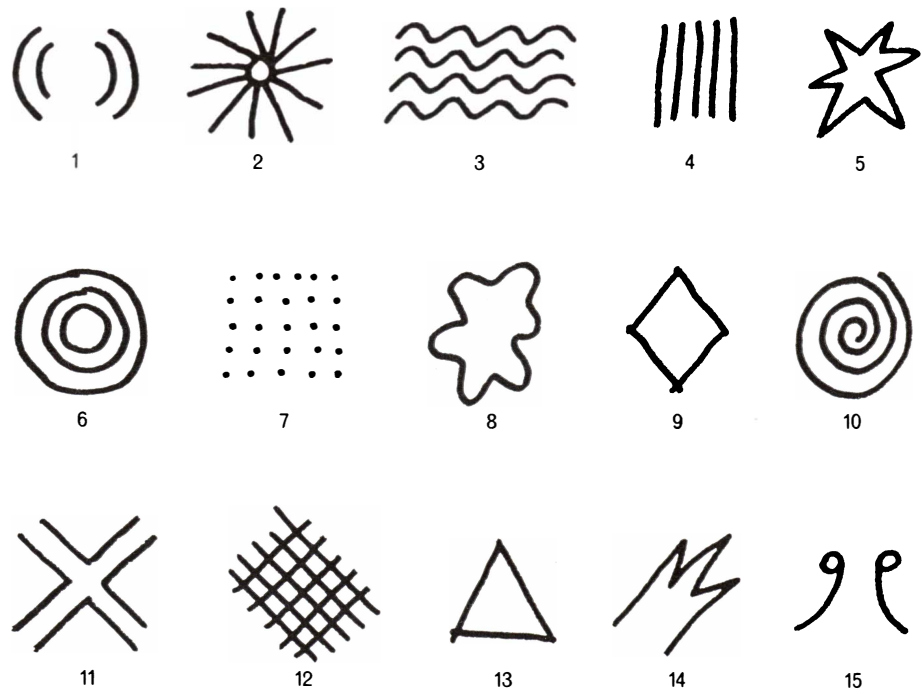
CHILDREN'S SCRIBBLINGS may be derived in part from phosphenes. A child's drawing progresses, according to Rhoda Kellogg, from "basic scribbles" (*a*) and "diagrams" (*b*) through "combines" (*c*) and "aggregates" (*d*) to pictorial figures (*e*). Many of the forms that appear in scribbles and diagrams are similar to typical electrically induced phosphenes.

could be excited, the patient would have enough resolving power to "read" ordinary printed letters one at a time; for normal reading speeds 600 centers would be required. Brindley and Lewin first experimented with baboons. They encapsulated tiny resonators—essentially radio receivers—in silicone plastic and implanted them under the scalp. Each resonator was connected (by a cable that passed through a hole in the skull) to a corresponding platinum electrode in contact with the visual cortex. The Cambridge workers were able to excite different electrodes by moving over the scalp a radio transmitter tuned to the natural frequencies of different resonators. (Such a transmitter might, if it were desired, be activated instead by photocells arranged so as to sense a pattern of light.)

After preliminary studies with baboons, Brindley and Lewin applied an array of 80 electrodes to the visual cortex of a human volunteer, a woman who had been blinded in both eyes by glaucoma. The patient reported seeing two distinct point phosphenes when resonators separated by only a tenth of an inch were excited. The phosphenes disappeared as soon as the stimulus was removed, although an afterimage was seen if the stimulus was very strong. As one might expect, there is no simple one-to-one correspondence between the location of the excited resonator and the position of the point phosphene in the visual field; if a patient were to recognize letters, it would be by learning to associate a particular pattern of phosphenes with certain letters. An alternative approach would be to somehow process the electrical inputs to the brain, coding them to provide a more literal picture of the letters.

The resonator-implant method may never be effective for someone who has been blind since birth. Such people do not report phosphenes, whereas many persons blinded by accident or disease are conscious of phosphenes and indeed find them a source of visual entertainment. I am now working with ophthalmologists to test the sensation and character of the phosphenes elicited by pressure and by electrical stimulation in patients suffering from various kinds of blindness, ranging from detached retinas through nerve destruction to invasion of the visual cortex by tumors. The idea is to see at what level one can induce the phosphene experience and therefore at what level it may one day be possible to intervene with some kind of visual prosthesis.

APPEARANCE of certain geometric forms in art from many times and places suggests that they may have a common origin in phosphenes. Such forms appear in a prehistoric painting from Almería in Spain (*top*) and in clay stamp motifs from Mexico (*bottom*).



CLASSIFICATION of electrically induced phosphenes was undertaken by Max Knoll. On the basis of reports from more than 1,000 volunteers he grouped the phosphenes into 15 categories, each represented here by a typical example and numbered in accordance with its commonness. Certain forms are characteristic of each pulse frequency for each individual.

The Rangelands of the Western U.S.

These vast tracts are mainly utilized for the grazing of cattle. They could be much more productive, not only from the economic standpoint but also in the recreational and the aesthetic sense

by R. Merton Love

The century-old war over the use of the wide-open spaces of the U.S. is now escalating year by year in scope and complexity. In the 19th century it was a relatively simple conflict, mainly between the cattle ranchers and the sheep raisers. Today it has become a huge contest among many interests vying for the space, resources and beauties of our Western rangelands. To the traditional claims on these lands by ranchers, lumbermen, miners, hunters, campers and nature lovers there are now added the demands arising from population growth and the consequent march of urbanization. A creeping encroachment by burgeoning cities and new towns, recreation resorts, highways, communication facilities, industries and intensive farming (displaced by the spreading urbanization of the East and Middle West) is pushing into the ranges and wilds of the West. The resulting pressures, not only for space but also for corollary necessities such as water, obviously make it essential to seek a strategy for management of the rangelands that will reconcile and accommodate the many different interests.

The rangeland region comprises most of the area of the 17 Western states—roughly the portion of the continental U.S. west of Omaha. A tourist roaming this largely wild domain (or seeing it from the air) may well wonder what all the fighting is about. It is a region of mountains, deserts, plateaus and dry basins; of low precipitation, rough topography and shallow, rocky, saline soil; of forests, semiarid grasslands and clumps of inedible shrubs. The terrain seems of little value for anything except the enjoyment of its beauty and the grazing of animals on its meager fare.

The appearance is deceiving. In productivity and economic importance this region, even in the wild state, makes substantial contributions to the national wealth. Its production of meat alone (not to speak of lumber and minerals) is impressive. The Western rangelands, constituting the major portion of the billion acres of range and pasture in the continental U.S., account for more than half of the national production of livestock, which is estimated to total $5 billion to $10 billion a year (compared with $14 billion for all other crops including forest products).

Why not let well enough alone? What could be accomplished by "management" of this beautiful and surprisingly productive region? Should we not restrict ourselves to "conservation" of what nature has wrought?

Experience tells us that we should not take so negative an attitude. The idea that we ought not to meddle with nature arises from several misconceptions.

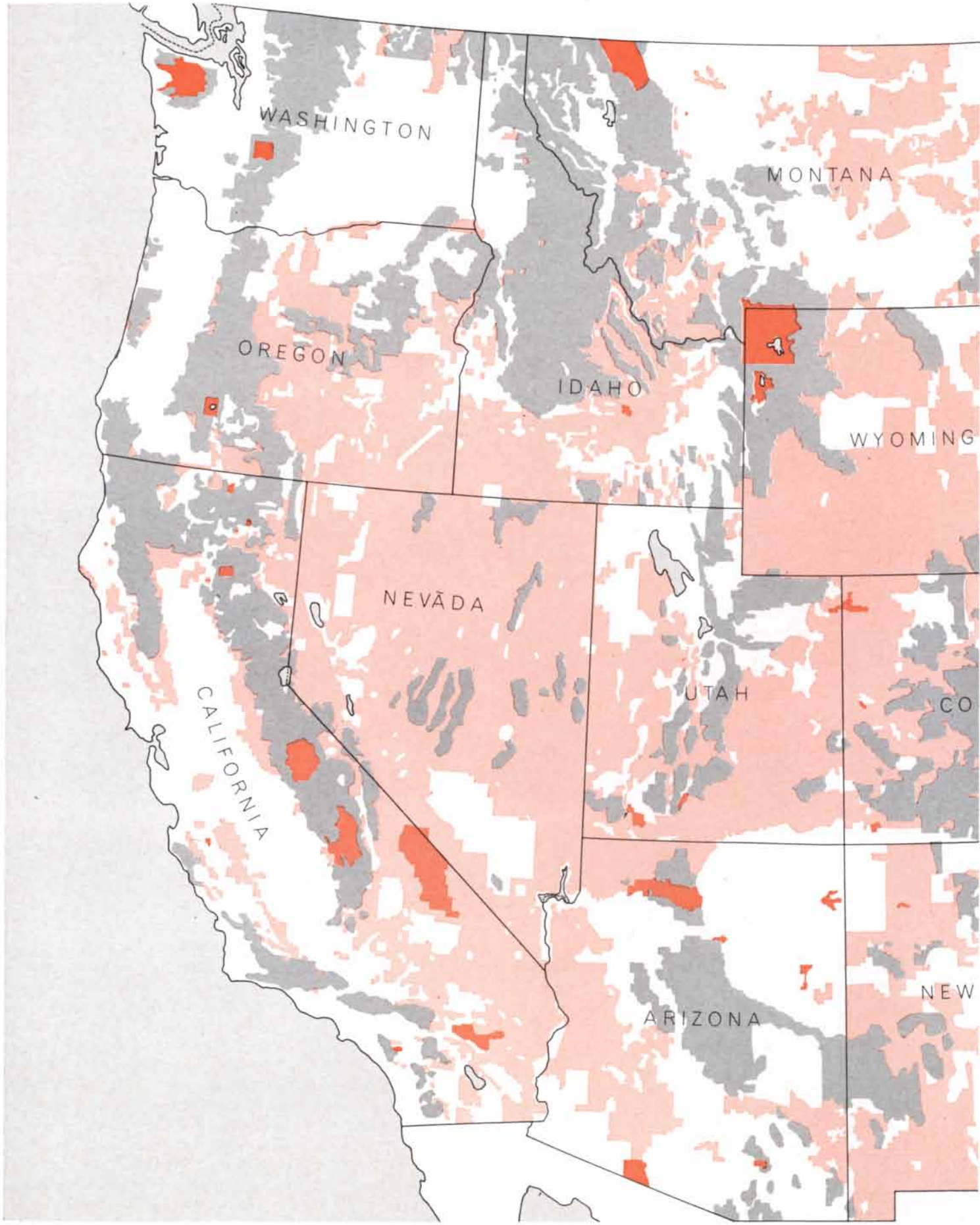
One misconception is that, by exploitation of nature's productivity (through intensive agriculture, grazing and lumbering), man is ruining the world's wildlands. Admittedly there has been reckless mismanagement in some cases. On the whole, however, the balance is on man's side; if his activities did not help nature more than they hurt, the land could not support the great world population it does today.

The foregoing misconception is based on a more elementary one: that the ecosystem created by nature is the best possible state. Man has shown in his management of agriculture that he can improve on nature; he has overcome its limitations and improved the quality and production of natural grains and other crops. Similarly, he can "farm" for a more productive grazing range, forest, wilderness or watershed. By proper management he can produce plants that are more useful for livestock and game and enable the land to meet the multiple requirements of man for food, water, recreation, mining, grazing, lumbering and so on.

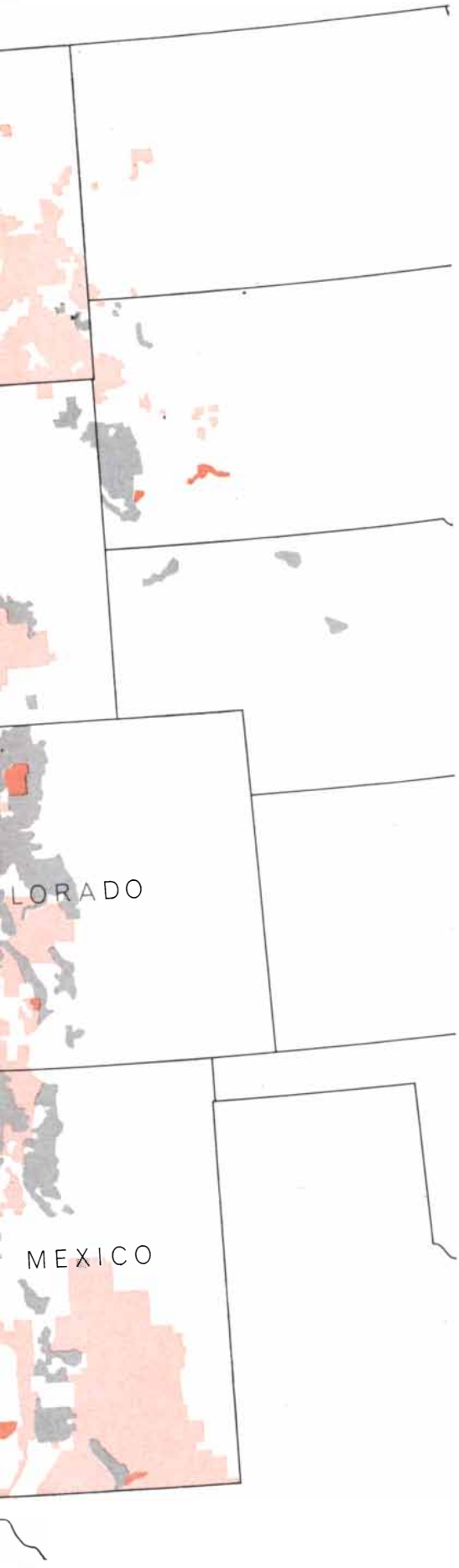
Cecil H. Wadleigh, Director of Soil and Water Conservation in the U.S. Department of Agriculture, has observed that man is engaged in a continual struggle with "the destructive actions of nature." He explains: "If we look at the historical record, one of man's greatest burdens has been that of surviving and progressing under the vicissitudes imposed by the natural environment. This record sends forth a clarion call that we expedite our efforts to protect our watersheds, curb soil erosion, abate floods, conserve soil moisture, improve soil productivity, develop improved varieties of crops and better strains of livestock, wage war on insect enemies, fight diseases of plants and animals, including man, restrict losses due to weeds and brush and continue to develop technology that will ever minimize needed labor efforts."

Consider the rangelands in the context

JACKSON HOLE, at the foot of the Teton mountains in Wyoming (*opposite page*), is typical of the better rangeland in the Northern Rocky Mountain area. Cattle once grazed in the foothills (*foreground*) in spring and fall and in the uplands (*background*) in summer. The harvest of hay from the level valley floor provided winter feed for the stock. The area is now a national elk refuge administered by the U.S. Department of the Interior.



ELEVEN WESTERN STATES of the continental U.S. hold a substantial part of the nation's land that still remains under Federal control. Shown on the map are public lands (*light color*), national parks and monuments (*color*) and national forests (*gray*); wildlife



refuges and Indian reservations have been omitted. Rangelands total 540 million acres.

of our growing needs. We are talking mainly about the 11 westernmost states, where almost 54 percent of the land (in contrast to only 4.6 percent in the Eastern states) is Federally owned. The ranges of this vast region can be divided into three distinct types: Northern Rocky Mountain, Intermountain and Southwest. The Northern Rocky Mountain area is characterized by high mountains, plateaus and narrow valleys and by a rugged climate, with sharp seasonal changes. Its plant life is predominantly open forest, bunchgrass, wet meadow grass and sagebrush. The Intermountain area has lower mountains, broad plateaus, deep canyons, extensive valleys, barren salt flats and a somewhat less rigorous climate than the Northern Rockies. Grasslands are rare in this region, and vast areas of it are dominated by shrubs, but there is good grazing in some of the wooded regions. In the Southwest, with its warm, dry climate, deserts and semideserts predominate. There are areas of vegetation, but even in these, unfortunately, grasses and other herbaceous plants tend to lose out to woody plants.

The relatively wild ranges of the Northern Rockies are grazed by migrant herds of sheep and cattle. The cattle use the open range eight months of the year (grazing in the foothills in spring and fall and in the uplands in summer) and return to their home ranches for feeding on hay in winter. The Intermountain ranges similarly provide seasonal grazing for cattle and sheep, as well as for big game. Wide areas of this region, however, are barren wastelands, and from season to season the cattle need to be moved great distances from one range to another. The traditional practice of driving the herds over many miles of trails is now being superseded by transport in trucks.

Needless to say, the vast grazing lands are not used solely for feeding domestic animals. They are shared with hunters and other users. Even where the lands are privately owned by ranchers, the owners commonly sell hunting privileges, and recently hunting clubs have begun to buy large tracts for their own use.

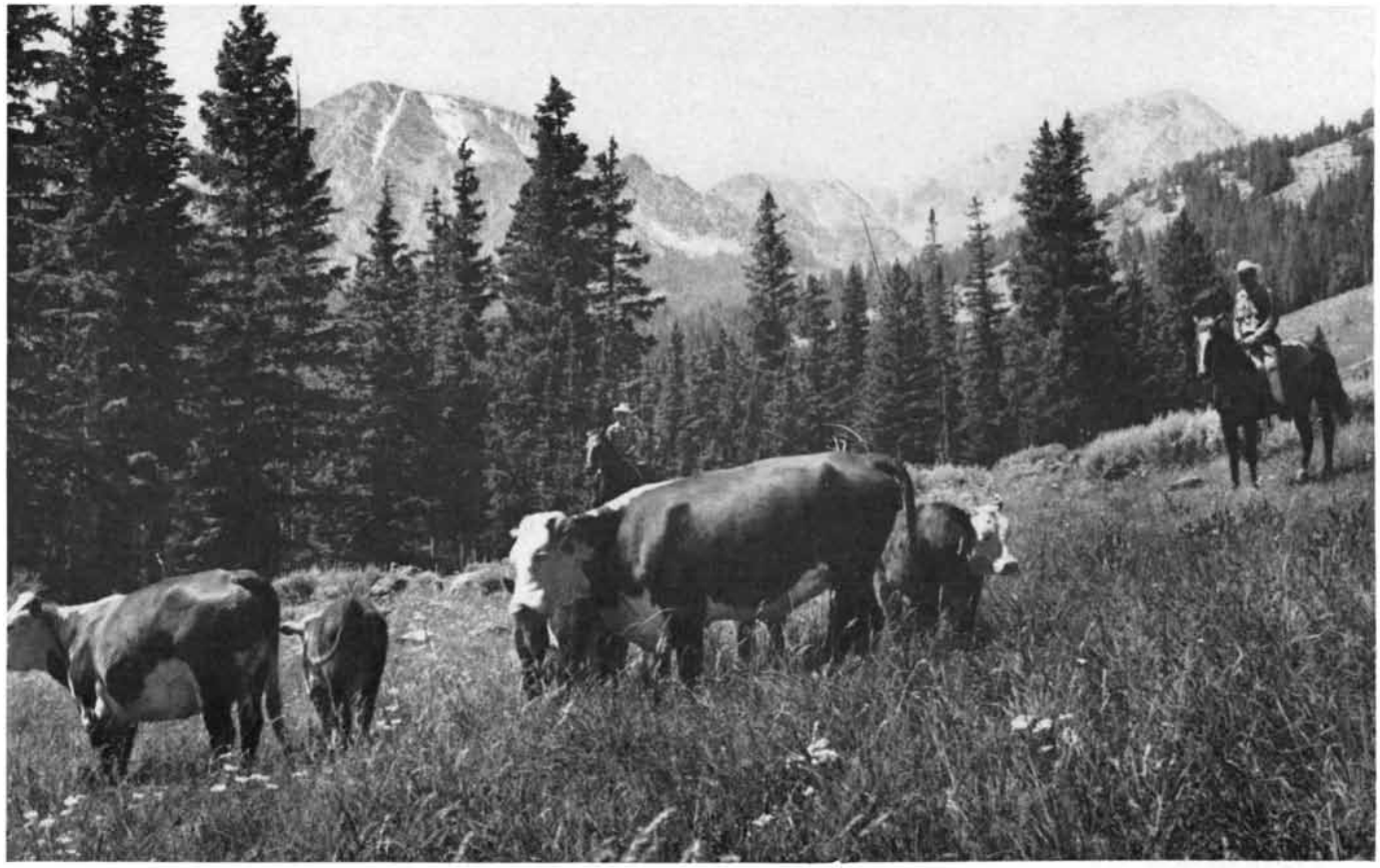
There is growing pressure for the dedication of more lands to recreation. An indication of the proportions this demand is likely to assume in the coming years was given in a 1960 report by the California Public Outdoor Recreation Planning Committee. In that year people in California spent some 235 million person-days in specified outdoor recreational activities, primarily swimming, picnicking, fishing and boating. By 1980, the committee estimated, such activities are expected to rise tenfold (to nearly 2.5 billion activity-days), with marked increases in camping, winter recreations, riding and hiking. For the nation as a whole Resources for the Future, Inc., predicts that by the year 2000 there will be a fortyfold increase in the patronage of vacation and resort areas in the U.S.

To make appropriate provision of lands for the coming recreation needs we shall need more information than we have at present as to the nature of those needs. A comparison of two resorts in California illustrates this point. Folsom Lake, which is only about 25 square miles in area and is little known outside the state, has twice as many visitor-days per year as the world-renowned Yosemite National Park, which has an area of 1,125 square miles. Obviously the efficient apportionment of lands to needs will require a systematic study of the trends in recreation.

Overall, in considering the impending "civilization" of the rangelands, we need to plan for a total system—not merely for particular uses or areas but for a complex of differing uses, so adjusted to one another that they can live together in harmony. The Federal agencies involved in managing these lands (principally the Department of the Interior and the Department of Agriculture) have adopted a concept of multiple use based on this broad principle. It contemplates applying general improvements that will benefit all users and invoking restrictions that will prevent any single use from unduly interfering with others. In terms of land area, the frame of reference is not particular localities but large areas such as an entire watershed. On this scale things can be done that will be beneficial to all interests.

The central problem in improving the rangelands for everyone's benefit—whether for livestock raising, habitation, recreation or simply enjoyment of the scenery—is that of managing the vegetation. The foremost enemy of the human and animal use of these lands is brush. It drinks up the scarce water, gives rise to devastating fires, makes many areas impenetrable and robs the land of its potential production of useful grasses and other plants. Enormous areas of the Western states are overgrown by the unwanted shrubs. The Intermountain country has 115 million acres of sagebrush. Brush occupies some 24 percent of California's total land area. In Arizona, New Mexico and Texas there are 60 million acres of the spiny shrub

PINE PLANTATION in the southeastern U.S. is an example of "multiple use" rangeland. The cattle feed on the grass that grows abundantly in this open forest environment without disturbing the pine seedlings that will provide a future crop for the plantation.



ROCKY MOUNTAIN UPLANDS also contain vast areas of rangeland with multiple-use potential. They offer good grazing in the summer months, hunting in fall and winter and other recreation the year round, as well as exploitable timber and mineral resources.

mesquite, and millions upon millions of acres of cactus, burroweed and snakeweed. Many species of brush thrive on the soils of the rangelands, and they have proved difficult to eradicate. Year after year the acreage taken over by brush, like the national debt, keeps increasing.

Ten years ago brush fires cost the state of California an average of $25 million per year for fire fighting, and the 250,000 acres scorched annually by these fires represented an additional loss of $25 million. Today such fires cost about $250 million per year. Ironically the efforts spent to prevent and contain the fires have only increased the hazard! Controlling the fires has enabled the brush to grow more thickly in the forests, with the result that most fires today are big ones. Nature and the aboriginal Indians in California managed better. Frequent fires, ignited by lightning or by man, kept the forest floor clean, so that the fires were small and did not burn the trees. The 19th-century naturalist John Muir, in his famous diaries, told of brush fires in California that consumed everything in their path until they came to the forest; there they subsided to small flames creeping along the ground because there was little combustible material to nourish them. Far from damaging the forest, such burns enriched it. We may be indebted to them for the giant sequoia trees now ennobling California forests; recent research has shown that sequoia seedlings can germinate in ashes but are suppressed under a thick layer of needles such as would cover an unburned forest floor.

To improve the rangelands for all concerned, then, our first step must be to get rid of the brush on selected sites. After this is done, by means of controlled burning, herbicides and uprooting, a good stand of grass can be established. A University of California test of the conversion of brushland to grass on a small watershed of 60 acres showed spectacular results: a dramatic increase in forage for animals, substantial improvement of the available water supply and a drastic reduction of the fire hazard.

Individual livestock operators have obtained similarly striking results. One farmer who burned off 2,400 acres of brush and seeded the area to grass found that within six years this area, which formerly had supported only 20 cows and a few deer and other wild animals, became capable of feeding 150 cows and a large number of deer. Another farmer who converted brushland to grass on a dry range found that streams that had formerly dried up in summer now flowed all year, enabling him to build a reservoir that supplied him with enough water to maintain irrigated pastures. Plant physiologists and hydrologists were not surprised at this seeming miracle. They know that every acre of brush soaks up six more acre-inches of water than herbaceous vegetation does.

Since 1945, under a legislative act permitting livestock ranchers in California to burn off brush under the supervision of the state forester and his deputies, more than two million acres have been burned off and the brush replaced with grass. It is estimated that the water yield from these areas has been increased by about a million acre-feet in the aggregate, and there have been great gains in livestock productivity and in the reduction of fire hazards. Many acres that were once covered with impenetrable brush now look like beautiful parks.

The conversion from brush to grass has been assisted by research and new technology. The Department of Agriculture developed a special tractor-drawn drill for grass-seeding rough terrain. Much study has been given to the various soils of the California rangelands, their fertilizer needs and the types of grass that will do best in these soils. Oddly enough, it has been found that certain imported grasses do much better than the native grasses in California. For example, hardinggrass (from Australia and southern Africa), smilo (from the Mediterranean region), veldtgrass (from southern Africa) and palestine orchard grass (from southwestern Asia) are considerably more productive in California than its native bunchgrasses are. An Australian investigator, William Hartley, concluded from an extensive survey that the pasture grasses most commonly cultivated around the world today originated in Eurasia and parts of Africa. Apparently these grasses, in the course of centuries of heavy grazing in those regions of early herding of livestock, evolved a high degree of vigor.

Man is only at the threshold of the immense exploration that will be necessary to mold the wilderness to his needs. Is the task, after all, too complicated? We can draw some optimism about our ability to master it from what has been accomplished in agriculture. In undertaking to replace the plant communities of nature with single crops of his own, man took on the problem of establishing and maintaining artificial ecosystems whose survival depended on his continuing efforts and ingenuity. In order to perpetuate a crop—a grain such as rice or barley, for example—he has to work at it year by year, seeding it, fertilizing it, fighting off its enemies: weeds, insects, diseases and depletion of the soil. He has found it possible to maintain such systems indefinitely. In the Orient ancient fields that have been cultivated for 40 centuries are still producing, in some cases at ever higher yields, thanks to advancing knowledge and genetic invention. Man has made many mistakes and often been carelessly destructive, to be sure, but through the ages he has steadily enlarged his understanding of nature and moved ahead to increasingly successful control.

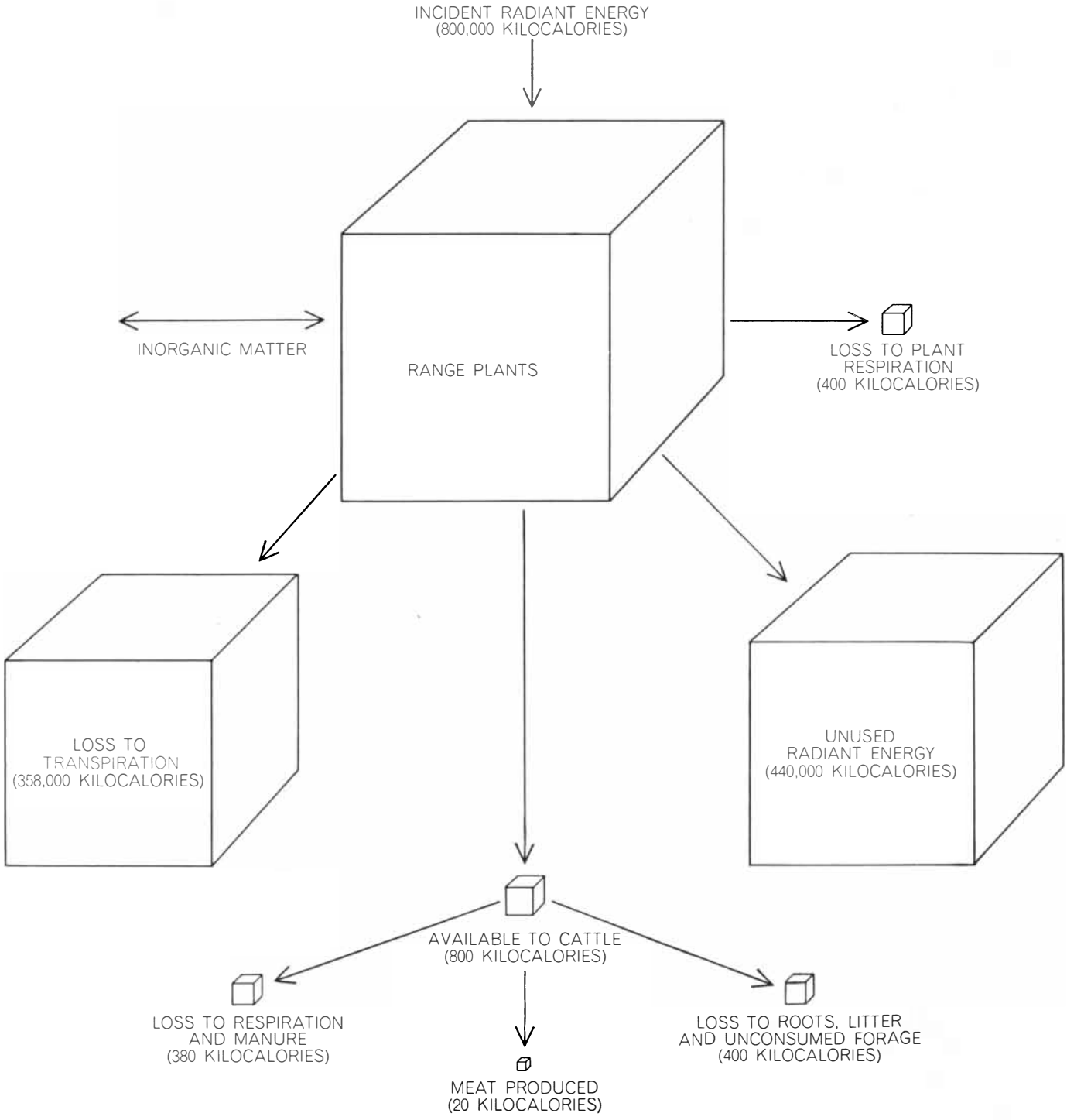
Managing the wildlands is of course a vastly more complicated undertaking than growing single crops. A committee of the California Agricultural Experiment Station after a five-year study proposed a program of needed researches that ranges over a great variety of questions, from the interactions between soils and plants to the appropriate diet for each domestic and wild range animal and the interrelations among the various forms of life present in the system (including man). Such studies of ecosystems are really only beginning to get under way. The ecologists engaged in them are enjoying the sense of excitement that is always coupled with new exploration. The investigation has opened new outlooks and generated new concepts.

Among these is a concept called "canopy architecture." It has to do with the photosynthetic response of a community of plants to a given amount of exposure to sunlight for the community as a whole. D. J. Watson, a British ecologist, recently introduced the idea of measuring the production of vegetation in terms of the total leaf area of the plant canopy. It turns out that for subterranean (ground-hugging) clover, for example, the daily production of foliage is highest when the leaf area amounts to about five square feet of leaf surface per square foot of ground area. Presumably when the leaf-area index is less than five some of the available sunlight goes unused and when it is higher than five there is too much shade. The facts suggest that in a pasture of subterranean clover the grazing of animals should be regulated to keep the leaf-area index as close to five as is practical.

Other plants respond differently. Research on white clover and cotton has indicated that the depth of the canopy may be important, which suggests that studies should be made of the flow of

sunlight through the foliage of various plant communities and also of the trapping of carbon dioxide within the canopy. The angle of the leaves can have considerable influence. It has been found, for example, that rice plants with erect (mainly vertical) foliage can tolerate a high leaf-area index; consequently such plants could be planted in greater density and produce a greater yield per acre. Breeding programs are under way to develop rice plants, other small grains and millets with an erect leaf habit. Perhaps these findings and ideas will be applicable to the vegetation of grazing ranges as well. Obviously, however, it will be no easy task to apply them to the ranges' multifarious communities, made up of many different species of plants.

Meanwhile we know that the ranges' production of meat could be multiplied, probably to as much as three or four times their present yield, by controlling the brush, planting grass and legumes and fertilizing. Analysis of the present yield of meat from the solar energy received by the rangelands shows that there is a great deal of room for improvement. A typical range in California receives 800,000 kilocalories of sunlight energy per square meter in a year. After deducting what is lost by reflection and



DIMINISHING RETURN is calculated in terms of energy input during eight months of meat production on an acre of rangeland in California. The top cube represents the 800,000 kilocalories of radiant energy available per square yard from October to May. Only .1 percent of this energy, or 800 kilocalories, becomes available as food for the cattle grazing the rangeland. Of this amount, no more than 2.5 percent, in the form of 50 pounds of meat on the hoof, is available for human consumption at the end of the eight months.

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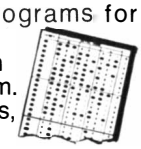

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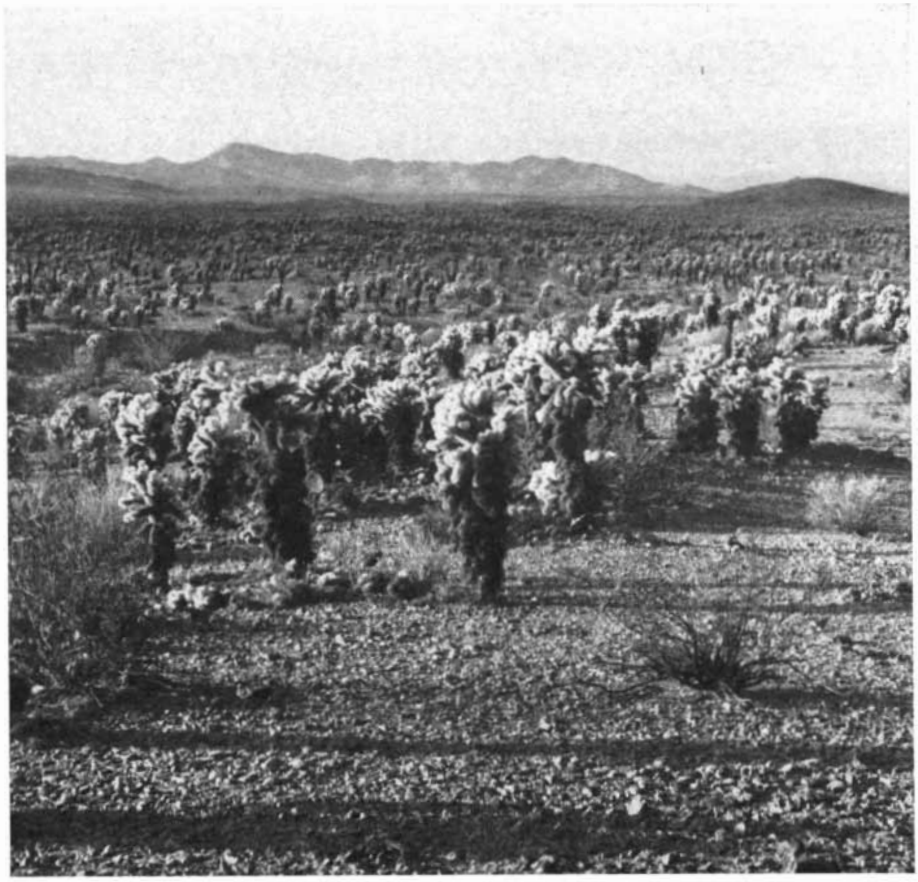

SOUTHWEST RANGELAND is predominantly semidesert and desert, and its areas of vegetation are usually dominated by drought-adapted plants. Cholla cactus and creosote bush are the principal plants in this arid section of San Bernardino County in California.

INTERMOUNTAIN RANGELAND is frequently dominated by shrubs. Here, near Lassen Peak in northern California, the unwanted growth consists of sagebrush and juniper. The Intermountain zone contains more than 100 million acres of such sagebrush-choked grazing.

heating, spent on the plants' requirements for respiration and photosynthesis and drained away into the roots and other unconsumable parts of the plants, we find that only 800 kilocalories are picked up by the grazing animal. The animal in turn spends nearly all this energy unproductively (from man's point of view) in respiration, waste matter and its inedible bones and hide, leaving a net of only 20 kilocalories per square meter, of the original 800,000, that goes into meat. On an acreage basis this represents about 50 pounds of beef on the hoof per acre. The more efficient utilization of sunlight achieved by fertilized legumes can raise this figure to as much as 300 pounds of beef per acre.

The California Highway Commission Budget for 1969–1970 totals $18,945,000: $8 million for 19 new landscaping projects, $10 million for maintenance and additional planning, $945,000 for maintaining safety roadside rests, plus $2 million for construction of 11 such roadside rests. This totals nearly $21 million, and this is fine. Constructing and landscaping our highways is a never ending task, but we are working at it. Why can we not have such constructive long-term planning programs for reduction of fire hazards and beautification of our watersheds and wildlands?

Private industry, builders, developers, realtors, subdividers and individual homeowners in fire-hazardous wildland areas could hire underemployed agricultural and urban labor, school dropouts and many who are now on welfare rolls to do this work on lands burned by wildfire. Unfortunately little urgency seems to be felt about tackling the preservation and improvement of our forests and brushlands. The Economic Opportunity Act provides an incentive to state and county agencies to put local people to work on this. Local government agencies would pay 25 percent of the labor costs, and the Federal Government 75 percent. (The latter ruling was made in February, 1967.) The state's Resources Agency has work camps for prisoners, but why should one have to commit a crime in order to be put to meaningful work? This would be one work program that would pay for itself as time goes on.

The attitude of those who believe we should become much more active in developing the values of our rangelands has been well stated by Stephen H. Spurr, dean of the School of Graduate Studies at the University of Michigan: "We should be positive and not negative, we should be active and not passive, we should be wilderness managers and not conservationists."

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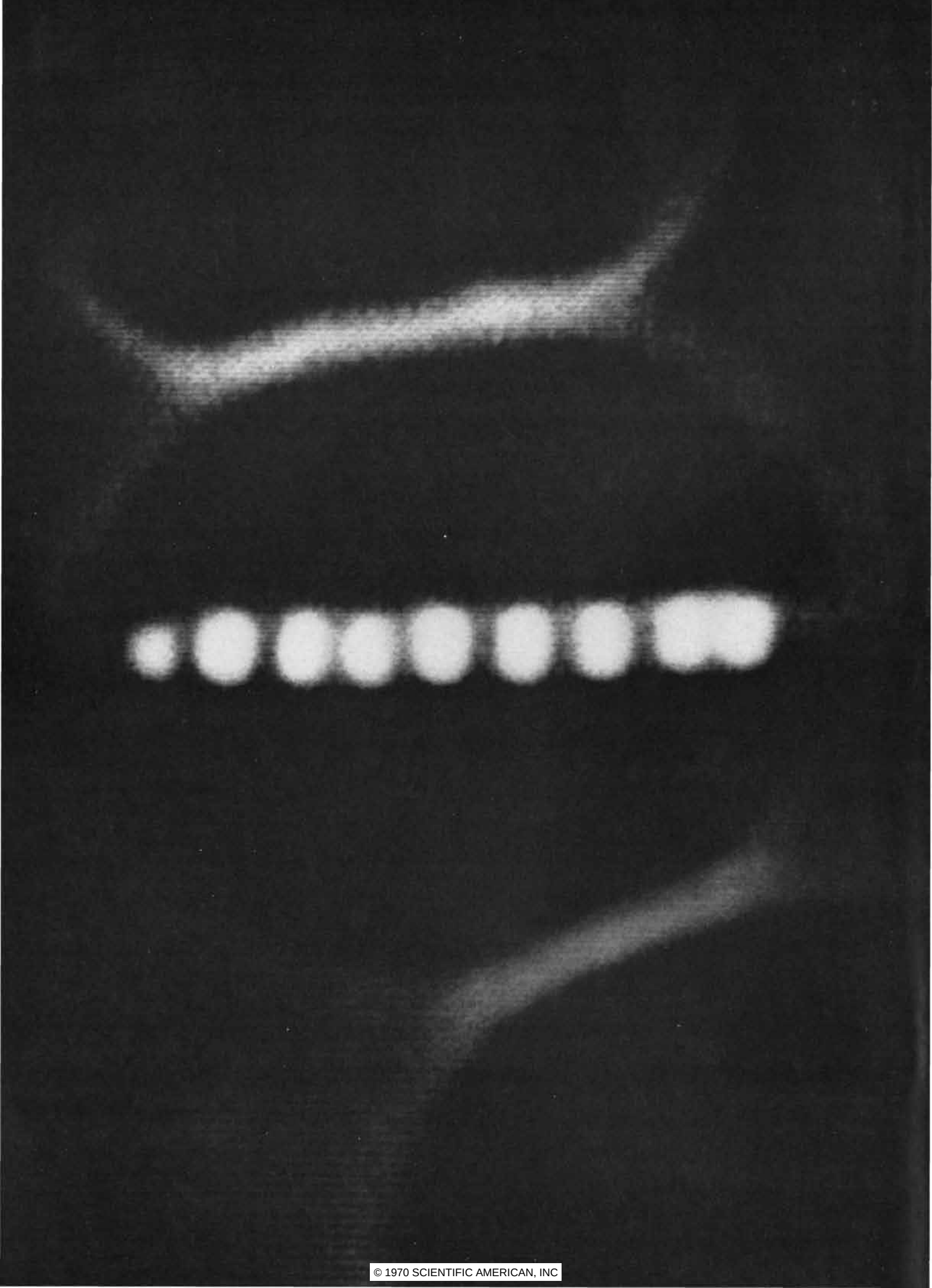

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The properties of laser light make it possible to conveniently focus it to an intense spot .0005 millimeter in diameter. This spot is small enough to produce lesions in individual organelles of the living cell

by Michael W. Berns and Donald E. Rounds

Traditionally when a physiologist has sought to identify the function of an animal organ such as a gland, he has removed or altered the organ and observed the effect on the animal. This experimental approach has not generally been available to the cytologist investigating the functions of the tiny organs ("organelles") of the living cell. Many of these organelles, which conduct the specialized internal activities of the cell, have a diameter of only one or two microns (thousandths of a millimeter). They are therefore too small to be removed or altered by even the finest dissecting needle. This restraint on the cytologist's methods has been eased by the development of a "laser scalpel." The instrument consists of a laser whose beam is focused by a microscope, together with other equipment that records the effects of the beam on the cell.

With this instrument the cytologist, like the physiologist, can destroy or alter structures in order to investigate them. He therefore has a useful tool that complements other experimental methods such as electron microscopy, radioactive labeling and centrifugation, which have yielded so much information about the structure and function of the cell.

The first efforts to selectively alter parts of individual cells were made with beams of protons, electrons, gamma rays and ultraviolet radiation. These experiments encountered difficulties. Usually the focused spot was several microns too large. Moreover, in most instances the equipment was formidably complex and expensive. Of these methods the ultraviolet microbeam technique has proved the most useful.

One other form of electromagnetic radiation, visible light, has also seemed promising because many organelles readily respond to it. Some organelles are affected by light because they contain natural chromophores: molecules that strongly absorb specific wavelengths of light. An organelle that contains no natural chromophore can often be stained with nontoxic artificial chromophores, or dyes, such as Janus green B or an amino acridine. When a natural or an artificial chromophore absorbs light, the molecule must rid itself of the excess energy. The dissipation of this energy may alter or damage the organelle.

A chromophore excited by light can return to its unexcited, or ground, state in several ways. The light energy can be converted into molecular vibrational energy, which is passed on to the surroundings as heat. The molecule can drop to the ground state by fluorescing, that is, by emitting light at a wavelength longer than that of the incident light. It can return to a lower energy state by going through a chemical transformation. Finally, it can return to the ground state by transferring its energy to a second kind of molecule, for example part of an organelle. This secondarily excited molecule must then dissipate the excess energy by one of the mechanisms listed above. It is therefore possible for the structure and function of an organelle to be affected by the dissipation of heat from a chromophore, by the chemical transformation of a chromophore, by the dissipation of heat from a secondarily excited molecule and by the chemical transformation of a secondarily excited molecule.

Conventional light sources cannot readily produce light with the features needed for precise microirradiation. The beam should be relatively monochromatic (or should at least be able to provide monochromatic light of adequate intensity), so that the wavelength can be matched with an absorption peak specific to the chromophore. The beam should be intense enough for cells containing a low concentration of natural or artificial chromophores to react to it. It would also be helpful if the beam were nondivergent (parallel) so that it could be reflected and focused by simple optical systems without losing its intensity. A laser beam has all these properties.

The basic elements of a laser scalpel are the laser itself and an optical system capable of focusing the beam so that it can produce in a living cell a minute lesion with a diameter of a few microns or less. Such a laser microbeam was first developed in 1962 by Marcel Bessis and his colleagues in Paris. The light source of their instrument was a ruby laser whose red beam could be focused to produce a spot 2.5 microns across. Since that time many workers have reported obtaining spots with an effective diameter ranging from one micron to two microns.

Bessis and his associates used their instrument to probe individual cells and portions of cells. Their most extensive studies involved irradiation of the mitochondria of cells maintained in a tissue culture. Mitochondria are the site of the many chemical reactions that extract energy from foodstuff and make it available to the cell. Because mitochondria do not absorb the red light produced by the ruby laser it was necessary to stain

RED BLOOD CELL, measuring seven microns (thousandths of a millimeter) across, has been perforated nine times by the beam of an argon laser. Lesions between .5 and .75 micron in diameter appear as bright spots in this television image. Portions of other cells surround perforated specimen.

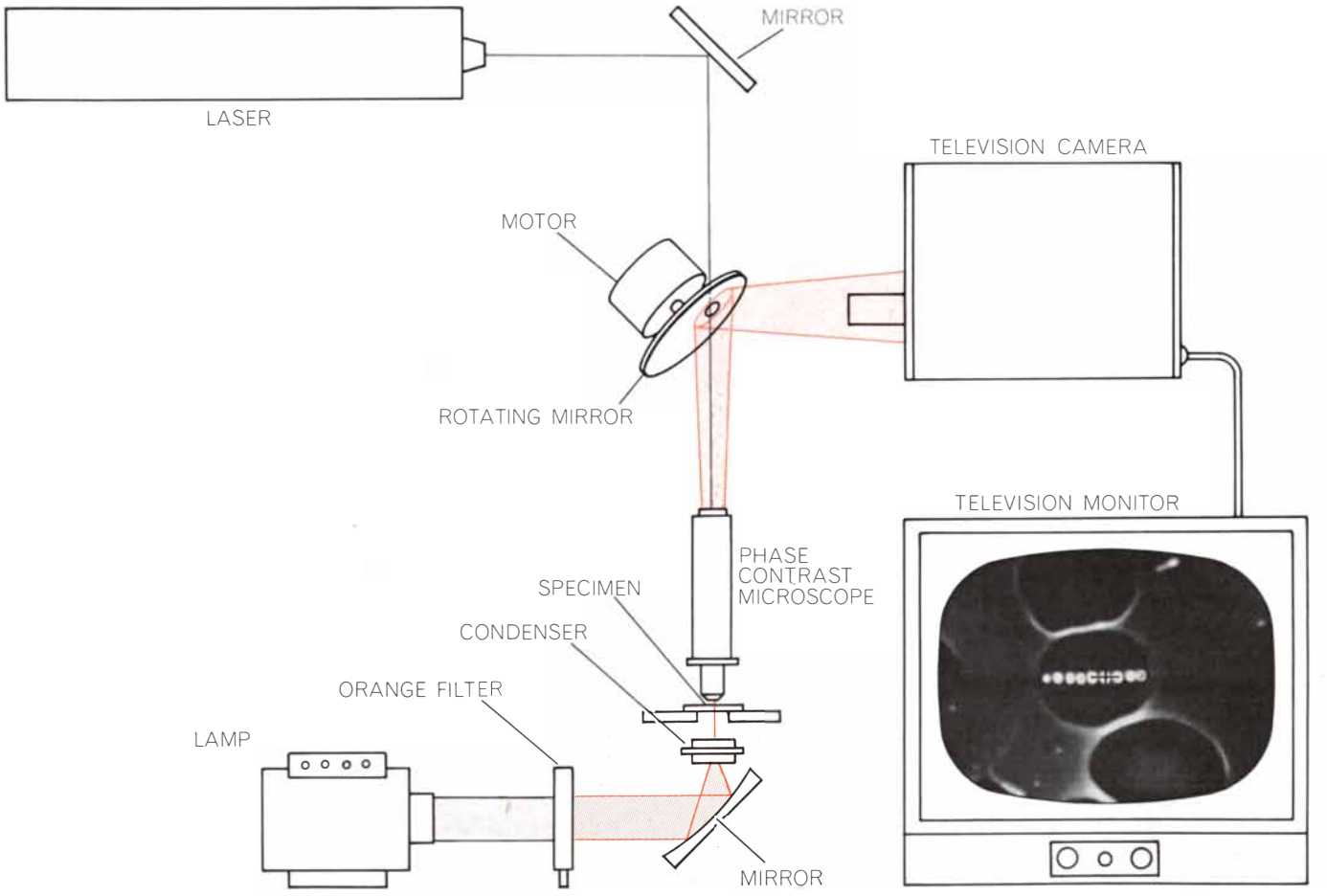
the cells with nontoxic concentrations of Janus green B.

When the mitochondria of cells were damaged by sublethal doses of laser radiation, the cells had an impaired ability to take up uridine, a constituent of ribonucleic acid (RNA). The impairment lasted for several hours, after which the cells resumed normal activity. These studies suggest that the synthesis of RNA is related to the functioning of mitochondria, although the evidence is not conclusive.

In a more direct approach to mitochondrial function, the French workers conducted a series of experiments that measured the effect of laser irradiation on the activity of the mitochondrial enzymes called dehydrogenases. As might be expected, heavy mitochondrial damage was followed by an almost total absence of dehydrogenase activity; these cells died two hours after irradiation. Moderate and light mitochondrial damage was not, however, accompanied by a corresponding degree of functional failure. Although distinct structural changes were produced, there appeared to be no decrease at all in the activity of the dehydrogenase enzymes. These findings indicate that certain changes observed in mitochondria with the electron microscope do not always mean changes in the levels of enzyme activity in those cells.

Bessis and his co-workers and other investigators established the laser microbeam as a useful tool in cell biology. The advent of the argon laser led our group at the Pasadena Foundation for Medical Research to develop the more versatile argon-ion laser microbeam system. The blue-green beam of an argon laser comprises five visible wavelengths, any one of which can be selected for use. There are many natural chromophores with absorption peaks in this region of the spectrum, including photosynthetic pigments, carotenoids, cytochromes and hemoglobin. Argon lasers are also commercially available either as continuously operating instruments or as rapidly pulsed ones capable of firing several hundred times per second. This feature facilitates the initial alignment of the beam and allows adjustments to be made with relative ease. The adjustments can be accomplished as the laser fires steadily through the microscope; therefore a secondary alignment beam such as that used in other systems is not needed. Moreover, the principles of optics tell us that a shorter wavelength can be focused to a smaller spot than a longer one can. (This point, however, is of purely theoretical interest at the present stage of our work.)

For our own system we chose an



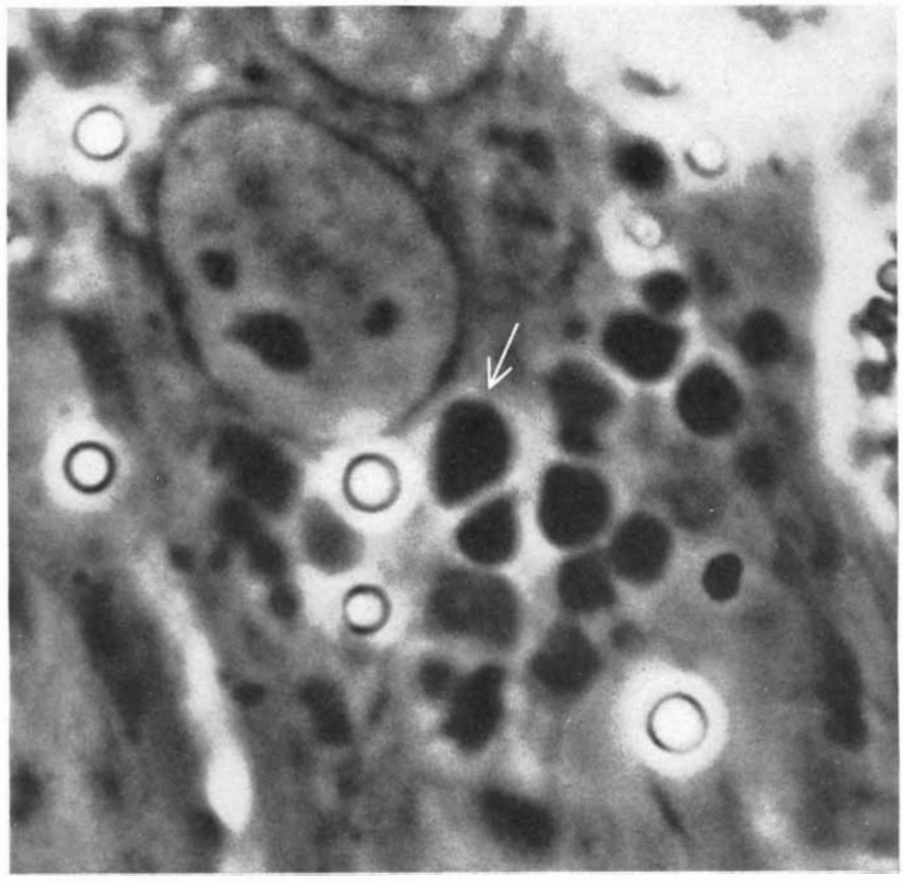
OPTICAL SYSTEM that produces the argon laser microbeam for the irradiation of cells is shown schematically. The specimen to be irradiated is placed under cross hairs on the television monitor screen at bottom right. The laser at top left is then fired. The mirror at top center reflects the beam down through a hole in a second mirror at center, which rotates synchronously with the laser pulses. The phase-contrast microscope at bottom center focuses the beam, which makes the minute lesion in the specimen cell. The lamp at bottom left illuminates the specimen on the microscope stage so that the microscope can produce an image of the cell that the rotating mirror reflects into the television camera at top right. The mirror is rotated so that the image of the hole does not mar the picture. The orange filter in front of the lamp removes the blue-green light (to which specimen responds) from lamp's beam so that the lesion will not be enlarged. The condenser below the microscope concentrates the light from the lamp on the specimen.

argon-ion laser that has a peak power of about one watt and emits 60 pulses of coherent light per second, principally at the wavelengths of 4,880 and 5,145 angstroms. The laser's unfocused beam, which is about three millimeters in diameter, is reflected downward at an angle of 90 degrees by a front-surfaced mirror. The beam then passes through a hole in a circular mirror that rotates at 60 revolutions per second, so that the opening appears in the path of the beam each time the laser pulses. When the beam is focused by the oil-immersion objective of a phase-contrast microscope, it can produce lesions approaching .5 micron in size. A lamp under the microscope's viewing stage projects an image of the specimen upward to the rotating mirror, which reflects the image into a television camera, a still camera or a time-lapse camera. (If the mirror did not rotate, the image of the hole would mar the viewing field.) With the rotating mirror the cells can be viewed by closed-circuit television or recorded photographically during the entire process of irradiation [*see illustration on opposite page*].

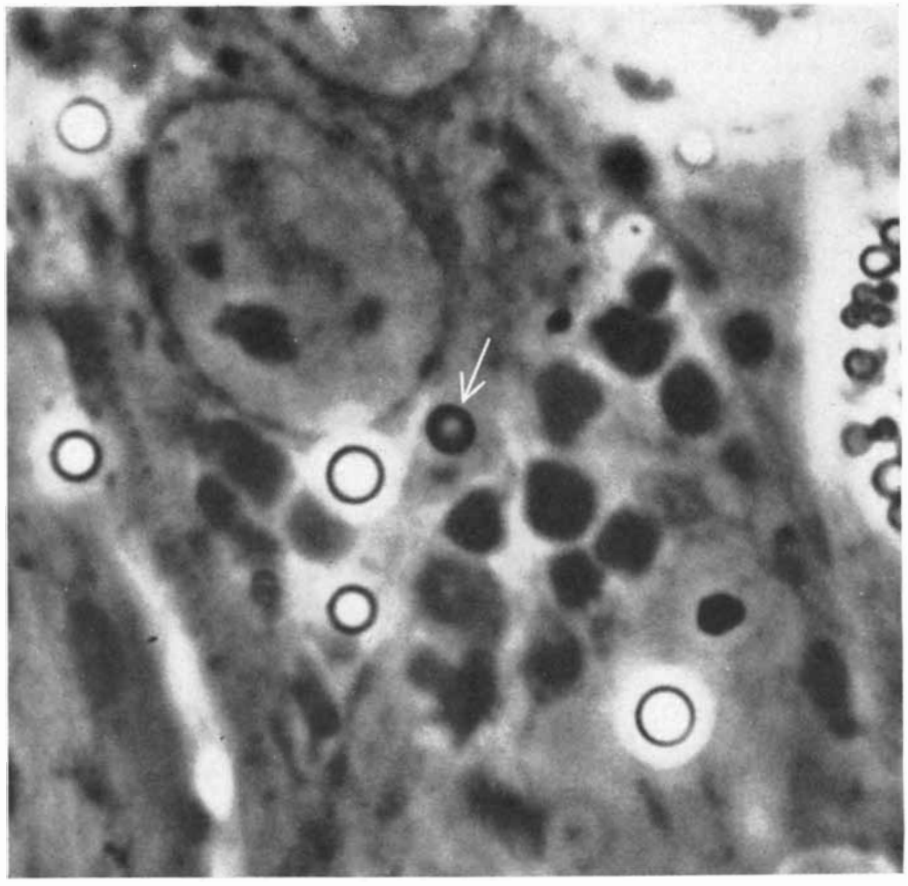
Once we had built the system we undertook a series of experiments both to test it and to obtain some information about structures within the cell. We chose as our first experimental subject mitochondria in myocardial cells from the heart muscle of the rat. These tissue-culture cells beat with the rate and rhythm of the muscle from which they are derived. The specialized mitochondria of the myocardial cell are unusually large; they are called sarcosomes. They respond to the argon laser because they contain the natural chromophores cytochrome *c* and cytochrome c_1; these proteins absorb light most readily at 5,200 and 5,500 angstroms.

When we irradiated the sarcosomes, we found that even the most drastic changes in the appearance of the organelles produced by the argon laser were not lethal to the cells: as many as 12 sarcosomes could be irradiated without killing the cell or changing the rate at which it beat. Investigations are currently under way to determine what chemical changes irradiation of the sarcosomes produces in the cell.

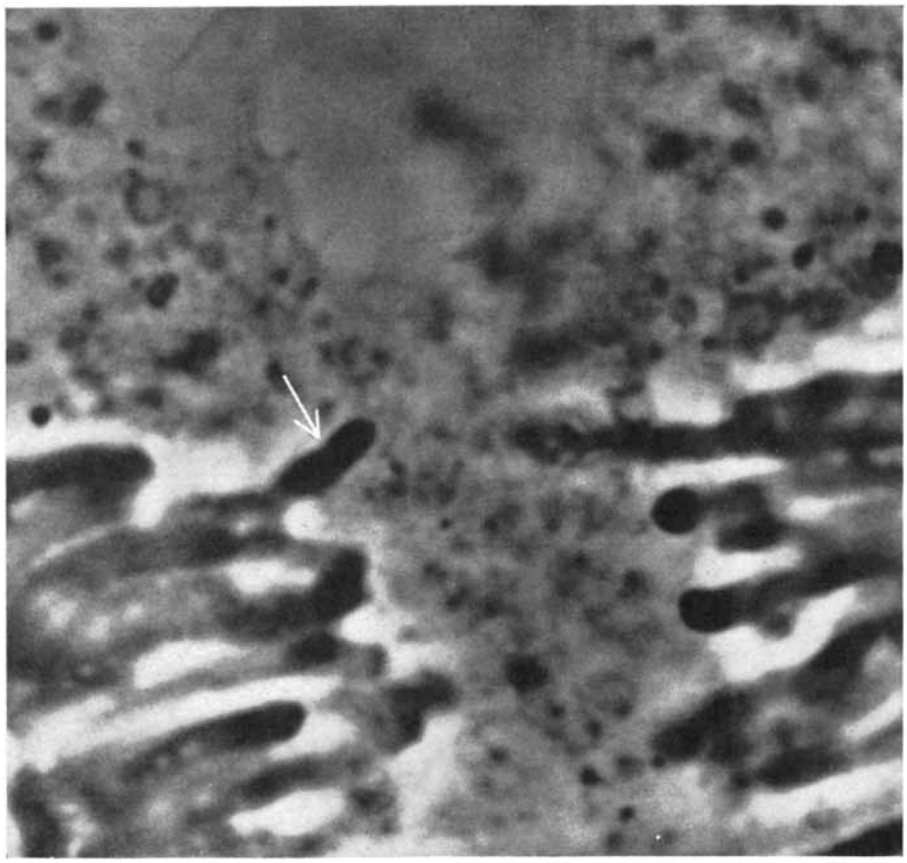
The chromosomes, which contain the hereditary material of the living cell, were the next structures we investigated with the microbeam. Chromosomes from salamander lung cells were chosen because they are large and there is a relatively small number of them in each nucleus (22). Moreover, in the process of



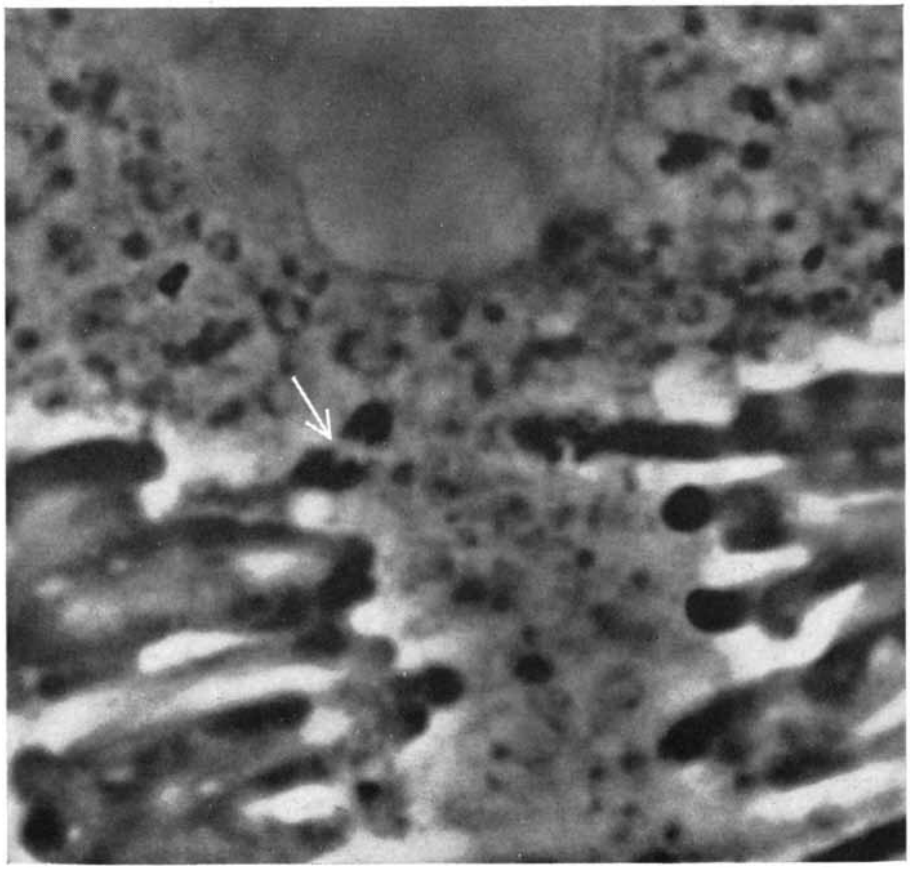
BEFORE IRRADIATION a rat myocardial cell has dark mitochondria such as the one at center (*white arrow*). These organelles are between one micron and four microns across.



AFTER IRRADIATION with argon laser, lesion .5 micron across appears on a mitochondrion in rat myocardial cell. Other organelles are undamaged. Light spots are bubbles.



UNIRRADIATED CHROMOSOMES from salamander lung tissue are in a stage of division during which the clusters separate. Arrow indicates chromosome that will be irradiated.



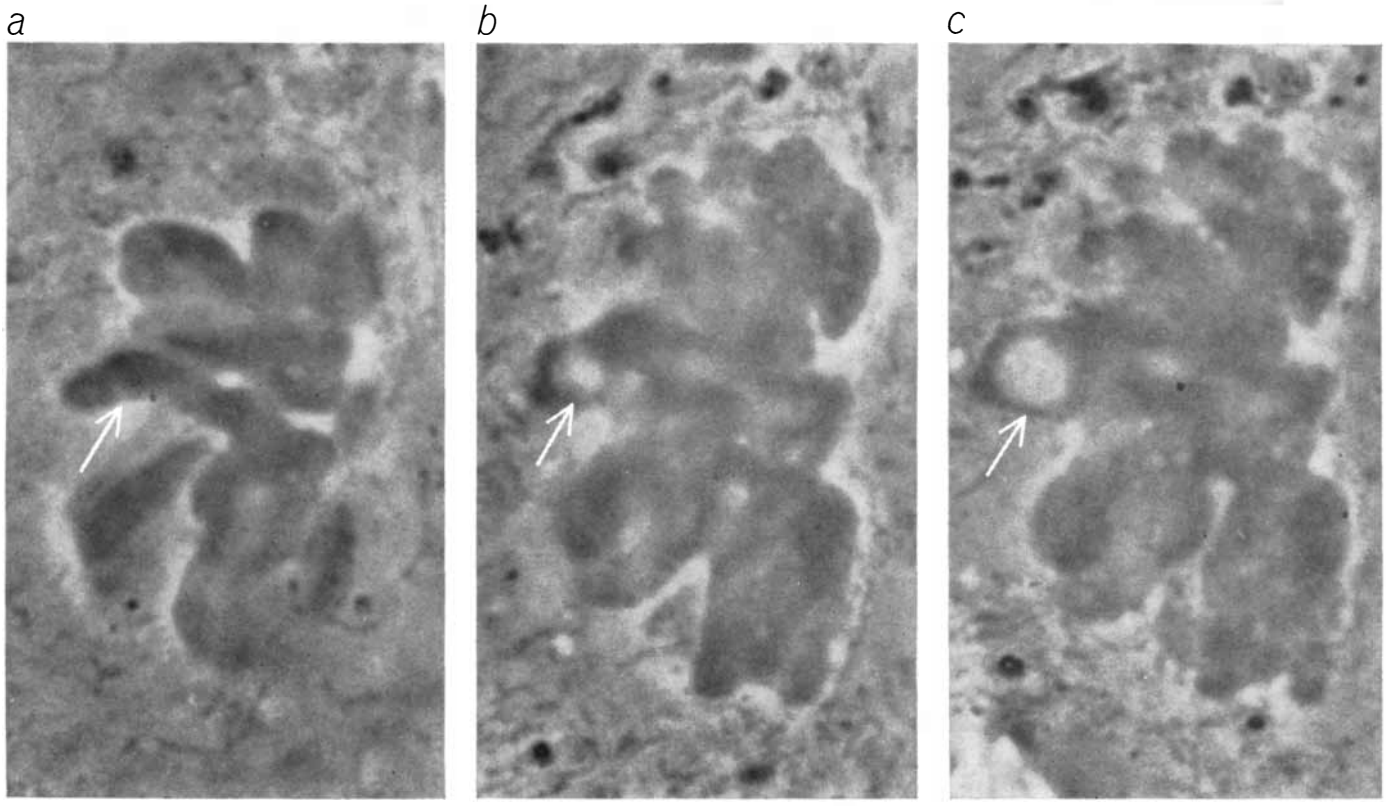
IRRADIATED CHROMOSOME (*arrow*) has been broken by three firings of the laser. The size of the lesion can be controlled by changing the amount of dye used to stain the cell.

division the cells themselves remain flat instead of assuming a spherical shape; this makes it easier to view the chromosomes.

The constituents of the chromosomes —deoxyribonucleic acid (DNA) and nucleoproteins—do not absorb visible light readily. It was therefore necessary to stain the chromosomes with a photosensitizing agent, acridine orange. In very dilute solution this dye, which binds itself directly to the DNA, does not seem to be toxic to cells. Cells were exposed to a 10^{-5} or 10^{-6} percent solution of the dye for five minutes and were then washed several times with saline solution. These cells divided normally in tissue culture and were not significantly different in appearance from control cells.

In the actual experiments a culture from one to three weeks old was treated with a dilute solution of acridine orange for five minutes. After several washings to remove excess dye we filled the culture chamber with fresh saline solution and placed it on the microscope stage. We then located a dividing cell in the microscope field, positioned part of the chromosome under the cross hairs and fired the laser. Later we sometimes drained away the culture medium and filled the culture chamber with an appropriate fixative so that the cells could be investigated by histochemical methods. Alternatively we refilled the chamber with culture medium so that we could keep the cells alive and make time-lapse or still pictures of them over a period of several days.

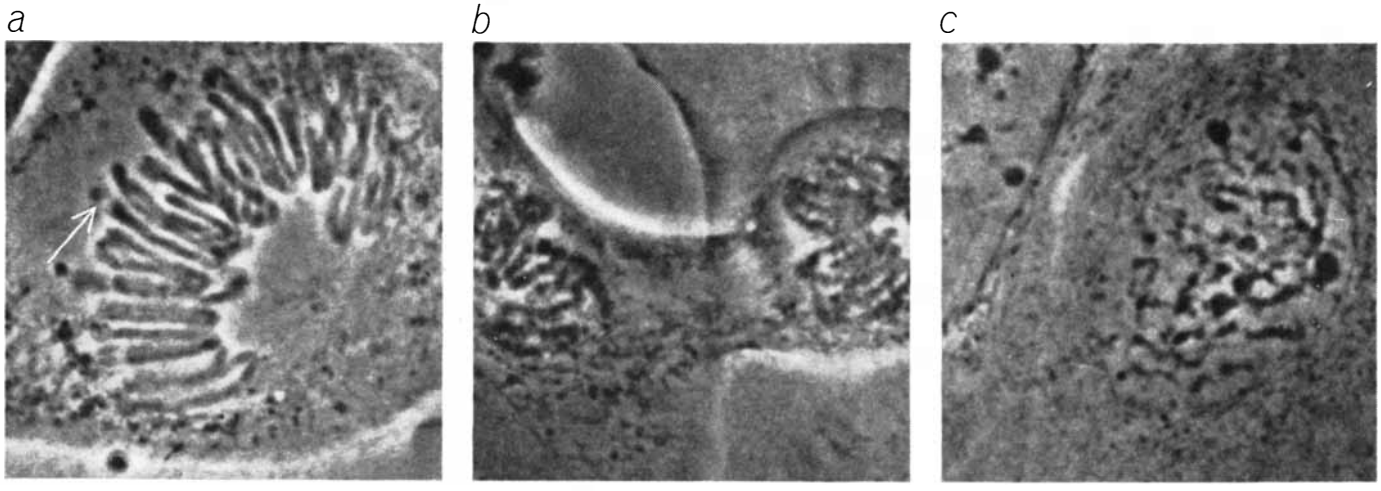
We found it possible to produce lesions of various sizes by changing the concentration of dye, the output of the laser or the optics of the microscope. With a more concentrated solution of acridine orange (2.5×10^{-3} percent) it seemed that distinct pieces of chromosomes could be broken off [*see bottom illustration at left*]. A chromosome could also be cut in half by firing the laser several times across it. More dilute concentrations of dye produced a lesion that appeared as a pale spot on the chromosome. Such lesions were reminiscent of those that had been obtained with an ultraviolet microbeam by Raymond E. Zirkle, William Bloom and Robert B. Uretz of the University of Chicago. We sometimes observed (as the members of the Chicago group did) an increase in the size of the lesion in the chromosome after it had been made. The diameter of the lesion usually varied from .6 micron to four microns, depending on the conditions of the experiment [*see top illustration on opposite page*].



CHROMOSOME CLUSTER in *a*, immediately before irradiation, is dark where the lesion will appear (*arrow*). In *b*, five seconds after irradiation, a pale spot begins to show up. In *c*, after a period of 30 seconds, the spot has grown to a size of several microns.

The appearance of a lesion in the phase-contrast microscope indicates that there has been a structural change in the chromosome, but such direct observation cannot reveal whether or not the beam has disrupted the nucleic acid of the chromosome. In an attempt to find out if the nucleic acid had been altered, we fixed the chromosomes after irradiation and stained their DNA by the Feulgen method. One would expect that if the laser had damaged a section of the DNA, the lesion would not be stained, whereas the undamaged portion of the chromosome would be. This, in fact, is what we observed. The result was not surprising, because the photosensitizing agent (acridine orange) is known to bind itself to the DNA molecule.

Would the cells with a damaged chromosome continue to grow and divide normally? We found that the effect of laser irradiation on the cells varied with the stage of mitosis, the multiphased process of cell division. If the lesions were made before the middle of mitosis ("metaphase"), the division would often stop, the chromosomes would become granulated and gradually fade from view, and the membrane of the cell nucleus and the nucleoli within it would re-form. Although the nucleus often became enlarged and developed lobes, the



IRRADIATION OF A CHROMOSOME in the nucleus of a salamander-lung tissue cell stained with acridine orange does not prevent the cell from dividing. In *a* lesion appears as a pale spot (*arrow*) 20 minutes after irradiation. In *b*, 40 minutes later, chromosomes have separated into daughter nuclei; barbell shape of the cell indicates that the process of cell division is almost complete. In *c* cell division has been successfully completed, and daughter cell containing the irradiated chromosome appears to be normal.

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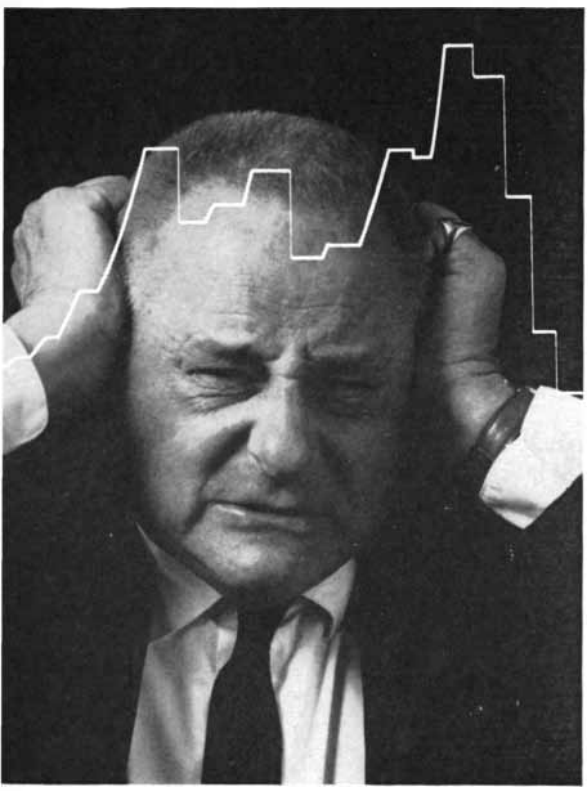

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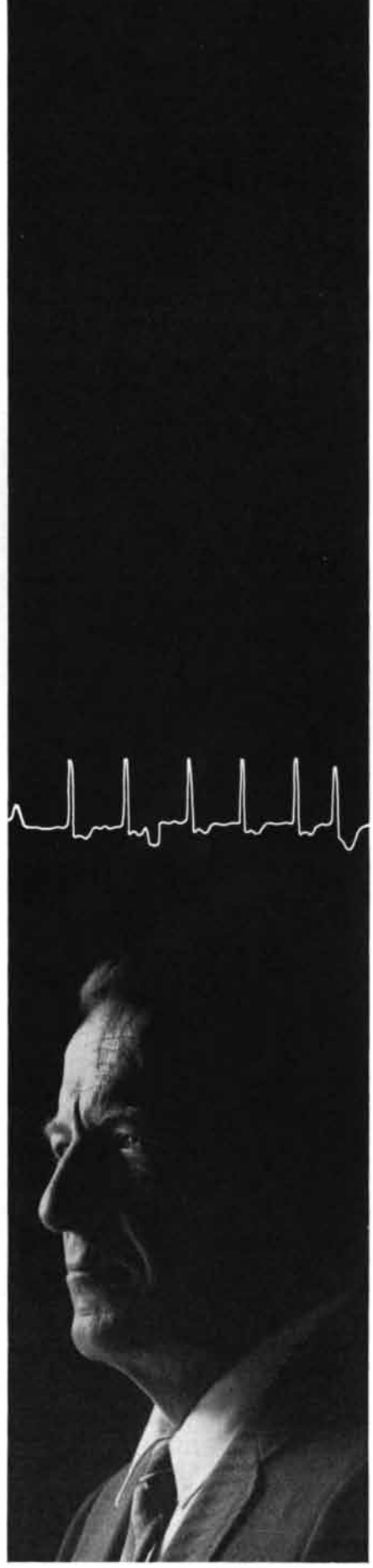

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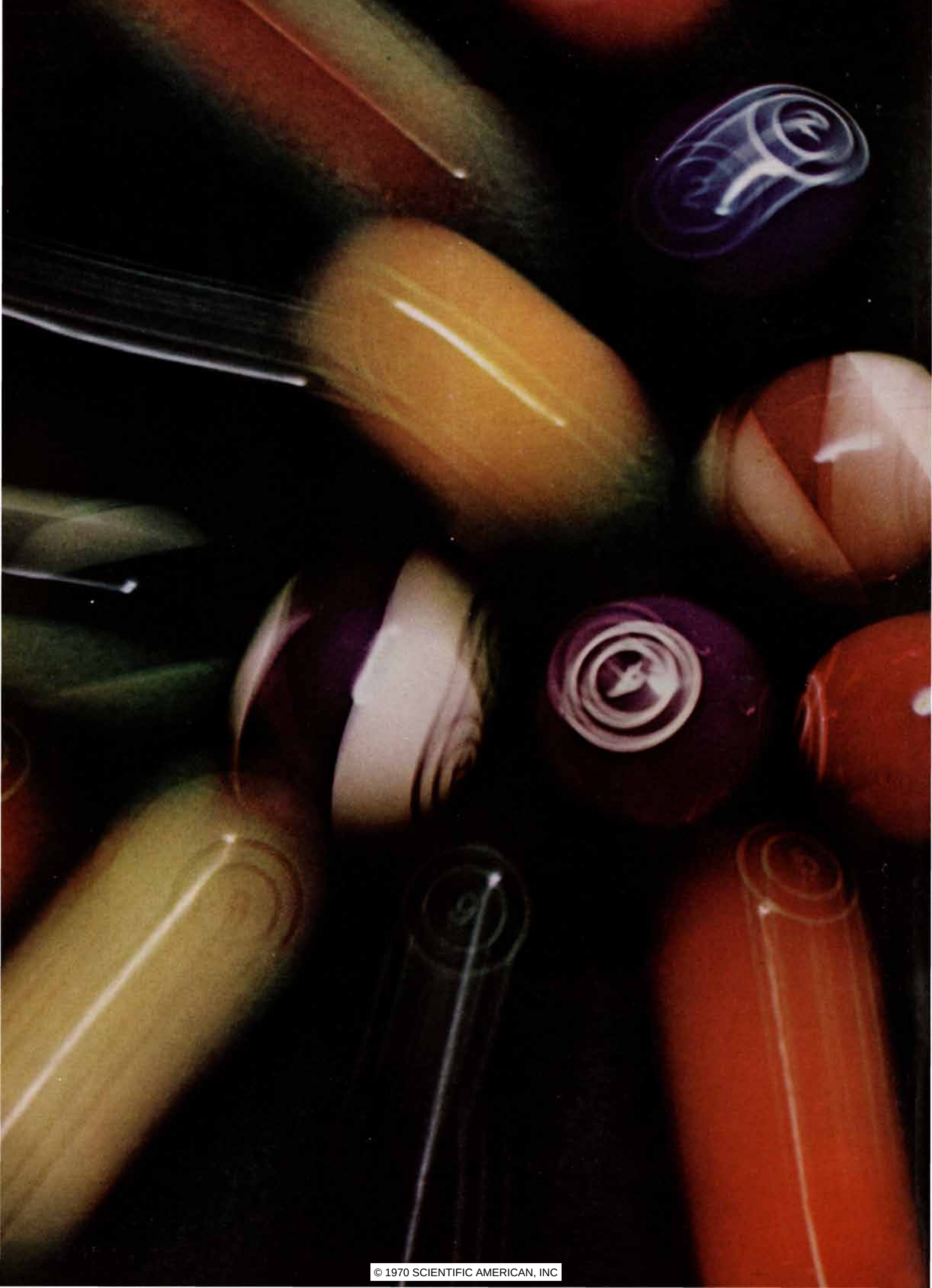

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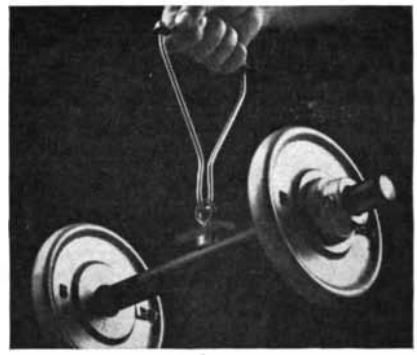

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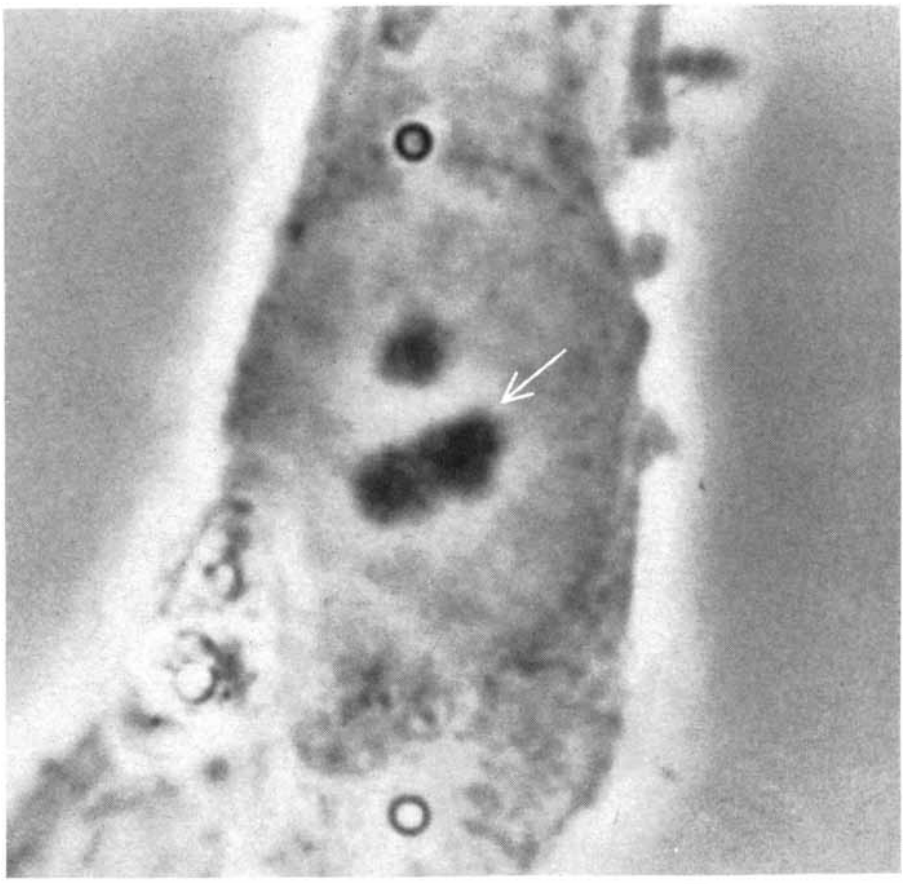
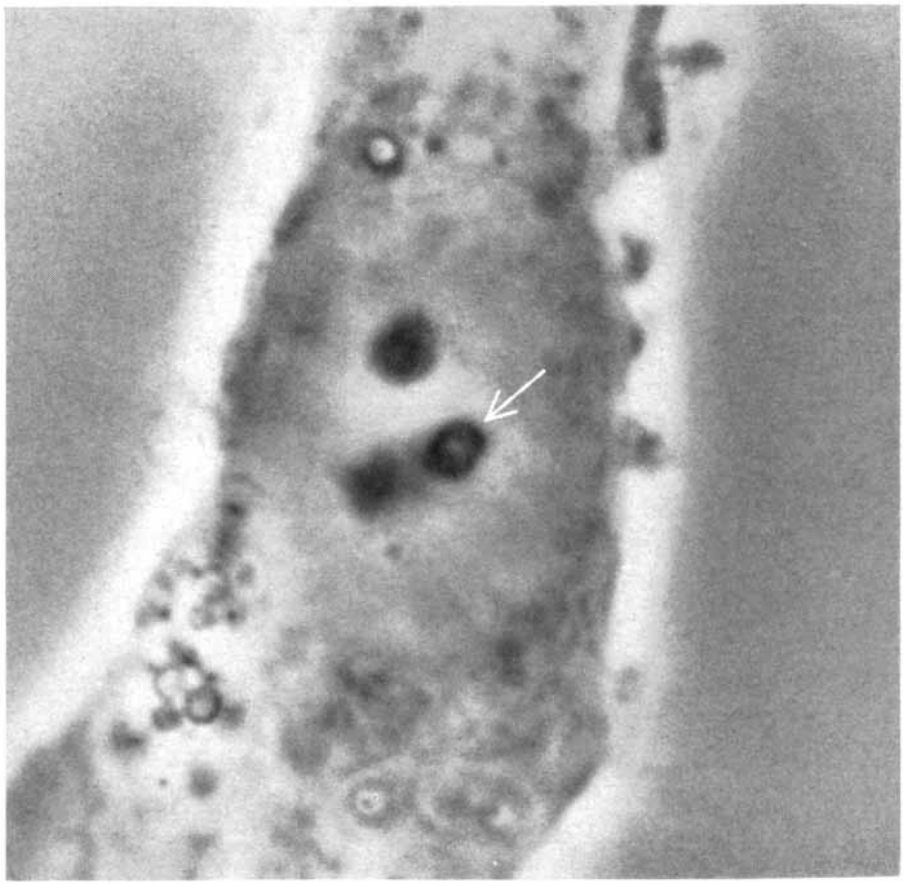


UNIRRADIATED NUCLEOLUS (*arrow*) of human cancer cell of the CMP line is dark. Nucleoli make RNA. They are dyed so that they will respond to blue-green laser light.



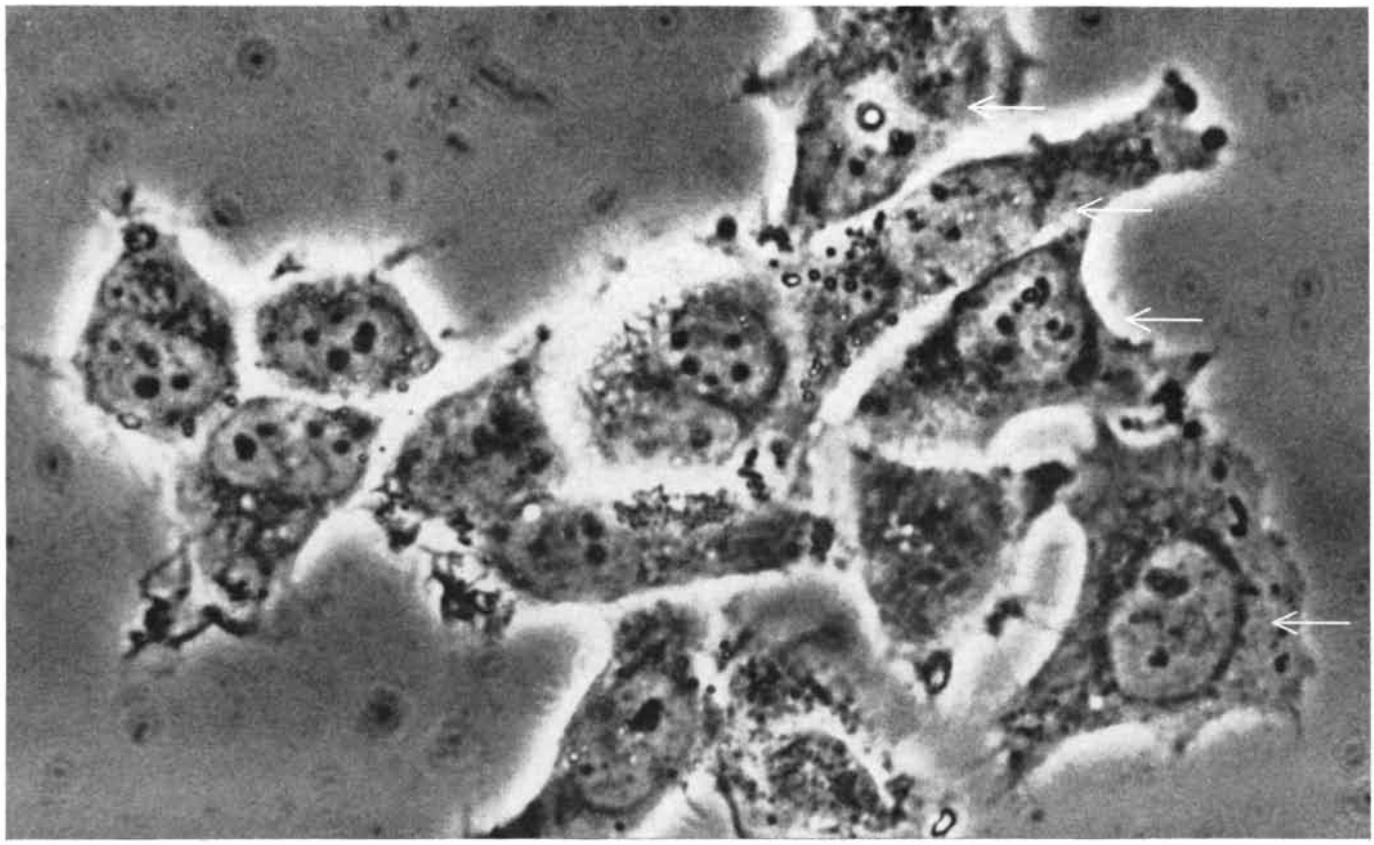
IRRADIATED NUCLEOLUS shows a small lesion (*arrow*). Whether or not a cell survives irradiation depends on number of organelles damaged and number of lesions in each.

cell did not die. If, however, the lesions were made after metaphase, division continued and two daughter cells were usually produced. This kind of result was most often observed when cultures at least four weeks old were irradiated. In cultures only one or two weeks old it was possible to make lesions in the chromosomes during any stage of mitosis and division would still take place. Such irradiated cells have been followed through subsequent divisions for as long as three weeks.

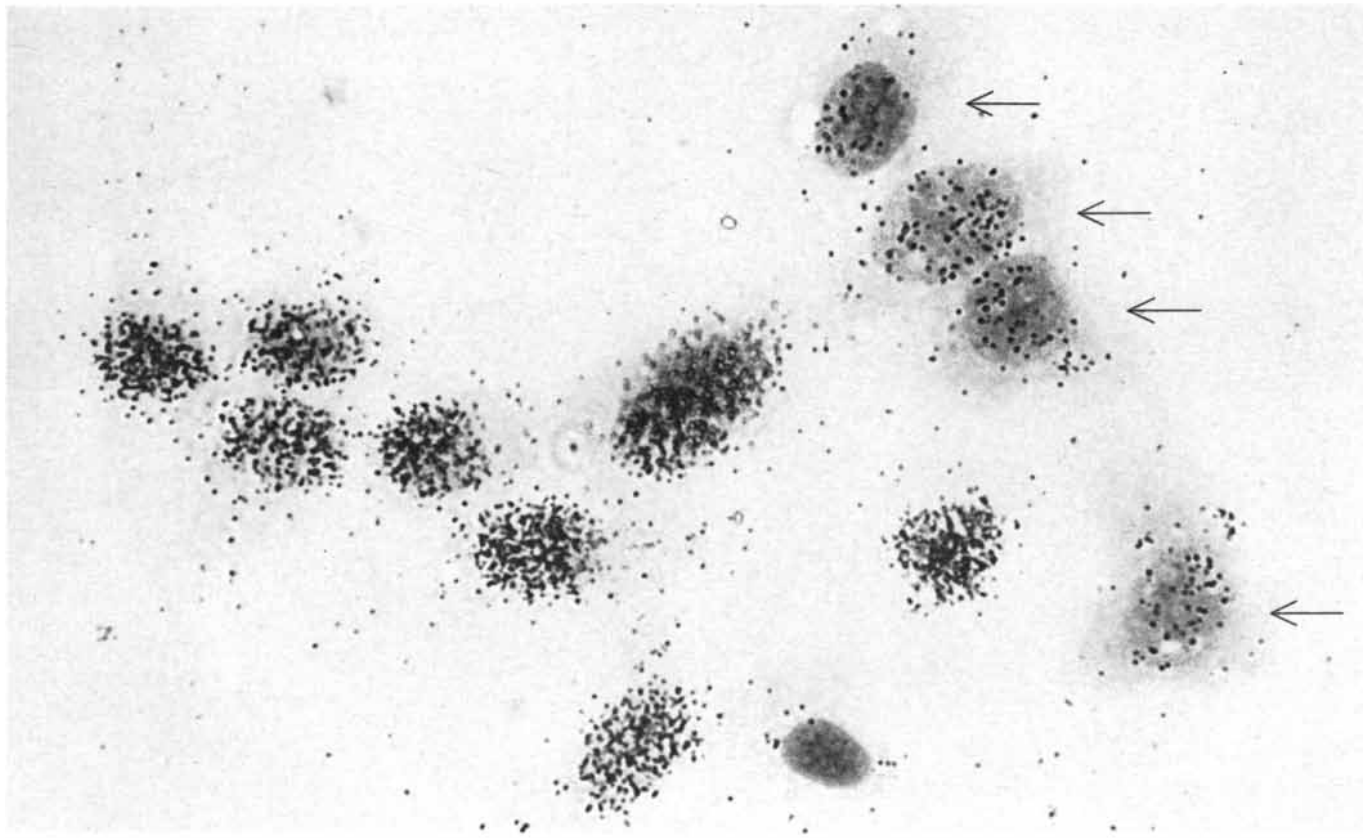
Could our instrument destroy a specific region of a chromosome so that the function of the region could be determined? We decided to simplify the test by choosing for irradiation a chromosome region that is easily recognizable because of its distinct shape. Many organisms have what are called secondary constrictions at the ends of certain chromosomes. There is much evidence to indicate that the secondary constrictions contain the genes that control the development of nucleoli when new cells are formed. Nucleoli are essential for the production of RNA. By irradiation of the secondary constrictions we and our colleague Yasushi Ohnuki have "knocked out" the functional capacity of this region. Cells have been selectively produced that lack one nucleolus, two nucleoli or all three of these bodies. Biochemical studies are now being conducted to investigate the formation and function of the nucleoli and the interaction between nucleoli.

Several experimental possibilities in genetics are suggested by this technique. Cells that have had lesions placed at specific sites on specific chromosomes can be examined for functional changes. It should also be possible to establish clones—colonies of genetically identical cells—from a single irradiated cell. Chromosome mapping and investigations of chromosome structure could be extended by the laser microbeam. A nucleus that has had a lesion placed on a specific chromosome might even be transplanted into an egg from which the nucleus has been removed. By comparing the growth and development of the resulting embryo with the growth and development of a normal embryo the extent and nature of the genetic damage might be revealed.

We have also been irradiating the nucleolus itself. In this area laser techniques supplement the work already done with ultraviolet radiation. The nucleoli that have been irradiated with the laser microbeam are those of cultured rat myocardial cells, rat endothelial cells,



LIVE CANCER CELLS (*arrows*) from CMP line have had all their nucleoli irradiated by beam of the argon-ion laser. Many pale lesions are visible on the dark organelles. Such irradiation can be expected to impair a cell's ability to incorporate vital materials.



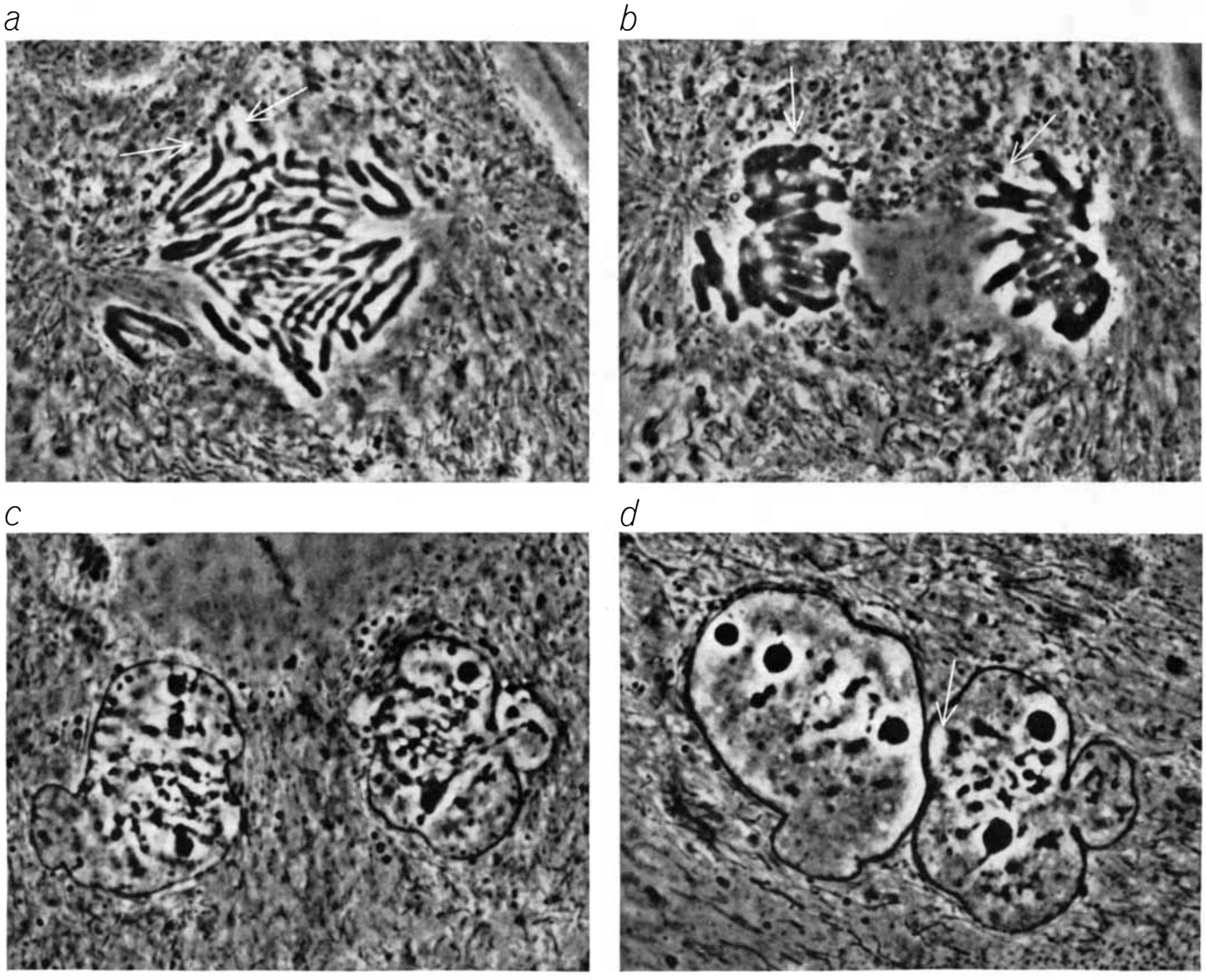
AUTORADIOGRAPH shows that cancer cells whose nucleoli had been damaged by laser beam have an impaired ability to incorporate uridine, a constituent of RNA. In this kind of autoradiograph cells are first grown on a slide in a medium containing uridine labeled with radioactive atoms. The cells are then fixed and the slide is dipped in a liquid photographic emulsion. Where the radioactively labeled uridine has been incorporated by the cells, grains in the emulsion are exposed (*black dots*). Cells that were not irradiated are much more densely covered with black dots than those cells are whose nucleoli were damaged by irradiation (*arrows*).

human skin fibroblasts, salamander lung cells and the line of human cancer cells designated CMP.

As in the chromosome studies, it was necessary to sensitize the nucleoli to the laser light. This was achieved by treatment with the antimalarial drug quinacrine hydrochloride. The steps in the irradiation process were slightly different from the chromosome sequence. Unlike acridine orange, quinacrine can easily be washed out of cells; therefore the drug must be present in the culture chamber during irradiation. If the quinacrine is washed out immediately after irradiation and fresh culture medium is placed in the chamber, the cells continue to grow. The morphology of the lesions was remarkably consistent with the morphology of the nucleolus: a lesion placed in a dense nucleolar region gave the appearance of a hole or a halo, whereas lesions made in less dense regions appeared as distinct dark spots. This observation was made on all the kinds of cells studied.

Currently we are employing autoradiographic procedures to monitor the uptake and movement of radioactively labeled uridine by cells that have had a nucleolus or several nucleoli irradiated by the argon laser microbeam. With these techniques it is possible to observe effects on the functioning of all the nucleoli in a cell, of a single nucleolus or even of part of a nucleolus. In addition we are examining the irradiated nucleoli with the electron microscope. Preliminary evidence suggests that an irradiated cell's survival depends on several factors, including the number of nucleoli irradiated, the number of lesions placed in an individual nucleolus, the period of time since the last cell division and the physiological state of the nucleolus at the time of irradiation.

As with any new system, there are many technical problems yet to be solved. The fact remains that the basically simple method of focusing a laser beam through a microscope provides a tool for probing any subcellular structure larger than half a micron. Biologists will find that the value of this instrument will increase as lasers are developed that produce more powerful beams at other wavelengths. Currently under development is a single laser-microbeam apparatus that will permit irradiation with wavelengths in the red, yellow, green, blue and ultraviolet regions of the spectrum.



NUCLEOLUS DEVELOPMENT can be affected by irradiation of the chromosomes. In *a* arrows mark chromosomes with constricted ends that govern growth of nucleoli. When a constriction is irradiated by the argon laser (*b*), a lesion is produced (*arrow at right*). Later (*c*), when nuclear division has been complete for an hour, the daughter nucleus at left has three nucleoli and the one at right only two. Lack of a nucleolus in cell at right can be seen even more clearly in *d*. Arrow indicates where missing nucleolus should be.

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MATHEMATICAL GAMES

Nine new puzzles to solve, some answers and addenda

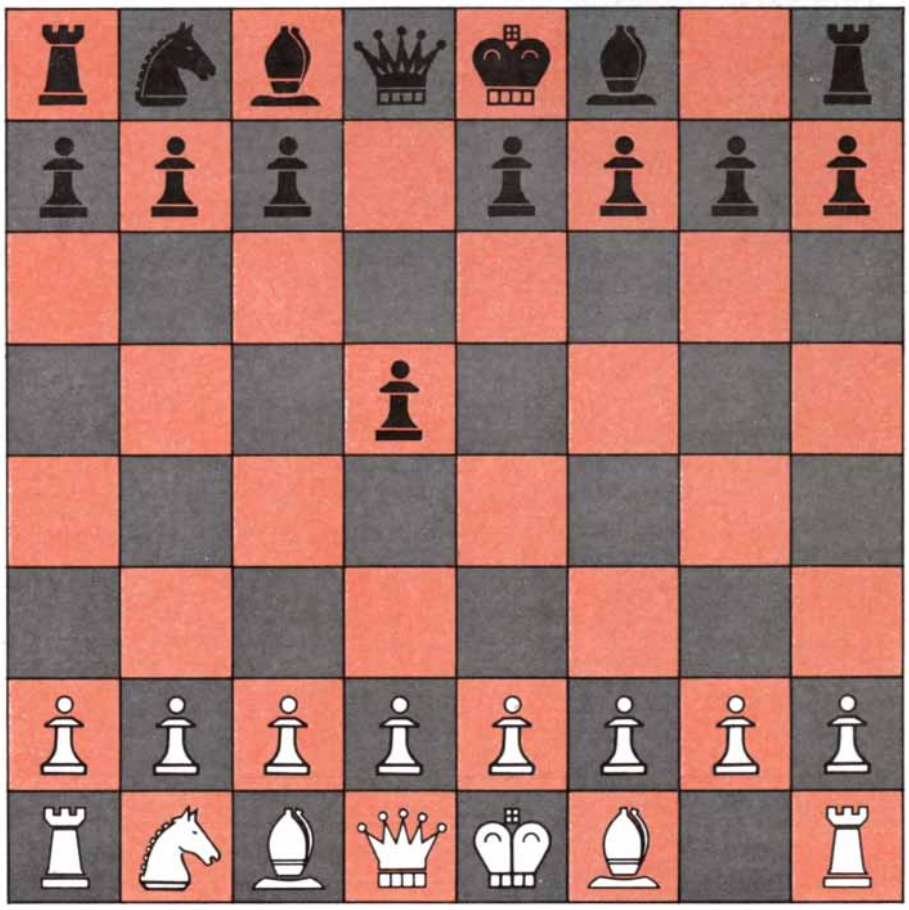
by Martin Gardner

The nine unrelated problems that follow call for no more than an understanding of elementary mathematics and, in one case, a knowledge of how to play chess. The solutions will appear next month.

1. On a recent visit to an imaginary chess club I found a game in progress between Mr. Black and Mr. White, the club's two most eccentric players. To my surprise the board appeared as shown in the illustration below. My first thought was that each player had started without his king's knight and that Black had moved first, but Mr. Black informed me that he had just completed his fourth move in a standard game that had been played as follows:

	White	*Black*
1.	N–KB3	P–Q4
2.	N–K5	N–KB3
3.	N–QB6	KN–Q2
4.	N takes N	N takes N

An hour later, after losing a game to another player, I came back to see what Black and White were up to. In their second game the board looked exactly the same as it had before except that now *all four* knights were missing! Mr. Black, playing Black, looked up and said, "I've just completed my *fifth* move."



Chessboard after Black's fourth move

a) Can the reader construct a legitimate game that leads to such a peculiar opening position?

"By the way," said Mr. White, "I've invented a problem that might amuse the readers of your column. Suppose we dump a complete set of chessmen into a hat—all 16 black pieces and all 16 white—shake the hat, then remove the pieces randomly by pairs. If both are black, we put them on the table to form a black pile. If both happen to be white, we put them on the table to form a white pile. If the two pieces fail to match in color, we toss them into their chess box. After all 32 pieces have been removed from the hat, what's the probability that the number of pieces in the black pile will be exactly the same as the number in the white pile?"

"H'm," I said. "Offhand I'd guess the probability would be rather low." Black and White continued their game with subdued chuckles.

b) What is the exact probability that the two piles will be equal?

2. This cryptarithm (or alphametic, as many puzzlists prefer to call them) is an old one of unknown origin, surely one of the best and, I hope, unfamiliar to most readers:

$$\frac{\text{EVE}}{\text{DID}} = .\text{TALKTALKTALK}\ldots.$$

The same letters stand for the same digits, zero included. The fraction EVE/DID has been reduced to its lowest terms. Its decimal form has a repeating period of four digits. The solution is unique. To solve it, recall that the standard way to obtain the simplest fraction equivalent to a decimal of n repeating digits is to put the repeating period over n 9's and reduce the fraction to its lowest terms.

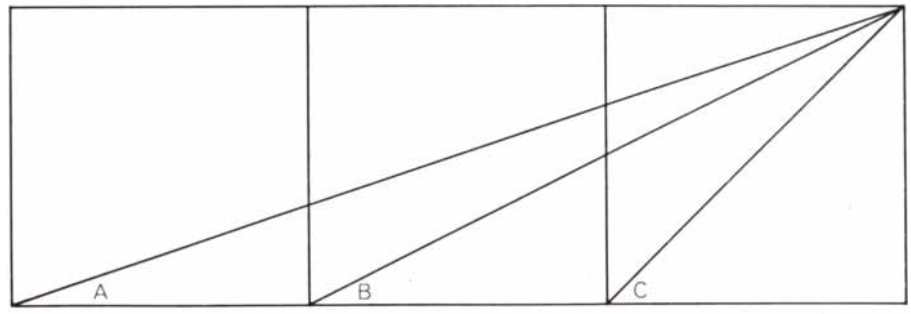
3. Frederik Pohl, a top writer of science fiction and the editor of *Galaxy* magazine, thought of this amusing stunt, which appeared in a recent issue of a magic magazine called *Epilogue*. Computer programmers are likely to solve it more quickly than others can.

Ask someone to draw a horizontal row of small circles on a sheet of paper to indicate a row of coins. Your back is turned while he does this. He then places the tip of his right thumb on the first circle so that his thumb and hand completely cover the row of circles. You turn around and bet you can immediately put on the sheet a number that will indicate the

total number of combinations of heads and tails that are possible if each coin is flipped. For example, two coins can fall in four different ways, three coins in eight different ways and so on.

You have no way of knowing how many coins he drew and yet you win the bet easily. How?

4. Using only elementary geometry (not even trigonometry), prove that angle *C* in the illustration at the right equals the sum of angles *A* and *B*.



***Prove that angle* A *plus angle* B *equals angle* C**

I am grateful to Lyber Katz of the Bronx, N.Y., for this charmingly simple problem. He writes that as a child he went to school in Moscow, where the problem was given to his fourth-grade geometry class for extra credit to those who solved it. "The number of blind alleys the problem leads to," he adds, "is extraordinary."

5. This remarkable sliding-block puzzle [*see illustration at right below*] was invented by Edward Brind Escott, an American mathematician who died in 1946. It appeared in the August 1938 issue of a short-lived magazine called *Games Digest*. No solution was published. The problem is to slide the blocks one at a time, keeping them flat on the plane and inside the rectangular border, until block 1 and block 2 have exchanged places with block 7 and block 10, so that at the finish the two pairs of blocks are in the position shown at the right, with the other pieces anywhere on the board. No block is allowed to rotate, even if there is space for it to do so; each must keep its original orientation as it moves up, down, left or right.

It is the most difficult sliding-block puzzle I have seen. (Simpler puzzles of this type were described here in February, 1964.) Next month's solution will be a 66-mover (counting each movement of one block as a single move even if it goes around a corner) found by Maurice J. Povah of Blackburn, England. It is the shortest solution known. The reader is urged to cut the 10 pieces out of heavy cardboard and to let me know if he finds a solution in fewer than 66 moves. I cannot reply to such letters but shall report on any shorter solutions I receive.

Escott was an expert on number theory who contributed frequently to mathematical journals. He taught at several schools and colleges in the Middle West and in his later years was an insurance company actuary in Oak Park, Ill.

6. Problems involving weights and balance scales have been popular during the past few decades. Here is an unusual one newly invented by Paul Curry, an official of the Associated Hospital Service of New York who is well known in conjuring circles as an amateur magician.

You have six weights. One pair is red, one pair white, one pair blue. In each pair one weight is a trifle heavier than the other but otherwise appears to be exactly like its mate. The three heavier weights (one of each color) all weigh the same. This is also true of the three lighter weights.

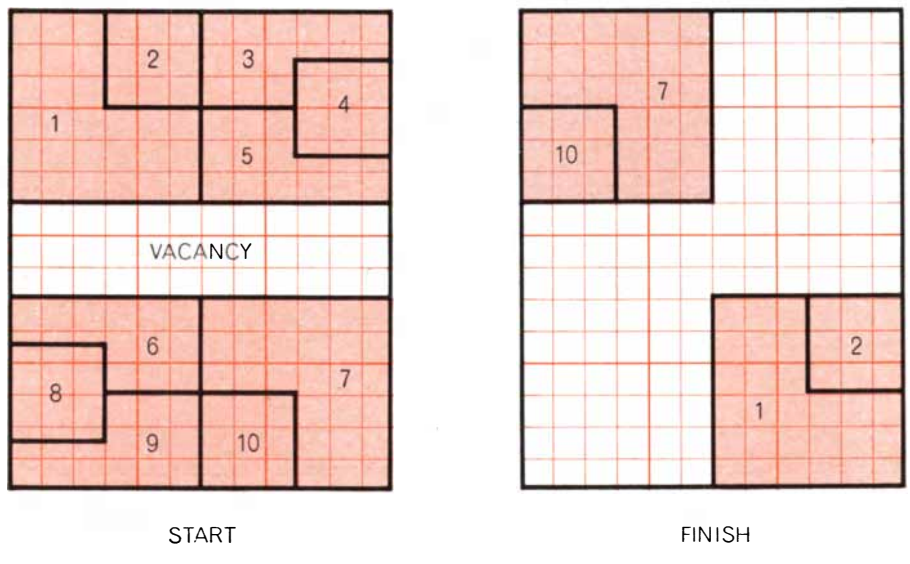
In two separate weighings on a balance scale, how can you identify which is the heavier weight of each pair?

7. In the 10 cells of the top illustration on the next page inscribe a 10-digit number such that the digit in the first cell indicates the total number of zeros in the entire number, the digit in the cell marked "1" indicates the total number of 1's in the number, and so on to the last cell, whose digit indicates the total number of 9's in the number. (Zero is a digit, of course.) The answer is unique.

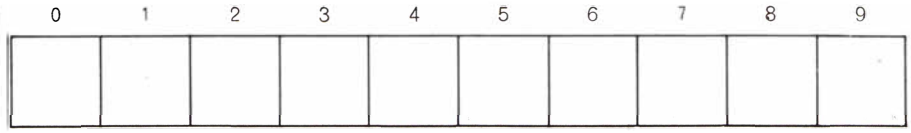
8. Kobon Fujimura, the leading puzzle authority of Japan, devised this tricky little puzzle, which appears in one of his recent books. Arrange 10 pennies in the familiar bowling-ball formation [*see bottom illustration on next page*]. What is the smallest number of coins you must remove so that no equilateral triangle, of any size, will have its three corners marked by the centers of three pennies that remain? Not counting rotations and reflections as different, there is only one pattern for the removal of the minimum number of pennies.

9. Knockout open-end geography is a word game for any number of players. The first player names any one of the 50 states. The next player must name a different state that either ends with the initial letter of the preceding state or begins with the last letter of the preceding state. For instance, if the first player gives Nevada, the next player can either affix Alaska or prefix Wisconsin. In other words, the chain of states remains open at both ends. When a player is unable to add to the chain, he is eliminated and the next player starts a new chain with a new state. No state can be named more than once in the same game. The game continues until only the winner remains.

David Silverman of Beverly Hills,



Escott's sliding-block puzzle



A digital problem

Calif., asks: If you are the first to name a state in a three-player game, what state can you name that will guarantee your winning?

The problem last month was to find the smallest number that, when it is multiplied by 17*d*, where *d* is any digit, gives a product that consists entirely of *d*'s.

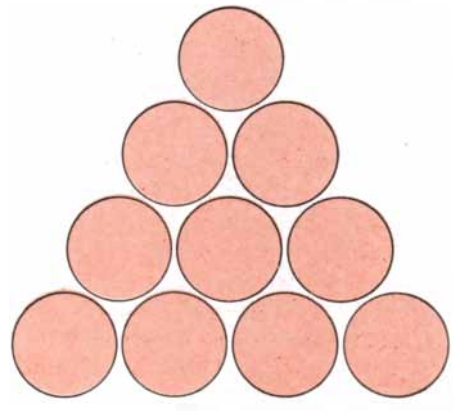
Such a number obviously must produce a string of 1's when multiplied by 17, therefore we divide 1111... by 17 to see if we reach a point where there is no remainder. Such a point is first reached by the quotient 65,359,477,-124,183, the answer to the problem. Since 17 times this number is 1,111,111,-111,111,111, a multiplier of $17 \times 2 = 34$ will produce a row of 2's, and so on for the remaining digits.

Because the infinite repeating decimal .1111... equals 1/9, or the reciprocal of 9, it can be shown that each integral magic number is the repeating portion of the decimal form of a reciprocal of uneven multiples of 9 that are not multiples of 5. In this case the magic number is the repetend in the decimal of 1/153, the reciprocal of the product of 9 and 17. An example of a nonintegral magic number is 1.375. Multiplied by 8*d*, the product consists entirely of *d*'s, provided that the zeros at the right of the product's decimal point are disregarded.

Louis M. Leichter, Myron R. Myerson and Donald R. Preuss were the first to call attention to the incompleteness of a statement last November about the relation of "perverse months" (months requiring six calendar rows) and Friday-the-13th's. The full statement is that the sum is four per year except for nonleap years beginning on Sunday or Thursday and leap years beginning on Sunday or Saturday, when the sum is five.

Ronald Gadzinski, Joseph G. Kelley and Eric Jamin were the first of scores of readers to point out that December's example of how to solve a domino grid problem does not have a unique solution as stated. If the 2–5 tile is changed to a horizontal position, three new solutions emerge. Of the two grid problems solved in January, the first has only one answer. The second, which I said had at least two solutions, has eight. Many readers sent all eight and a number provided proofs that there are no other solutions. I regret that I can list only the first three who wrote: William M. Daly, R. S. Fleischmann II and George C. Puram. There are three basic patterns: the one given, which has two forms because of a trivial rearrangement of two tiles; a second pattern with two forms arising from a rearrangement of the same two tiles, and a third pattern in which there are two order-2 squares, each with two arrangements, to make four more solutions.

Pentomino buffs will be interested in an article on "Packing a Rectangular Box with the Twelve Solid Pentominoes," by C. J. Bouwkamp, in the *Journal of Combinatorial Theory*, Vol. 7, No. 3, November, 1969, pages 278–280. (The monthly is published by Academic Press, 111 Fifth Avenue, New York, N.Y. 10003.) A solid pentomino is formed with five unit cubes instead of squares. Bouwkamp, of the Philips Research Laboratories at Eindhoven in the Netherlands, reports that his computer program found 3,940 solutions for the 3-by-4-by-5 box, 264 for the 2-by-5-by-6, and 12 (which he reproduces) for the 2-by-3-by-10. Of these 12, one is unique in having as few as two pieces that do not lie entirely on one of the 3-by-10 layers and another is unique in having the *L*-pentomino entirely within one of the layers. Other curious aspects of the 12 solutions are noted.



Coin puzzle from Japan

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Keeping up with the astronauts kept most Americans fairly preoccupied during the past year, at least so far as science was concerned, but scientists themselves were keeping busy in other ways. Working at the sites of ancient cities, or under the ocean, or in laboratories around the world, they have been involved in projects vital and fascinating to all of us. To provide an up-to-the-minute review of these newsworthy developments, the editors of TIME-LIFE BOOKS have brought together in a hardbound, profusely illustrated annual a record of the most important events in these fields last year.

The annual includes a wide variety of superb interpretive articles and picture essays. There is an article by TIME Medicine Editor, Gilbert Cant, on the ethical implications of heart transplants, (e.g., When is a donor dead?) and another dealing with the discovery of Sybaris—the ancient Greek colony deemed one of the most important archeological finds since Pompeii. Former LIFE Science Library Editor, Robert Claiborne, writes about the possibility that the world's largest and most majestic mammal, the whale, may be hunted into extinction by the end of the decade. Other articles examine the slow drift of the continents, pulsars, those stars that emit precisely regular pulses of radio energy and the comeback of steam and electric cars. The five striking picture essays include a study of the geological features of the moon; a discussion of hybrid agricultural products that may provide some answers to the world's hunger problems; and a fascinating look at some African wild dogs which display many of the same behavior patterns that distinguish early man from the other primates. All of this is contained in 192 information-filled pages, 64 of which are in full color. The book is durably hardbound and measures 8½" x 11".

For easy reference by students or anyone else who needs accurate up-to-date information, the editors have included a summary of events in nature and science during 1969, a listing of Nobel Prize winners and their achievements, as well as a complete index.

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THE AMATEUR SCIENTIST

A tunable laser using organic dye is made at home for less than $75

Conducted by C. L. Stong

An ideal laser, from the amateur's point of view, would be easy to make, reasonably inexpensive and capable of generating light of any color. An instrument of this kind has been built by J. R. Lankard of the International Business Machines Corporation. He made it at home with ordinary hand tools for less than $75, largely to prove that it could be done.

The amplifying medium of the laser is a dilute solution of organic dye that is periodically "pumped," or illuminated, by a homemade flash lamp. The output is an intense beam of coherent light five millimeters in diameter that can be focused to a point with lenses. The sharpness of the point is limited only by the wave nature of light. The beam can also be spread into a pattern of diverging rays. The color of the coherent rays is determined by the nature of the dye.

Various dyes can be used. Each of them generates light that spans a characteristic portion of the spectrum. The laser can be tuned to generate light of any wavelength within these ranges by means of a diffraction grating. When the laser is pumped at a sufficiently high rate, say 60 pulses per second, the output beam appears to the eye to be continuous. This modification increases the cost substantially, because the size of the power supply must be increased and provisions must be made for cooling the unit.

Like the helium-neon laser, the dye laser consists essentially of a slender amplifying tube, or dye cell. The ends of the tube are closed by a pair of flat windows that face a pair of mirrors. A second tube, the flash lamp, is mounted parallel to the amplifying tube. Both tubes are surrounded by an aluminum tube of elliptical cross section with an interior surface that is highly polished to function as a mirror. The axis of the amplifier tube occupies one focus of the elliptical mirror and the axis of the lamp occupies the other focus. White light emitted by the lamp is thus concentrated by the mirror on the amplifying tube [*see illustrations on opposite page*].

The amplifying tube is filled with an alcohol solution of dye that is known to fluoresce. When such solutions absorb white light, some molecules of dye acquire an abnormal amount of energy and so are raised to what is termed their lowest excited singlet state. Later they spontaneously emit the excess energy as light of longer wavelength. This is the phenomenon known as fluorescence.

If the white light is sufficiently intense, as it is in the dye laser, a majority of the dye molecules absorb more than enough energy to reach the singlet state. Hence they are raised to one or another of the possible higher energy states. From these levels they can also drop back spontaneously to lower energy states by emitting light. Some of these emitted waves, strictly by chance, head toward one or the other of the laser's flat mirrors, which reflect the light waves back into the amplifier tube. Here the waves stimulate other excited molecules to emit excess energy. The resulting emission is identical in color, and so in wavelength, with the stimulating waves. The waves merge and thereafter proceed in lockstep. In effect, the waves that were emitted spontaneously are amplified and continue to accumulate energy as they are subsequently reflected back and forth through the tube [see "Organic Lasers," by Peter Sorokin; SCIENTIFIC AMERICAN, February, 1969].

The flat mirrors of the dye laser are coated with aluminum. One mirror reflects about 92 percent of the incident light and absorbs 8 percent. The other mirror, which has a thinner coating, reflects 74 percent, absorbs 8 percent and transmits about 18 percent. The transmitted portion constitutes the output beam of the laser. In Lankard's apparatus it amounts to about 5,000 watts per pulse, which is a million times more intense than the output of the helium-neon laser! This substantial power and the tunable feature of the laser open new experimental opportunities to amateurs who have been restricted to the helium-neon and argon lasers previously described in this department [see "The Amateur Scientist"; SCIENTIFIC AMERICAN, September, 1964, December, 1965, February, 1967, and February, 1969].

It bears repeating that laser action occurs only if the dye is exposed to white light of sufficient intensity. Lankard developed the required intensity with an extraordinarily simple lamp. It is a tube of fused quartz provided with stainless-steel electrodes and filled with air. The electrodes are connected to the terminals of a 15-microfarad capacitor charged to a potential of 3,000 volts. To flash the lamp Lankard pumps air from the tube. When the pressure falls to about 60 torr, the capacitor discharges through the lamp. The resulting flash consumes some 35 megawatts of power and persists for about two millionths of a second. The capacitor is specially designed to discharge in that brief interval. Ordinary capacitors discharge more slowly and will not work in this application.

The dye emits only a small part of the absorbed energy as coherent light. That part is transformed into heat that causes random differences in density throughout the column of dye and, as a result, random differences in the optical refraction of the fluid. Fortunately the heating effect lags behind the flash by several millionths of a second. By the time the optical distortion becomes substantial the laser light has been emitted.

The dye must be at uniform temperature, however, before the laser can be pulsed again. A convenient method of cooling is to circulate dye continuously through the amplifier tube. The tube consists of an 80-millimeter length of seven-millimeter quartz tubing with a bore of five millimeters. The ends of the tube are closed by flat windows cemented in place at the edges with epoxy cement. Dye solution flows into one end of the tube through a port in the side and out through a similar port at the other end.

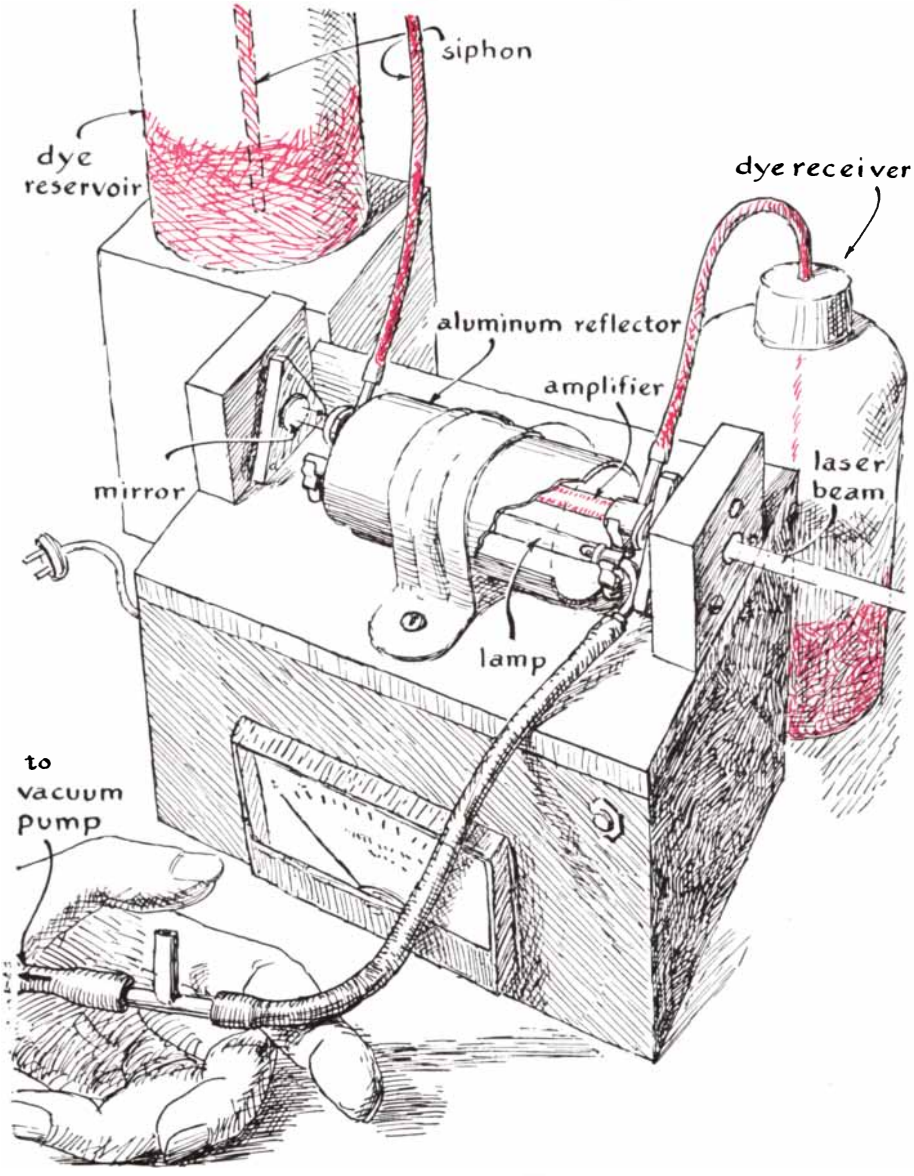
The ports can be made by welding short lengths of quartz tubing, as side arms, near the ends of the amplifier tube. Fused quartz is difficult to soften and manipulate. It must be worked in an oxyacetylene flame. Lankard suggests the use of metal tubing as an alternative. A *T* fitting can be improvised from copper or stainless-steel tubing. The inside diameter of the *T* should be seven millimeters to match the outer diameter of the quartz tube. One end of the crossbar of the *T* can be slipped over the end of the quartz tube and fixed in place with epoxy. The quartz window, which has a diameter of about 10 millimeters and a thickness of one millimeter, is put on the remaining end of the crossbar and held in place while a coat of epoxy is applied to the joint. A short nipple of copper or stainless steel forms the leg of the *T* and functions as the port through which the dye solution flows [*see top illustration on next page*].

Dye solution can be circulated through the laser by a small pump. The cost of the pump can be avoided by siphoning dye solution from an elevated container and discharging it into a similar container at lower elevation. The dye should flow at the rate of about one liter in 15 minutes.

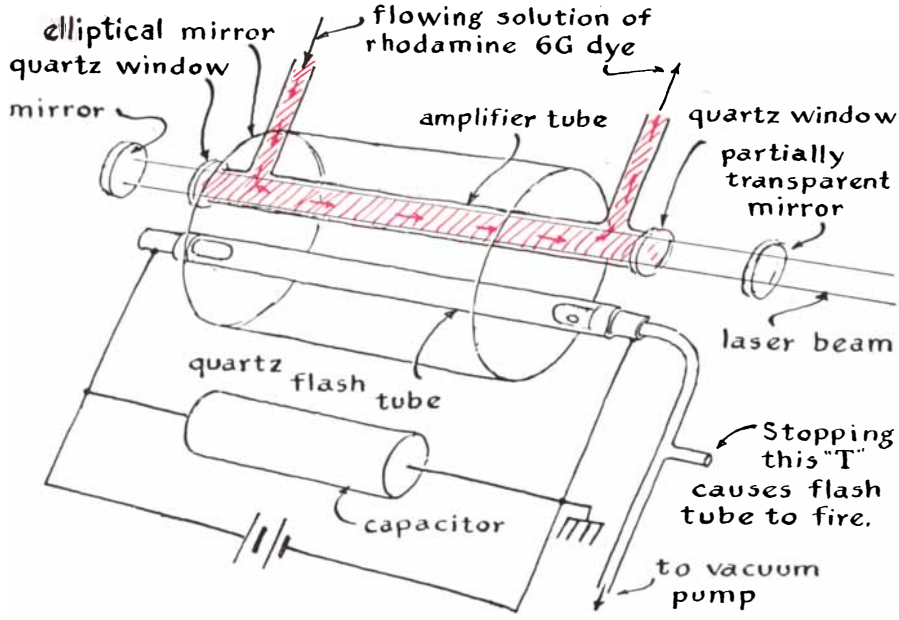
The pump that evacuates the lamp tube can be the sealed compressor from a discarded electric refrigerator that is in reasonably good condition. Connect the exhaust port of the lamp to the inlet tube of the compressor. Usually the inlet tube is the larger of two copper tubes welded into the sealed unit as a pair. The smaller of the tubes resembles a wire about 3/32 inch in diameter; it is actually a capillary that serves as the outlet of the compressor. Cut the capillary by filing a nick about 1/32 inch deep and bending the tube at the nick until it breaks. Run a small hose from the capillary to a bucket of soapy water.

Oil of any kind—indeed, any contamination of the dye—will suppress laser action. Do not use ordinary plastic tubing in any portion of the dye plumbing. Most plastics contain an oily plasticizer that preserves the flexibility of the material. Use glass reservoirs and connect them to the amplifier with either glass or Kodak Polyflow tubing, a plastic that contains no plasticizer. Do not attempt to operate the laser in a room where the air may be contaminated with oil, and remember that mechanical vacuum pumps discharge oily fumes. Such fumes can be minimized by discharging exhausted air from the pump through a container of soapy water.

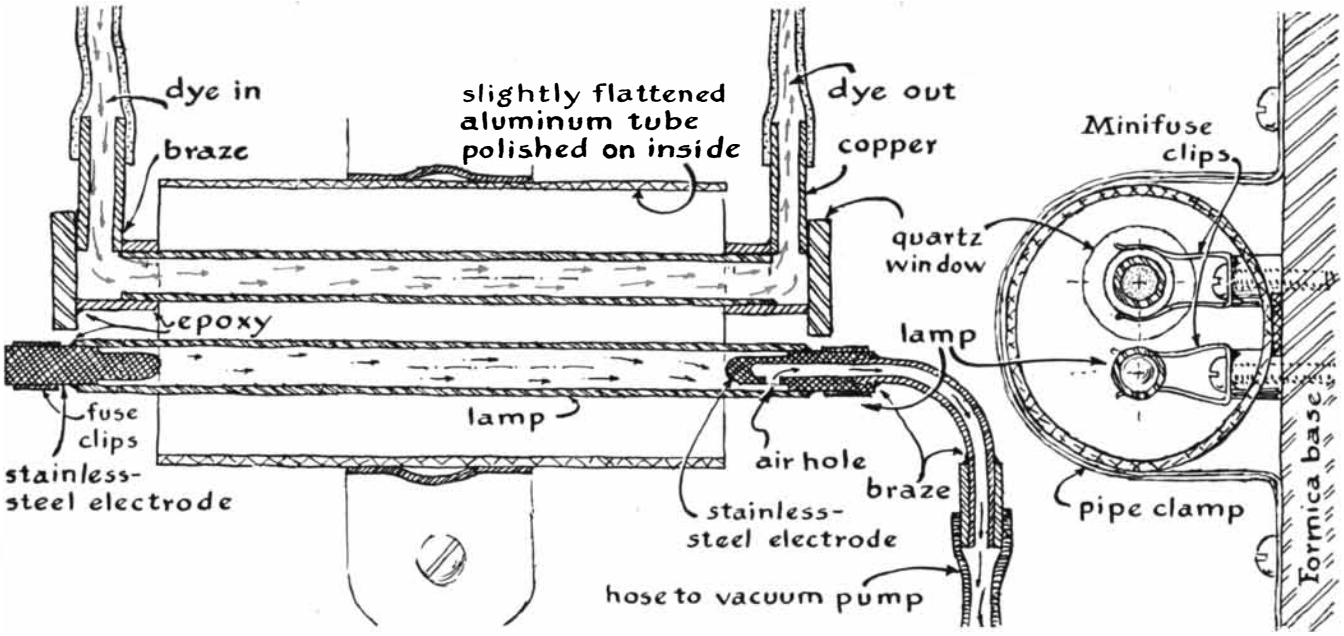
The lamp can be flashed by either of



Elements of the dye laser made by J. R. Lankard



Arrangement of the laser's components

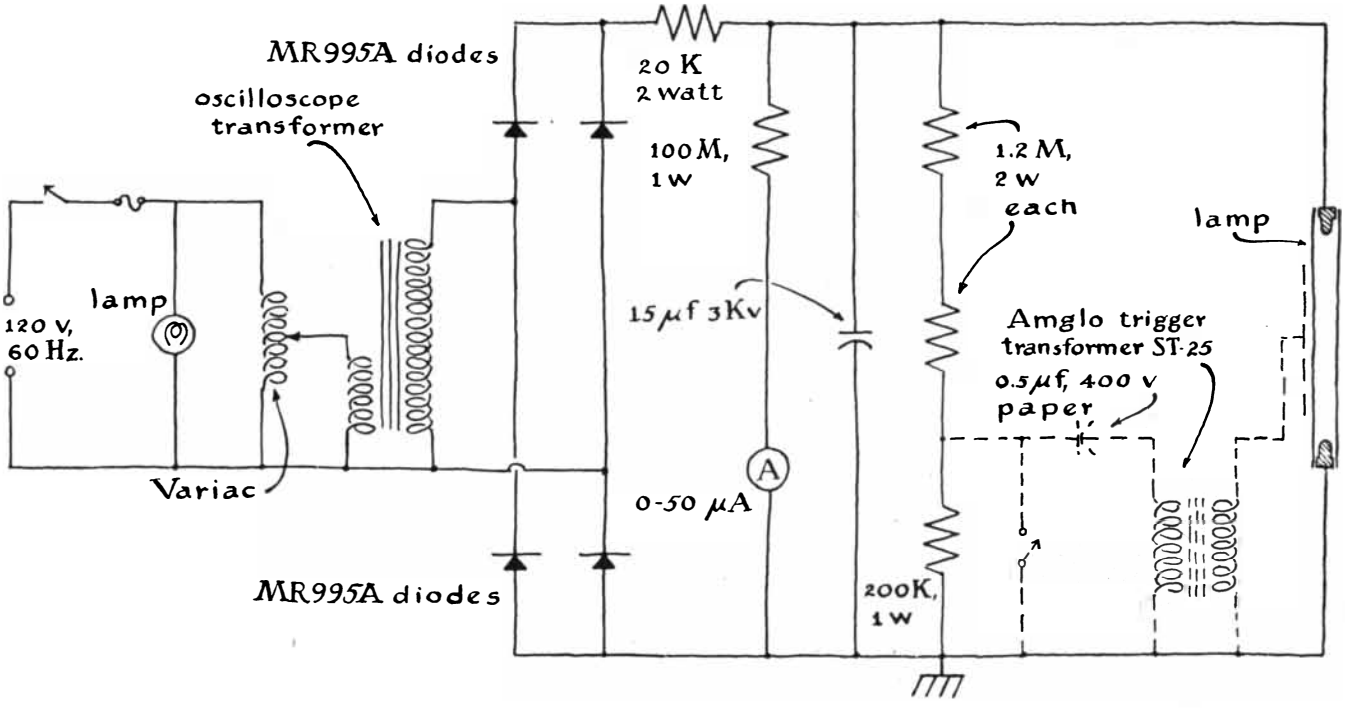


Details of the trigger lamp and the amplifier

two triggering schemes. In the simpler and cheaper of the two a *T* fitting is installed in the tube that leads from the lamp to the air pump. Cut the tube at a convenient point and insert the crossarm of the *T*. Air will be pumped through the open leg of the *T*. To flash the lamp, plug the opening of the *T* with your thumb. When the pressure drops to about 60 torr, the lamp will flash. The grounded side of the power supply must be connected to the electrode through which the air is exhausted or you will get an electric shock when the lamp flashes.

The second scheme is a special triggering transformer in the power supply. This device develops high potential, much like a spark coil, when power is applied to its primary winding. One terminal of the transformer is connected to ground and the other one to a few turns of fine wire wrapped around the middle of the lamp. The lamp is exhausted to a pressure about 10 torr above its normal firing pressure, which must be determined experimentally. Then, with full voltage applied across its terminals by the charged capacitor, the lamp can be fired by applying power to the primary winding of the triggering transformer. High voltage ionizes air inside the lamp and initiates the discharge, as indicated by the broken lines in the illustration below. The scheme is convenient when an experiment requires that the laser be fired electronically by an associated apparatus that includes a switch for closing the triggering circuit.

The lamp must have a port for exhausting the air. A side arm of quartz can be welded to the tube. Alternatively, the air can be withdrawn through one of the electrodes. The electrodes are preferably made from small rods of stainless steel that make a snug fit with the bore of the quartz tube. The diameter of the inner portion of both electrodes should be reduced to about four millimeters



Circuitry of the laser

through a length of about eight millimeters and the end rounded into a polished hemisphere. The portion of reduced diameter, along with about six millimeters of the full diameter of the rod, is inserted into the end of the quartz tube and sealed in place with an external coat of epoxy cement. The reduced diameter provides a 1/2-millimeter space between the metal and the quartz. The space prevents hot plasma from concentrating in the zone where the metal and the quartz make contact. The portion of the rod that extends outside the tube may be of any length convenient for the attaching of leads from the capacitor.

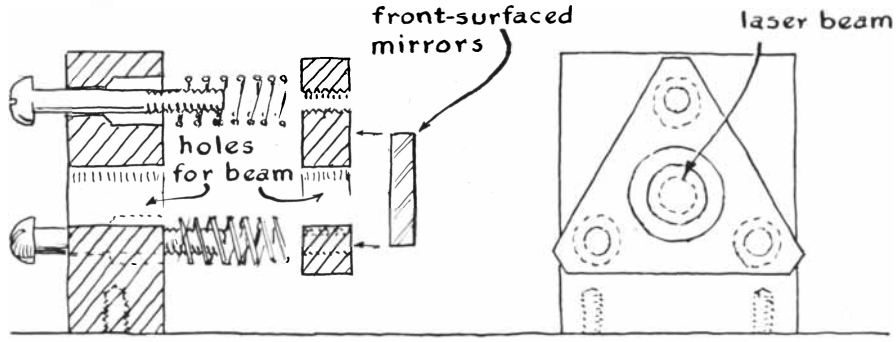
The machining can be done by clamping the rod in the chuck of an electric drill and cutting the metal with a file as the drill turns. Air can be exhausted through a hole about a millimeter in diameter drilled partway through the axis of the rod and joined at a right angle by a hole of similar size drilled from a point close to the shoulder. Do not drill the axial hole completely through the electrode. A tube of copper capillary can be brazed to the outer end of the electrode for attaching the air pump. Connect this electrode to the grounded side of the power supply.

The lamp and the amplifying tube are mounted parallel, 15 millimeters above the base, with their centers separated by about 12 millimeters. The base can be a slab of Formica about 1/2 inch thick. Lankard clamps the tubes in Minifuse clips attached to the base.

The reflector consists of an 80-millimeter length of aluminum tubing that has an inner diameter of about 25 millimeters. The inner surface must be highly polished; the polishing can be done with a small buffing wheel. Bring the surface to a semipolish by applying tripoli to the buffing wheel. After washing the metal with soap and water complete the polish with a clean buff to which rouge is applied.

The polished tube must be converted into an elliptical mirror. Clamp it in a vise and by trial and error exert just enough pressure to deform the metal. When the pressure is released, the tube should spring into an ellipse with its major axis some three millimeters longer than its minor axis. If you squeeze it too much, so that the difference in length is more than three millimeters, correct the error by rotating the tube a quarter of a turn in the vise and squeezing it again.

Mount the reflector to the Formica base with a pipe clamp. The major axis should be made parallel to the base. The Minifuse clips are attached to the base at points such that the axes of the amplifier and the lamp coincide with the focuses of the ellipse, which lie 12 millimeters apart.



Construction of the mirror cells

Cells for supporting and adjusting the position of the mirrors consist of two aluminum plates fastened together with machine screws and helical springs of the compression type [*see illustration above*]. One of the plates, a rectangle that serves as a pillar, is fastened to the Formica base with machine screws. Three holes spaced 120 angular degrees apart admit machine screws that engage threads in the second plate, which can be of triangular form. Compression springs that surround the screws hold the plates apart. A hole about eight millimeters in diameter is drilled through both plates of one cell. The hole is centered in the triangular plate. The partially transmitting mirror is cemented at its edges to this triangle, with the aluminum coating facing the dye cell. The hole functions as an aperture for the output beam. The fully transmitting mirror is similarly cemented with epoxy to the remaining cell.

The power supply can be assembled in a metal box that supports the Formica base. It is extremely important to use the shortest possible leads for connecting the 15-microfarad capacitor to the lamp, preferably leads of copper strap about one millimeter thick and 10 millimeters wide. The leads can be cut from copper flashing of the kind available from lumberyards and tinsmiths. Attach the leads to the screws that fasten the Minifuse clips of the lamp to the base. This construction minimizes the electrical inductance of the circuit and the interval required for the capacitor to discharge. The intensity of the light varies inversely with the rate of discharge.

The microammeter, which can be mounted in one side of the box, functions as a voltmeter, the scale indicating hundreds of volts. A reading of 30, for example, indicates that the capacitor is charged to a potential of 3,000 volts. A potential of 120 volts applied to the primary winding of the oscilloscope transformer appears as 2,400 volts across the terminals of the secondary winding. The rectified voltage that appears across the capacitor is equal to the output potential of the oscilloscope transformer divided by .707; a potential of 120 volts applied to the primary winding develops 2,400/.707, or 3,400 volts, across the capacitor.

This potential exceeds the breakdown rating of the capacitor. To protect the capacitor, Lankard inserts a variable transformer between the power line and the power supply and adjusts the potential to 3,000 volts as the capacitor accumulates charge. Do not omit the three resistors shown at the right in the bottom illustration on the opposite page. They function as bleeders, draining charge slowly from the capacitor. Without this safety provision the capacitor would retain a substantial portion of its lethal charge indefinitely. Never touch the power-supply circuit until the capacitor has been short-circuited, even though the circuit includes bleeder resistors. Short-circuiting can be done by briefly connecting a short length of copper wire across the terminals of the capacitor. The wire should be fixed to a dry wooden handle about a foot long.

Several dyes have been used successfully in the laser, and others are under investigation. A good one for a beginning experiment is rhodamine 6G. This orange dye emits light that spans a spectral range of some 440 angstroms from yellowish-green to red. The molecular weight of the dye is 449. It is used as a 10^{-4} molar concentration in methanol. The concentration can be achieved by dissolving .045 gram of the dye in methanol to make one liter.

An interesting dye, which emits a strong blue laser beam that is tunable from 4,300 to 4,900 angstroms, is 7-diethylamino-4-methylcoumarin, a dye found in commercial detergent whiteners. It has a molecular weight of 231.3 and is used in the laser at a concentration of 75 milligrams of dye per liter of meth-

anol. Another dye, sodium fluorescein, is used at the same concentration as rhodamine 6G but in an ethanol solution. The molecular weight of sodium fluorescein is 370. Laser emission from this dye centers on 5,500 angstroms. Mix the dyes in clean glass containers, and be careful to avoid oily contamination.

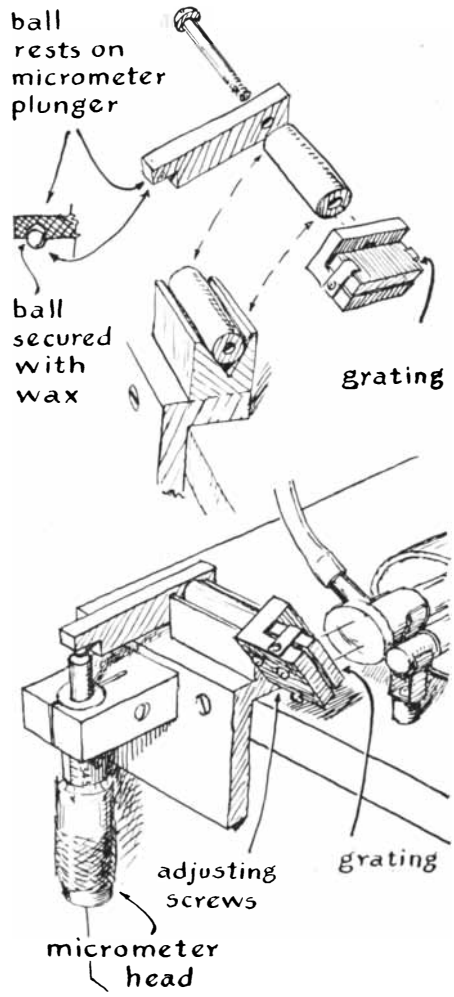
The operation of the fully assembled laser requires one critical adjustment: the mirrors must be positioned so that their surfaces are exactly parallel and perpendicular to the axis of the dye cell. When the surfaces are so aligned, light rays that are emitted parallel to the axis of the amplifier tube are reflected back on themselves and thereafter oscillate between the reflecting surfaces as though trapped in a cavity. Several schemes have been devised for aligning the mirrors. The most convenient one involves the use of an instrument consisting of a small telescope, an optical beam splitter and a source of light. Lankard's instrument consists of a seven-power telescope that is available from the Edmund Scientific Co., 600 Edscorp Building, Barrington, N.J. 08007 (catalogue number 50,249). The telescope comes with a diagonal mirror that deflects the incoming light at a right angle into the eyepiece.

Lankard substituted for the diagonal mirror a beam splitter that is also available from Edmund Scientific, and behind the beam splitter he installed a pinhole aperture and a small incandescent lamp [*see illustration below*]. Rays from the lamp proceed through the pinhole, the beam splitter and the objective lens of the telescope. When the telescope is aimed at a distant mirror that reflects the light back into the telescope, a portion of the incoming light is diverted into the eyepiece by the beam splitter, and an image of the pinhole appears in the eyepiece.

To align the laser, Lankard removes the partially transmitting mirror and, with the telescope, looks through the axis of the empty dye cell at the distant fully reflecting mirror. That mirror is then adjusted to center the image of the pinhole in the eyepiece. The partially transmitting mirror is reinstalled. Two images of the pinhole, usually displaced, now appear in the eyepiece. The partially transmitting mirror is adjusted to bring the two images into exact register. This completes the adjustment. When the laser is thus adjusted, it will emit a pulse of coherent light each time the lamp flashes. The beam appears yellowish in the case of rhodamine 6G dye.

The laser can be tuned to emit any desired spectral line within the range of the dye by substituting a reflecting diffraction grating for the fully reflecting mirror. The grating, which need be no larger than 10 millimeters square, is mounted so that it can be rotated in three planes: its own plane, the horizontal plane and the vertical plane [*see illustration at right*]. The rulings are placed exactly parallel to the horizontal axis of rotation. (The grating, which must be obtained commercially, should be ruled with at least 1,800 lines per millimeter and blazed for 5,000 angstroms in the first order.) When the grating is properly aligned, it reflects light of a single spectral line into the amplifier. The color depends on the horizontal angle the grating makes with the axis of the amplifier tube.

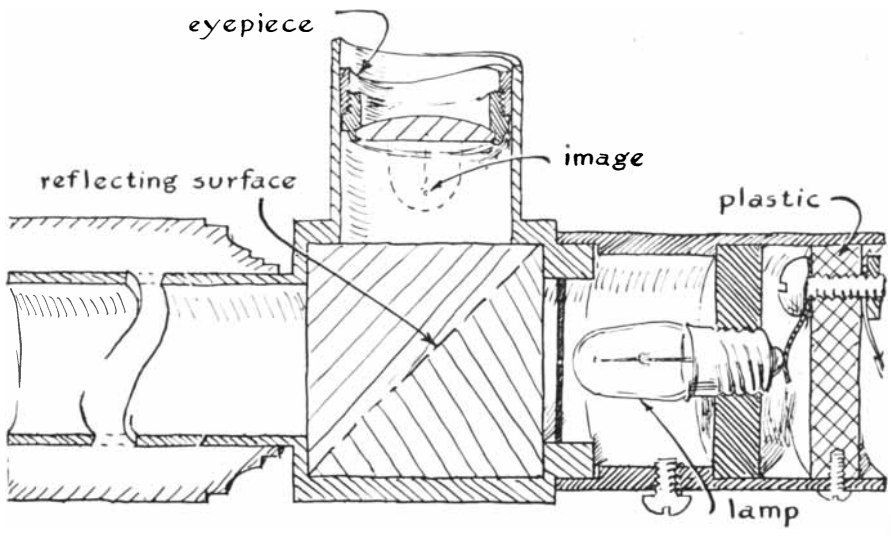
Initially the grating can be set to an angle of about 70 degrees. A colored image of the filament will appear in the alignment telescope. When the image is brought into register with the white image reflected by the partially transmitting mirror, the laser will emit light of the selected color. The output beam can then be tuned to any other part of the available spectrum (from a shade of green through yellow and to red) by rotating the grating on its vertical axis.



Mounting of the diffraction grating

The laser can also be tuned within broad limits by altering the concentration of the dye or—what amounts to essentially the same thing—by altering the length of the amplifier tube. In general the wavelength of the output beam increases with the concentration of the dye or the length of the amplifier tube.

All the materials required for the construction of the dye laser, with the exception of the telescope, beam splitter and diffraction grating, can be obtained from Henry Prescott, 116 Main Street, Northfield, Mass. 01360. Many parts can be improvised from odds and ends. Lankard's instrument came largely from his scrap box. Do not attempt to economize on the 15-microfarad capacitor. Capacitors characterized by higher inductive reactance will not work. Do not substitute other materials for fused quartz. Finally, avoid the laser beam as if it were the flame of an oxyacetylene torch. It can fry tissue, including the tissue in your eye.



Arrangement of the telescope for aligning the mirrors

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BOOKS

The bodies in the bogs, marine partnerships and other topics

by Philip Morrison

THE BOG PEOPLE: IRON-AGE MAN PRESERVED, by P. V. Glob. Translated from the Danish by Rupert Bruce-Mitford. Cornell University Press ($7.50). All across northern Europe, from County Down to the far side of the Vistula, men still cut peat as they have for centuries from the lowland bogs that are the legacy of the glaciers. The bogs are strange, silent places, soggy, overgrown by bracken fern and coarse weeds, with pools and watercourses screened by a darkening tangle of alder, birch and willow. Even 2,000 years ago the bogs were wooded patches in a cleared rolling terrain freed from the old grip of the ice. The end of the finger that Denmark sends north into the sea is such rolling land today. An area the size of Massachusetts, it is striped with bog and fen, the uplands often bearing the funeral tumuli raised long ago to honor the great dead of the Bronze Age. The very notion of the Bronze Age began in Denmark; it is a land of archaeology. The men who cut peat there for winter fuel have become archaeologists too; for as long as they have been working with the spade, they have from time to time uncovered well-preserved, brown-tanned bodies of people. The peat bog stores stagnant water freed of all dissolved oxygen and rich in the acidic iron ions that tan skin proteins to leather. "There is a strange power in bog water which prevents decay," a Danish almanac stated in 1837. There are nearly 700 records of bodies found in the peat all over Europe, a third of them found in or adjoining the Danish mainland.

At first the fresh-seeming bodies were believed to be those of the newly dead—someone lost in the bog, or a person strangled in some foul murder. When in 1952 the body of a man was found near Grauballe, throat slit, stark naked, hair and beard stubble intact, fingernails and fingerprints as in life, an old farmer's wife at once recognized him by his features as one Red Christian, a peat cutter and ne'er-do-well poacher she had known in her childhood, who had disappeared without a trace "in 1887, or the year following." The newspapers loved this commonsense deflation of the savants who had made so much of the dead man and had had him put on display in the Museum of Prehistory at Aarhus. Alas, in due course the headlines had to report "Red Christian Knocked Out by Atoms"; carbon-14 dating had placed his age at 1,650 years!

Of course, Professor Glob had had no reason to doubt his interpretation even without the clicking judgment of the proportional counters. There were no artifacts associated with the man, but the layers of peat above him were undisturbed, and the microscopic study of the pollen content revealed the entire floral history of the many centuries since his death. In his digestive tract were the remains of his last meal, a strange repast eaten just before death. That meal closely resembled the one discovered in the Tollund find of two years earlier, a man so well preserved that he appears to be sleeping, dressed in the leather cap and girdle of the Iron Age, bearing the skin noose that had hanged him. The meal is a gruel made up of a mixture of many grains—63 species in the Grauballe find! The two principal ingredients are barley (still grown by the farmers of Jutland) and knotweed (*Polygonum nodosum*, a close relative of buckwheat, the only cereal still widely cultivated that is not a grass). To these grains of ancient cultivation are added many seeds of the weeds common to plowed land. There is no trace of berry, fruit or greens. Death came in winter before spring began. Although the Iron Age people ate meat, cheese and milk, as remains in other graves prove by bone and utensil, the bog people had eaten pure grain meals.

We can turn to written records, not intimate ones but rather the distant account of Cornelius Tacitus, in his *Germania*. That great historian was eager to contrast the free savagery of the red-haired northern aliens with his effete Imperial Rome. He tells of their obligate rites of spring, in which the goddess Nerthus—the Earth Mother—was displayed in a chariot drawn by cows, then married and her ministrants "straightaway swallowed" by a lake. It is a plausible conjecture that the bog men, whose hands do not show the calluses of the plowman, are her priest-grooms, sacrificed to the Earth Mother after a ritual meal of "an abundance of just those grains and flower seeds which were to be made to germinate, grow, and ripen by the goddess's journey through the spring landscape." The bog people went to their wet graves unornamented; the fatal twisted neck rope found on one or two may be the ironic symbol of the massive bronze torcs elsewhere dedicated to the grim and generous goddess.

MARINE ANIMALS: PARTNERSHIPS AND OTHER ASSOCIATIONS, by R. V. Gotto. With illustrations by Gloria Sidwell. American Elsevier Publishing Company, Inc. ($4.25). Style informs every page of this brief book, in the acute, personal, pithy text and in nearly three dozen woodcuts that display form in massy black and texture in sharp white line. The account of the adaptations by which differing species live one with another in all their "subtle gradations" is full of wonder as much as it is of diverse charm. The level of discourse is precise but nontechnical; the book is an overall sketch, wide in scope and well organized, for the student and for the general reader, but its author and artist know and depend on the monographic literature. The shallow sea is the oldest of all the seats of life, and in its spacious but dense three-dimensional haven there has been ample time for the shaping of "patterns of organic architecture, unthinkable in other environments." The marine focus does not limit the impact of the examples.

Mothers, monkey and human, groom and clean their young. In the sea many species set up cleaning stations, which are visited regularly by the local fish population, including large and toothy predators. There the cleansing is done with skill and care. The Pederson shrimp

of the West Indies is a sedentary little fellow whose advertisement is a leggy display of white stripes and violet spots and a spray of "immensely long antennae." It sways and waves its antennae as a customer swims by. The shrimp, which itself always lives in company with a particular species of sea anemone, stations itself at a good location—say a rocky outcrop on the bottom—and plies its trade. The shrimp is a barber-surgeon, licensed even to make small incisions to extract parasites from under the skin and to enter the predator client's large mouth in perfect safety. Within this laundry trade a confidence game has developed too. A certain small cleaning fish has evolved a kind of display dance to signal its patrons. "Now the size, form and colour of *Labroides,* and even its dancing movements, are simulated by a blenny, *Aspidontus taeniatus,* which thereby elicits an invitation to clean. This blenny is, alas, a wolf in sheep's clothing, being a fin-eater which savagely attacks the deceived client.... We may observe, however, that this subtle evolutionary gambit is not, as yet, perfected. The resemblance between model and mimic is only good enough to deceive younger fish."

The young of a form of shrimp settle down in pairs within the narrow passages of the spongelike Venus flower basket. They grow, and can no longer escape. "Their elegant prison ultimately becomes a tomb. The beautiful skeletons... with their contained shrimps are given as wedding presents in Japan." We see the long years of adaptation in a kind of flash photography, freezing a process that is essentially dynamic. One whelk thrusts its proboscis into the soft tissue of barnacles and cleans them out. A related sea snail uses a similar trunk to hold, pierce and suck on the long tube-tentacle of a sea worm, taking the food particles in transit to the worm. The difference is mainly that the second form does not kill its victim. We see here how small animals might evolve gradually toward becoming parasites on larger hosts. Microbiologists know of a rule named after Theobald Smith: The less virulent the disease, the older the relationship between parasite and host. The effect is at work in the age-old sea.

The giant bivalve clam *Tridacna derasa,* sometimes six feet across, has a huge hypertrophied growth of soft mantle tissue, gorgeous as colored velvet, all peacock blue and moss green. The color is enriched by a dense population of special marine algae, held within the phagocytes of the clam's blood, within which they can grow and divide. The algae are bathed in the nutrient-rich wastes of the clam's life processes. These clams live in the shallow warm waters of the South Sea; the clams orient themselves in the water so as to hold their photosynthetic algal friends upward. In the surface of the mantle are many tiny lenses, once rudimentary light-sensitive spots but now used to focus light into the deep layers of tissue where the algae live. The pigments of the mantle tissue shield the clam's cells from the sunlight. The clams digest the algae not in the gut but directly in the bloodstream. Is not the huge size of these mollusks a tribute to the success of their peculiarly intimate form of agriculture?

PHYSICS FOR PRINCES: THE GEORGE III COLLECTION, by V. K. Chew. Her Majesty's Stationery Office, British Information Services, New York ($1.30). THE APPARATUS OF SCIENCE AT HARVARD 1765–1800, by David P. Wheatland, assisted by Barbara Carson. Harvard University Press ($20). The Prince in London lost the allegiance of the merchant princes of Boston. In their elegant system no divine sun remained, only a mechanism of checks and balances, of Newtonian equilibrium obedient to the rules of right reason, of the ballot box and of the market. But George III was in mind no monarch out of the past; he was at one with the revolutionaries themselves. He was perhaps a little dull, but he was schooled in the Enlightenment and was amused and edified with them by the same natural philosophy. The King and Queen began and long maintained a collection of the instruments and set pieces from which science was taught in that age, starting with an assemblage of devices, royally ornamented but otherwise familiar, that served to exhibit the principles of mechanics, pneumatics, electrostatics, magnetism and after many years even the taxonomic sciences. (Witness a "petrified turtle" at Kew and a dried Maine flounder skin at Harvard.) Harvard lost its oldest collection of Philosophical Apparatus at one blow when Harvard Hall burned down in 1764. The Massachusetts legislature assumed responsibility (they were meeting in the building at the time) and within two years shipments from London had replaced and enlarged the lost collection. In part the same makers of instruments supplied Harvard and the King. (George's set was mainly assembled between 1760 and 1768.) These two books, the first a handsome small paperback meant for museum visitors in London, the second a very attractive large volume, serve as a

museum without walls, presenting the apparatus in excellent photographs and in old drawings, and giving a compact account of their history. They are both mainly picture books, and they are good ones. Air pumps, whirling glass globes for generating electrostatic charge, silver-mounted lodestones, glass vessels with vacuum fittings, "A Compleat Sett of Mechanicall Pullies" and much more are found on the two shores. The most interesting pictures are a little out of the general run: Chew does not show the famous silver microscope—all tiny statues, wedding-cake ornament and little drawers—made by George Adams for George III while he was still Prince of Wales but presents instead a color photograph made through the instrument. Naturally the picture shows a flea, violet chromatic aberration and all, in memory of Robert Hooke and of court life in the 18th century. Wheatland for his part cannot resist displaying the large orrery made by George Pope, a watchmaker of Boston, paid for by public lottery authorized by the legislature and given to Harvard in 1788. The brass parts used were too weak, and the device never worked well: "Suddenly the whole solar system would give a tremendous jump, to the despair of its inventor." Handsome in death, it can be seen to this day in the Houghton Library basement. There one can also admire the foot-high bronze figures of Benjamin Franklin, Governor James Bowdoin and—two inches taller—Sir Isaac himself. The Fogg Museum at Harvard has just exhibited a fine sample of the old instruments together with portraits of the men who chose and used them.

AN ATLAS OF MAMMALIAN CHROMOSOMES, by T. C. Hsu and Kurt Benirschke. Springer-Verlag New York Inc. ($30.20). Human anatomy, even microanatomy, was long regarded as a nearly perfected science. Yet it has been only 13 years since it became clear that *Homo sapiens* is coded in 46 chromosomes, not 48, as the books had held for generations. In the old days the pattern of tiny stained segments of nucleic acid and protein was hard to read in sections of fresh tissue or squashed cells. Nowadays rapidly growing tissue cultures from skin, kidney or blood provide many cells at the right stage of division, and special pretreatment with colchicine spreads the chromosomes neatly. The job is easier and the result is clearer; it is an excellent tool for anyone who wishes to study mammalian populations or identify mammalian species. The work has grown steadily in interest and volume. These two expert participants have made an atlas: sheet after sheet of halftones, each displaying the set of paired chromosomes, male and female, of one species of mammal. The work is looseleaf and will continue to grow; eventually it can be arranged in taxonomic order by family, genus, species and so on. There are 50 sheets issued per annual volume; each shows a photograph, with references and a few sentences of text, in a tight jargon. The general reader can gain only an impression from the work, but it is a strong one. There's no art to find the beast's construction from its chromatin. Dogs of all breeds have the same pattern, with possible variations in one tiny segment. Man and chimpanzee and gorilla differ in number of chromosomes by only two, and superficially these chromosomes differ rather little in form. The marsupials have the fewest chromosomes among mammals, some of them fewer than 20, but man, be not proud: the lofty vicuña owns 74.

It is necessary to report that this interesting set of photomicrographs seems nowhere to make any reference to size, scale or magnification. One does not know from this extensive collection whether chromosomes are similar in size from species to species or vary over a large factor. Surely the information is worth listing in detail; it is an omission hard to excuse.

REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION. General Assembly, Twenty-fourth Session, Supplement No. 13 (A/7613), United Nations ($4). The same ingenious technique and deepened understanding that have made an atlas of chromosomes possible have been used within the past few years in the study of the important questions of radiation-induced aberrations in human chromosomes. Leucocytes of human blood can be stimulated to divide in vitro in a synthetic medium. The agent that stimulates mitosis is a plant protein; one source is pokeweed. Low doses of radiation do produce visible chromosome lesions in this sensitive system, but the UN expert committee, although it notes a single proved clinical result (one form of leukemia is sharply correlated with a particular chromosome lesion in bone-marrow cells), does not so far draw any new conclusion about the risks of radiation.

The atmospheric burden of radioactive contamination continues to decrease. The bones of Danish infants show a strontium radioactivity slowly but steadily diminishing since the high peak of 1964 and the sharp decline through 1966. There have since been six explosions in the central Asian atmosphere, 13 in the South Pacific and a number of underground ventings "observed from time to time." But the test ban still works for public health, if not for arms control. The present report is not self-contained; it is a rather technical addendum to earlier reports. This one was completed in the spring of 1969.

WHAT IS IT?... AT THE BEACH, by Paul Giambara. The Scrimshaw Press, Barre Publishers, Barre, Mass. ($1.95). DINOFLAGELLATES OF THE CARIBBEAN SEA AND ADJACENT AREAS, by E. J. Ferguson Wood. University of Miami Press ($12). The titles neatly discriminate these two different genres of guide. The first is a rather personal guide to shore life, a paperback aimed at beach walkers on both our coasts. It treats the common forms, from rockweed and sea jelly to quahog and whelk, each with a pen-and-ink sketch and a few sentences of text. The second book, although it is not a standard taxonomic monograph, is still a technical work. It seeks to bring the nonspecialist student and the working ecologist the means of identifying some 400 forms found in the plankton net. What is most noteworthy for the general scientific reader is the look of the two books. The first guide for the beginner has 60 "pages which can be hand-colored," as the blurb puts it. These bear some 200 open, clear outline drawings, rather like the photoengraved diagrams common in scientific books since late Victorian days. But there is a difference. These drawings are a little warmer, and the text is hand-lettered in a free (if not very personal) style. A single artist has done the job, working on paper with his pen, and photographic offset methods have brought us his work. The second book, whose text is set in clean type, is also an offset product. Here the welcome novelty is a drawing for each of the microscopic forms described, done in soft pencil. The attractiveness and clarity of this technique compared with the usual hard-line drawing, so inadequate to the soft forms and translucent substance of most of the little beasts of this 100-micron world, is striking. Perhaps the black-and-white diagram, as helpful an aid as it has been to science, is beginning at last to feel itself free of the strictures of tradition.

IN THE EARLY WORLD, by Elwyn S. Richardson. Pantheon Books ($7.95). About 1950 a young graduate of a teacher's training college in New Zealand

went to teach in a small primary school in the rolling coastal country of the North Island, drawn there by the chance to work at the natural history of the seashell. His pupils were young children, both of British and of Maori stock, from the farm homes of that quiet sheep- and cattle-raising countryside. Richardson is an amateur botanist and something of a potter. This book, beautiful to eye and mind, tells of how he and his pupils and their parents grew. The pages tell of kiln and map and model and survey and computation; you can see for yourself the strong linoleum cuts and read the precise poetry these children made year by year. Irene, 13, named the book with her verse "The blue heron stands in the early world,/Looking like a freezing blue cloud in the morning."

This is not a new book, but it is the first American edition; for a few years it has been widely read in this country in the New Zealand editions. More than any other volume so far it has been able to express and to rally that trend in modern education—very congenial to the scientist—which sees in freedom within the classroom values that extend far beyond the subjective. For the people of the school at Oruaiti freedom was not indulgence but the condition of their growth toward mastery.

THE UNIVERSAL BEAD, by Joan Mowat Erikson. Drawings by Mary Austin. W. W. Norton & Company, Inc. ($10). Among the millions of books in our tongue this informal, amateur, loving study by a jewelry-making author who claims to be "a craftsman more than a scholar" appears to be the only one devoted to a study of the bead. Yet these small, rounded, shining, usually repeated objects, of the most diverse materials, from beetles to gold, are ubiquitously prized among the cultures of men. Mrs. Erikson pursues beads over space and time. Unfortunately she presents almost no apparatus of footnotes or references to slake the thirst of those who might want to know more, but she strings out a fine tale, even if it is a sketchy one. There are more than a dozen excellent photographs in color of strings of beads, about twice as many in black and white, and line drawings as well. The oldest-known object made of glass is a bead; the first synthetic material was perhaps faïence, first used for beads.

Why? Mrs. Erikson has a plausible theory. Experimenters have shown that a plain round mask with two eye spots is all you need to elicit a baby's smile. Before speech, eyes are the life of the mother's face; the bead is the eye.

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Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

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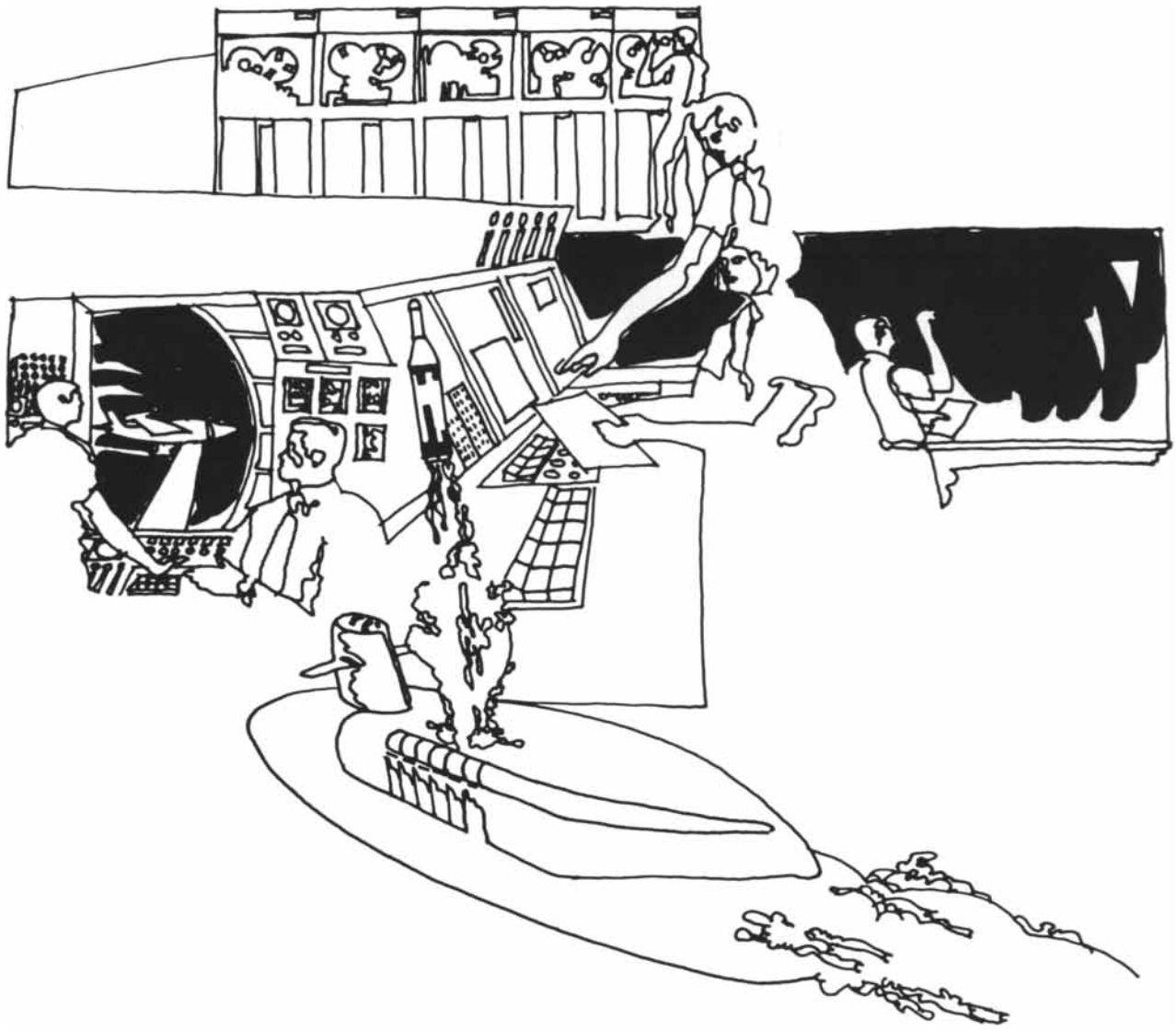

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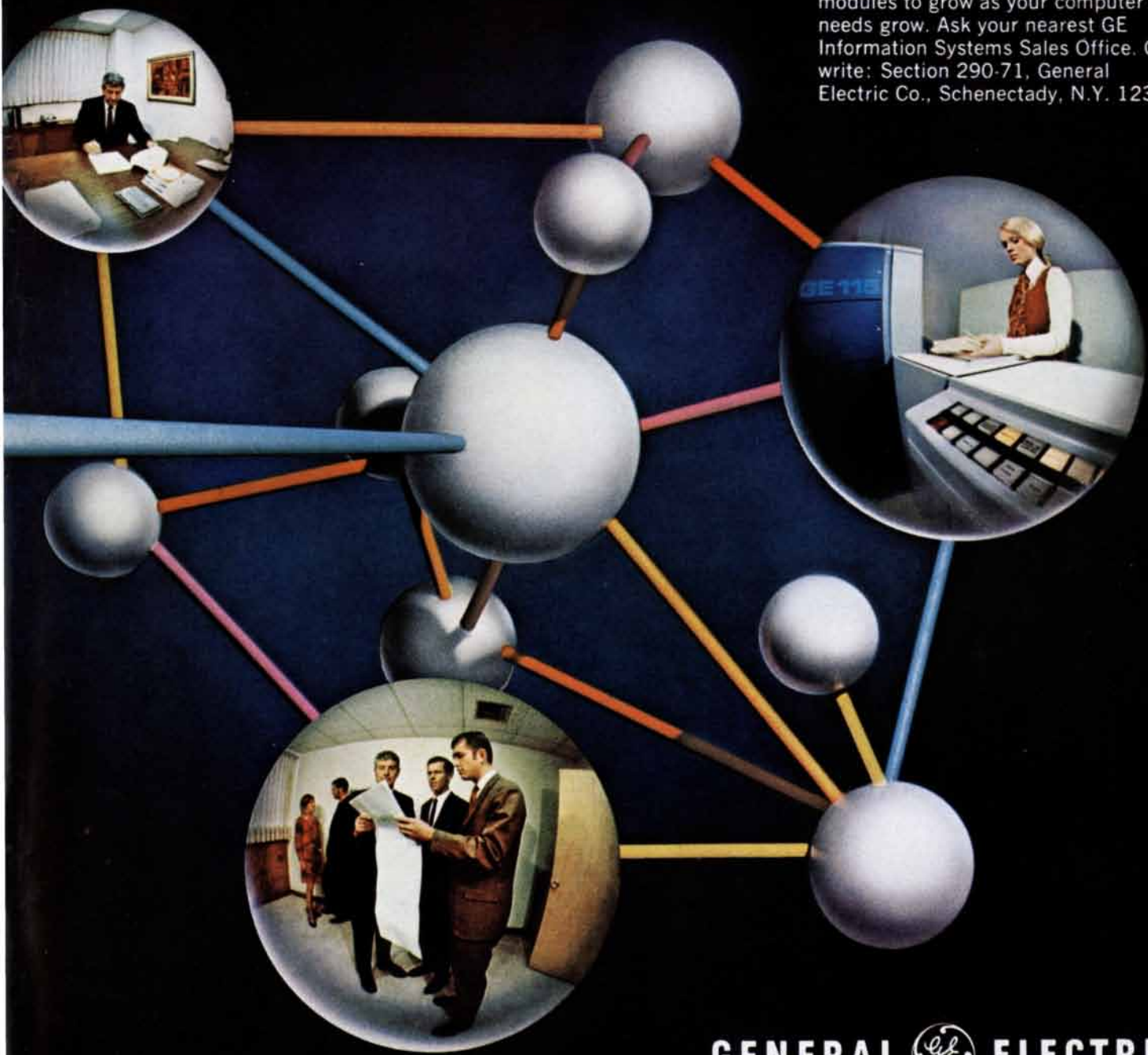

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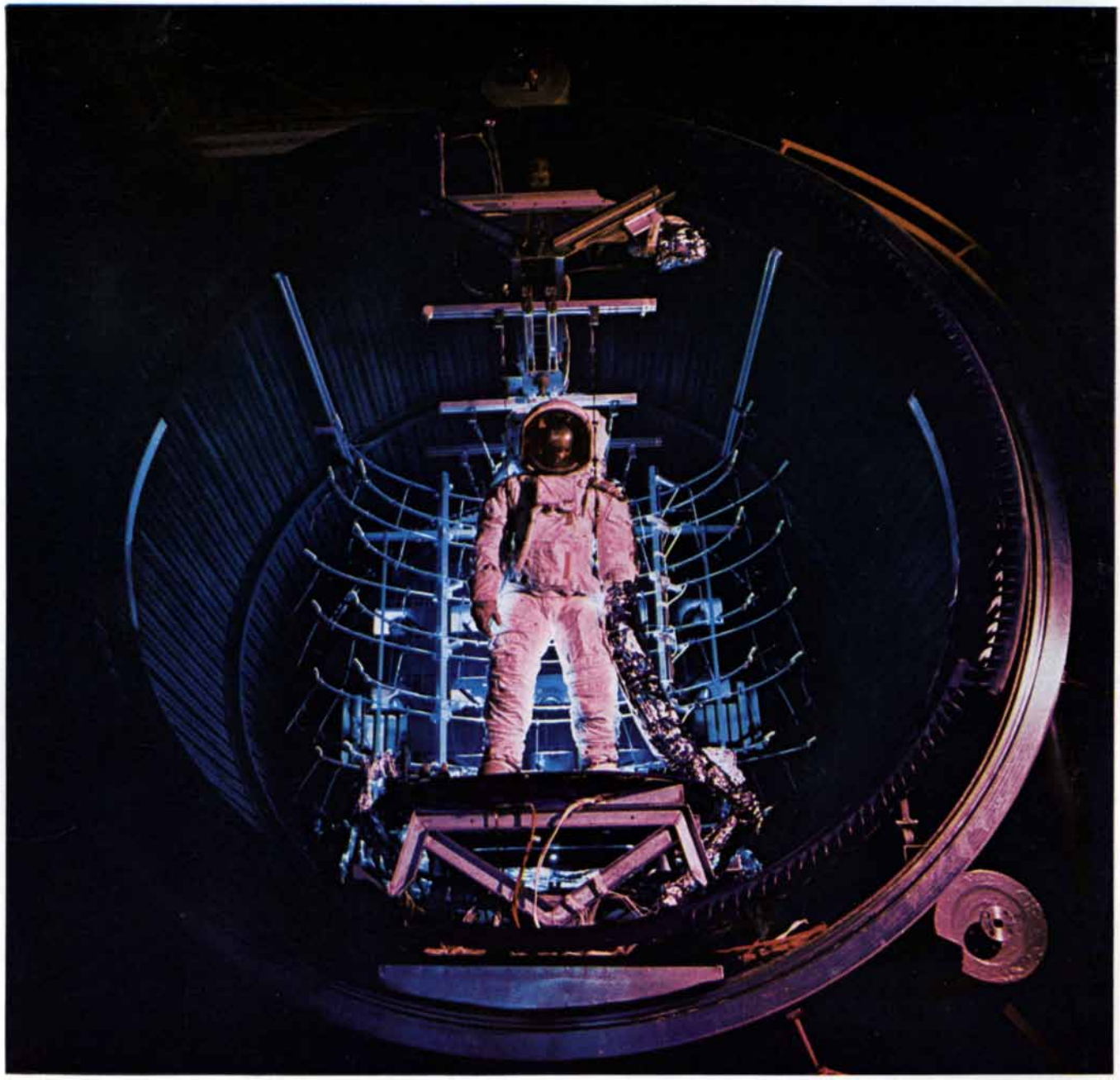

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