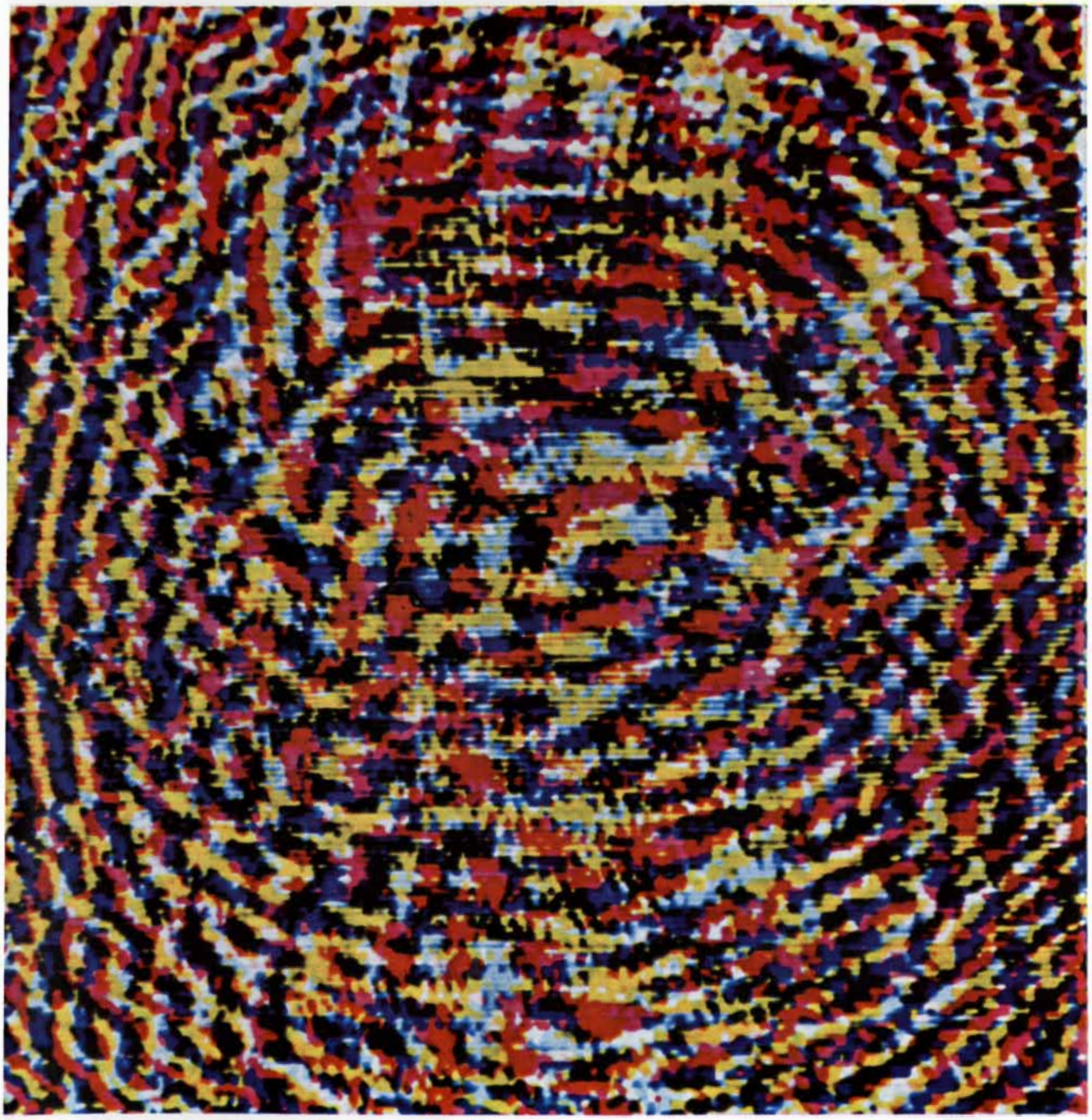
SCIENTIFIC AMERICAN



ACOUSTICAL HOLOGRAPHY

ONE DOLLAR

October 1969

from anti-pollution to problem solution

UOP has a piece of the action in your life.

We're all against pollution. We'd better be. The impact of polluted air and water on man and his environment is growing more severe all the time. We need more and better action. Now.

Universal Oil Products Company offers some practical ways to cope with this acknowledged menace. UOP Air Correction Division is a leader in offering source testing service. This specialized survey studies problems in depth, analyzes the solid or gaseous pollutants and prescribes the exact equipment needed for control. Economically. With flexibility for the future.

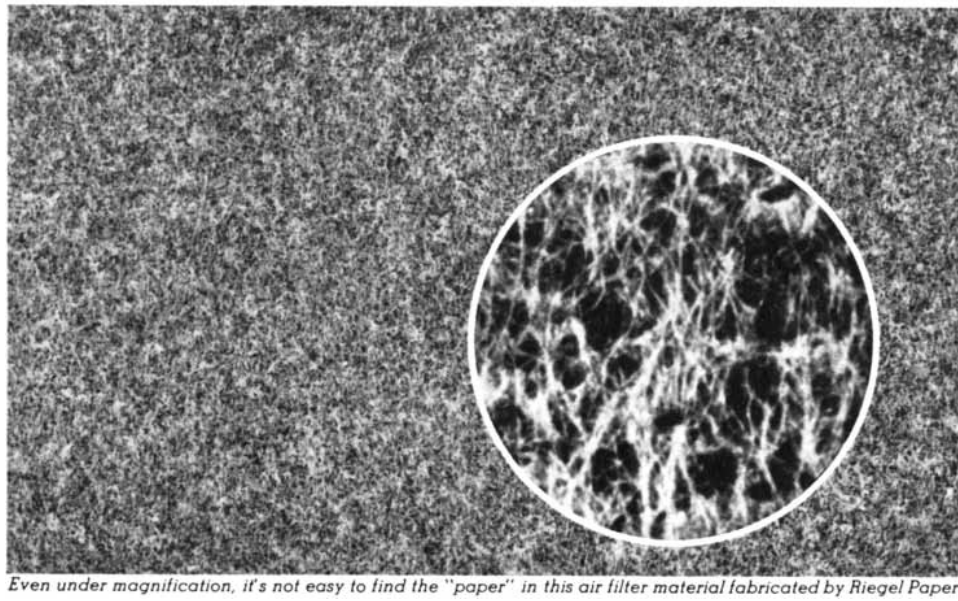
Meanwhile UOP Process Division is solving the big problem of how to desulfurize fuels to eliminate noxious fumes from residential and industrial furnaces.

At the same time work is far advanced against the overwhelming problems of cleaning up fumes from automotive and diesel exhaust systems. UOP has practical answers ready. Now.

Water contamination is another target of UOP scientists who are commercializing unique chemical processes that help free rivers and streams of foaming detergents. And UOP Johnson Division is an innovator in the development of high efficiency screens for water purifying systems.

What makes possible the solving of big problems like these? Well, at the center is a deep reservoir of scientific knowledge, stretching back into history, reaching into the future. This practical kind of research-in-search-of-results is also being used by UOP "family members" working in fabricated metal products; air and ground transportation equipment; construction services; plastic laminates and chemicals.

On the research and development horizon there is no end in sight. Wherever you are, whoever you are. UOP has a piece of the action in your life.



Even under magnification, it's not easy to find the "paper" in this air filter material fabricated by Riegel Paper.

We started with paper and came up with a filter medium that is 80% charcoal. What can we start for you?

Paper is paper, as everyone knows. Essential, no doubt, but hardly remarkable. Not what you'd call high-technology stuff.

On the other hand, a filtration material which is four-fifths activated charcoal (and you know how crumbly charcoal is), yet which can be continuously produced on a commercial paper machine (with all the volume economies it makes possible)—well, that's something else.

The paper comes from Riegel. And so does the filtration material. We begin with paper—but there's no telling what we'll end up with. Or where it might be used.

The paper-like charcoal material is used as the filter element in gas masks, as well as industrial applications. It was made possible through Riegel's thermoplastic technique, which enabled the material to be produced in a continuous web.

Today Riegel is the country's leading supplier of military gas filter materials.

From forest to filters

Gas mask materials are some of many Riegel developed for use in filtration. Others include pleatable materials for oil and air filters for the automotive industry; materials for aviation fuel filters; for filters for the food industry, in such applications as coffee and shortening; and for disposable vacuum cleaner bags. New fields we have entered include synthetic materials for blood filters and for filtering odors.

As paper makers, Riegel plants the seeds. Harvests the trees. Produces the pulp. Manufactures the paper. And at this point, where most paper mills leave off, we're just beginning.

Paper's endless possibilities

You might be surprised what can be done with paper.

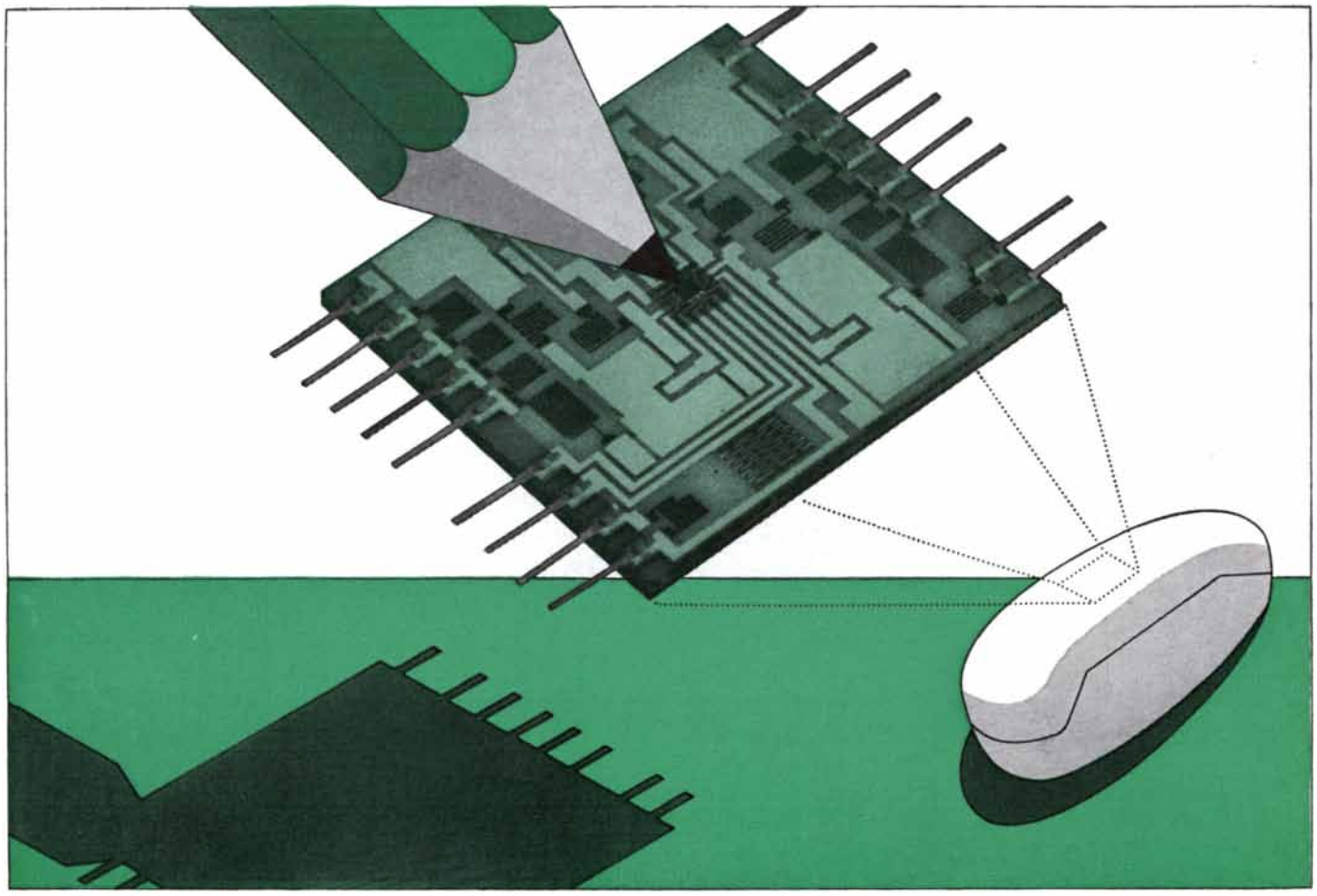
Particularly in the hands of a research-minded company that knows paper backward and forward.

Particularly when it's Riegel.

When you're really stumped for a solution, and you're practically certain paper can't do it, come to Riegel. If anyone can, Riegel can. Riegel Paper, Technical Papers Group, 260 Madison Ave., New York, N.Y. 10016.

Riegel

Much more than paper



Big future for little circuits

Bell Laboratories engineers have developed a special TOUCH-TONE Trimline® handset that suggests great possibilities for designers of future telephones. In this one, the musical tones you hear when you push the buttons are generated by two oscillators in a "hybrid" integrated circuit (one combining tantalum and silicon technology).

Such tiny, inexpensive circuits free designers from limits imposed by bulky, costly to assemble, discrete components—which restricted the type and complexity of circuit functions that could be designed into a telephone handset. Now, designers can think of people first—of what is easy to use—knowing that the electronics can be made to fit. The postage-stamp size, rugged integrated circuit above, for instance, contains 14 transistors, a diode, and 16 resistors in the silicon chip (under the pencil point), and 19 resistors and 8 capacitors made with tantalum film on the substrate.

Much of Bell Laboratories' integrated circuit work combines tantalum thin-film circuits (for precision passive components) and silicon integrated circuits (for active devices). To unite the two, we invented beam leads—small gold conductors which are formed as an integral part of the silicon circuit. They allow us to bond the silicon to the tantalum circuit in a simple one-shot operation. We've also developed a chemical-metallurgical system which fully seals off and protects the vulnerable parts of the circuit from environmental damage. So, we don't need costly vacuum-tight enclosures.

The extreme operational and environmental conditions of telephone use gave us some problems: Tailoring the resistance of thin-film resistors so that the resistance-capacitance product remains constant despite changes in temperature. Designing oscillator circuits whose output frequencies are not affected by varied loadings due to differing cable lengths between telephone and central office. Finding an encapsulant to adequately insulate closely spaced conductors in high humidity.

To customers who use them, handsets with this new circuit will seem like other TOUCH-TONE Trimline sets—though a trifle lighter. But this new telephone technology opens the way to greater freedom for designers and even better telephones for Bell System customers.

From the Research and Development Unit of the Bell System—

Bell Labs

Established 1845 **SCIENTIFIC AMERICAN** October 1969 Volume 221 Number 4

ARTICLES

DEPARTMENTS

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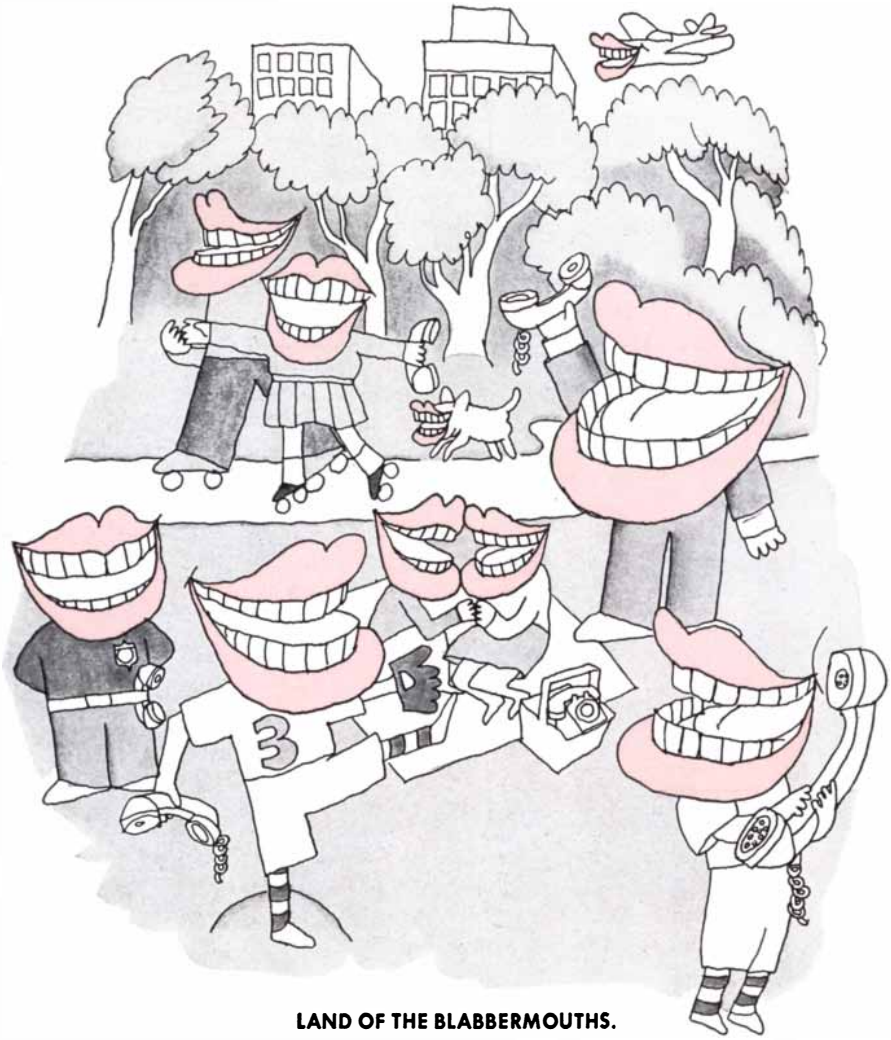
THE COVER

The picture on the cover is a hologram produced by "illuminating" an object not with coherent light waves, as is done in making an optical hologram, but with coherent sound waves (see "Acoustical Holography," page 36). The object was illuminated with three pure tones of sound whose ratios correspond to those of the primary colors red, green and blue. The acoustical hologram from each tone was translated into a black-and-white television image and photographed. To produce the composite image on the cover, each of the holograms was printed in a color corresponding to the wavelength of the "illuminant." If the three-color hologram were illuminated with coherent white light (that is, a beam containing a balanced mixture of red, green and blue light, each from a coherent source), the original object would be reconstructed in three dimensions and in colors corresponding to the reflectivity of the object at different acoustical wavelengths.

THE ILLUSTRATIONS

Cover photograph by Alexander F. Metherell

Page	Source
21–27	Jerome Kuhl
29	Martin Lubin, Dartmouth Medical School
30–32	Bunji Tagawa
33	Masayasu Nomura, University of Wisconsin
34–35	Bunji Tagawa
37	Alexander F. Metherell, McDonnell Douglas Corporation
38	Jim Egleson (*top*); Alexander F. Metherell, McDonnell Douglas Corporation (*middle, bottom*)
40–42	Jim Egleson
43	Battelle Memorial Institute (*top*), Jim Egleson (*bottom*)
44	Alexander F. Metherell, McDonnell Douglas Corporation (*top*); Jim Egleson (*bottom*)
54	National Aeronautics and Space Administration
56	U.S. Air Force
57	U.S. Air Force and Dan Todd
58	National Aeronautics and Space Administration
59	The Boeing Company
60	National Aeronautics and Space Administration
64	Jim Egleson (*top*), The Boeing Company (*bottom*)
66–70	National Aeronautics and Space Administration
72	Dan Todd
76	Paul Weller
78	Eric Mose
79–80	William F. Windle, New York University Medical Center
81	Eric Mose
82–83	William F. Windle, New York University Medical Center
84	Dumbarton Oaks Collections
88	Oliver E. Overseth, University of Michigan
90	Allen Beechel
91	Nuclear Physics Laboratory, University of Washington, and Allen Beechel
92–100	Allen Beechel
103–110	Thomas Prentiss
114	Ken Heyman
116–118	Dan Todd
119	Oscar Lewis, University of Illinois
120–121	Dan Todd
122	Ken Heyman
126–128	Alan D. Iselin
135–138	Roger Hayward



LAND OF THE BLABBERMOUTHS.

Blab blab blab. The communications flow in the U.S. is turning into a gusher. Can technology keep up? Martin Marietta communications people are studying unusual new digital techniques to expand the volume of conventional circuits. We're also conducting transmission experiments in the millimeter wave region. It could give some much-needed tongue room in the crowded electromagnetic blab spectrum.
Martin Marietta Aerospace Group. Headquarters: Friendship International Airport, Maryland.

MARTIN MARIETTA

LETTERS

Sirs:

...It may be foolish for a layman to intrude on a technical argument, but Herbert F. York's splendid article "Military Technology and National Security" [SCIENTIFIC AMERICAN, August], which I desperately wish could be put in the hands of each and every citizen of the U.S., invites the nonspecialist. His conclusion that our safety finally lies in the ordinary world of politics and not in technical expertise raises a fistful of hard problems, but I want to ask only one, an ethical problem.

If one imagines the worst—and today our policy seems to be built on imagining the worst—and the U.S. suddenly knew one day that it was the target of a devastating nuclear attack, by what political or ethical criterion would a "preprogrammed" President of the U.S. decide, in the space of about half an hour, to retaliate? If Dr. York is correct in saying that both sides have achieved parity in the sense that either side could lay waste the other, although not prevent a first strike by the other, then we are pushed to confront a human and not a tactical choice. That is, if we *know* that (to use the vulgar expression) we have had it, that our destruction is a given in the problem, by what value do we decide to wreak vengeance on the other side, except the sheer fury of vengeance? Retaliation serves no practical purpose that will accrue to Americans; it only destroys millions of other human beings who might otherwise live and whose destruction has no effect on our doom....

JOHN WILLIAM WARD

Professor of History
Amherst College
Amherst, Mass.

Sirs:

Herbert F. York's summary of the ABM debate in its proper context is a reiteration of reason and therefore of humanity. The subtitle comment on "the futility of searching for technological solutions to what is essentially a political problem" should be extrapolated and enlarged to say that it is unreasonable to ask science to solve a moral problem or to believe that machines can do what men should do.

One question York raises answers itself from first principles: "To what extent [should] decision-making authority ...pass from...human beings to machines?" Machines have no self-interest. Therefore the best of machines is worthless as a political decision-maker. Because machines and men both have input-output capabilities, an externally oriented science occasionally mistakes one for the other. But machines care neither for themselves nor for other machines nor for human beings nor anything else....

It is remarkable that the situation in which men here look toward machines to take over their functions is defined in passive terms: When *X* happens, perform *Y*. This means that the thought of activity has been abandoned. Such passivity (as Spinoza, among others, knew) is truly the loss of freedom, enslavement to fear. We shall only solve our dilemma if we care about Russian and Chinese cultures as much as we care about our own and act accordingly. This truism is of course just a necessary condition of the solution. In this regard we shall be going further astray if we turn to any technology for necessary and sufficient conditions in the solution of human problems. The probabilistic predictions that are the best technology can hope to furnish do not, I think, reduce fear, and they tend, I also think, to delude us that there is less need for responsible action in the face of risk in an uncertain world.

NORMAN GUTTMAN

Professor of Psychology
Duke University
Durham, N.C.

Sirs:

The article "Military Technology and National Security," by Herbert F. York, was a comprehensive and concise summary of a difficult, complex subject. Certain aspects, however, were touched on so briefly or obliquely as to deserve some additional comment:

Remarks concerning possible degradation of alertness and operational capability are applicable to virtually all defensive and counterstrike systems, not just ABM.

The broad concept of an ABM system, impractical a decade ago, admittedly had advanced to "marginal" status by 1967. Any continuation of this trend would be of considerable significance.

Improved effectiveness up to one order of magnitude might be achieved by locating ABM sites along the Arctic Circle to intercept over-the-pole missiles before any shift into MIRV configuration; additional effectiveness and flexibility might also be obtained through use of shipboard ABM installations.

The degree of future reliance on Polaris/Poseidon must be weighed against continuing high-priority efforts by the Russians to neutralize our SNB's.

The large number of warheads and megatonnage involved in a massive nuclear exchange poses grave hazards to both superpowers from fallout factors alone. Accordingly alternate strategies premised on moderate or limited nuclear strike/counterstrike must be considered as realistic, along with estimates of probable effectiveness of an ABM system under such circumstances.

Viewpoints as to stabilizing or destabilizing factors are largely subjective and conjectural. Nevertheless, few situations appear more destabilizing than several nuclear missiles headed toward the U.S., with massive retaliation the only possible response. A "thin" ABM system might thus be considered a stabilizing element....

DALE TAPP

Seguin, Tex.

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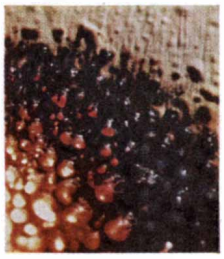
NAME

NEW ADDRESS

OLD ADDRESS

The wall paint that bubbles gives them time to flee a fire.



These bubbles come from a special paint that looks like any other paint until things get hot. Then it bubbles up to insulate walls against fire for a few precious extra minutes —minutes that can be used to put the fire out or to escape from it.

Phosphorous formulations from Monsanto give ordinary smooth-flowing latex paints and solvent-type interior paints this fire-fighting ability. Even if walls painted with these special fire-resistant paints are washed again and again, they're always on guard to slow down a fire.

We're developing new ways to control other types of fires, too. From air-dropped chemicals for forest fires, to fire-retardants for paper clothing. These new developments are coming from Monsanto—where science and research are working for people.

Monsanto

Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, Missouri 63166

1970:

YEAR OF THE GREAT BIRDS.

Soaring into the '70's far ahead of the rest . . .
A new flight of Thunderbirds!
New in beauty. Size. And aerodynamic grace. With dramatic new front-end styling, shaped to slice the wind. And a powerful 429 V-8 so smooth you wonder if you're really on earth at all.

Inside, every luxury and convenience you've ever wanted. Power steering. Power ventilation. Power front disc brakes. SelectShift Cruise-O-Matic transmission. New long-life radial-ply tires. Even AM radio and electric clock. All standard.

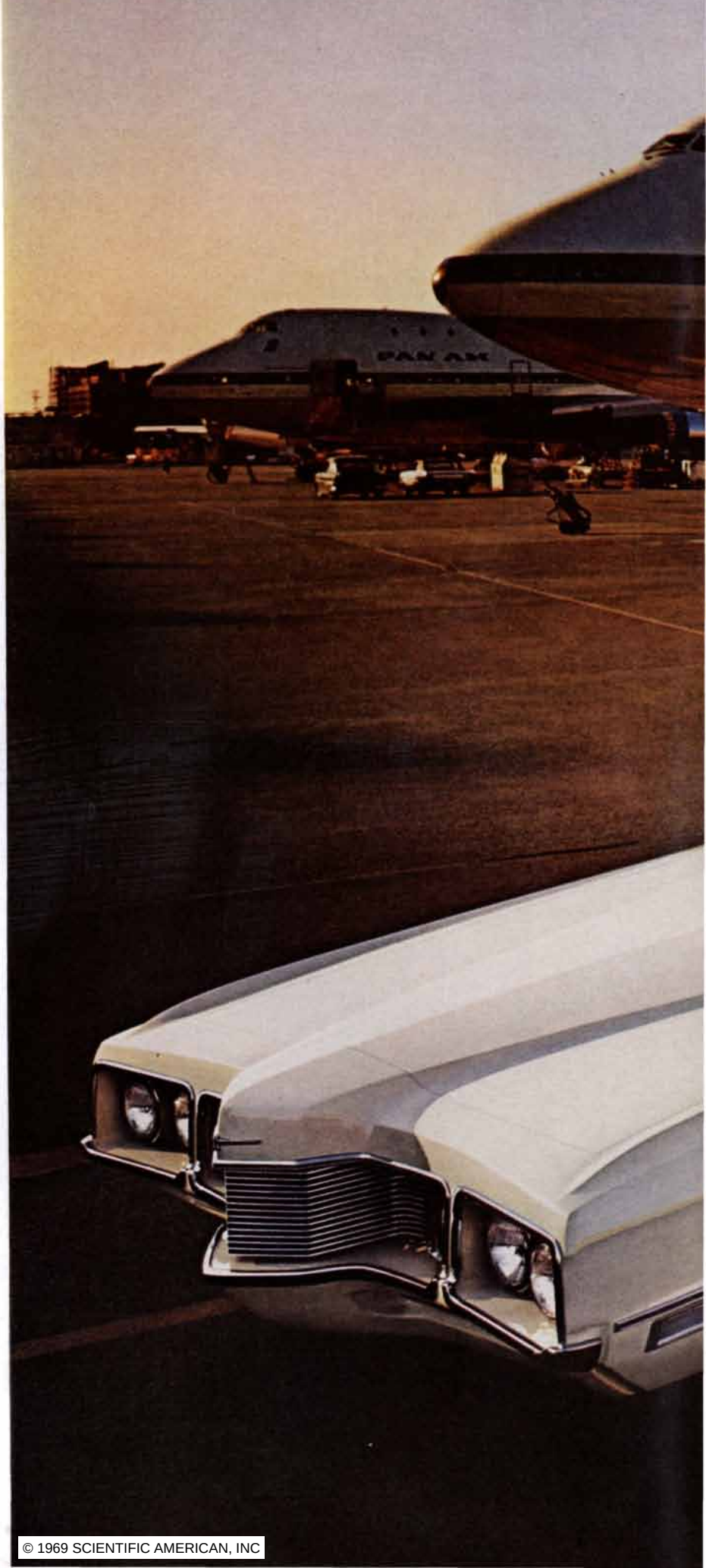
Plus a wide choice of Bird options like a push-button sun roof. Tilt steering wheel. Highway Pilot automatic speed control. And more!

This year, Bird quality runs deep. In a computer-designed ride. Printed circuits. New space-age techniques that set standards of quality as unique as the Bird itself.

Choose Hardtop or Landau, two doors or four. And launch yourself into the space age in the 1970 Bird. A very rare species.

Two beautiful new ways to fly! Pan Am's® Boeing 747 Jet and the 1970 Thunderbird Special Brougham Two-Door Landau.

THUNDERBIRD Ford



50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1919: "A recent paper by Mr. Harlow Shapley brings to a focus the long-standing disagreement between physical astronomers and geologists concerning the duration of solar radiation and the consequent age of the earth, and also the question of the age of the stars in general. The short time scale of the astronomers is based on the assumption that the sun's heat, flowing uniformly at the observed rate in all directions, comes from such recognized sources as gravitational contraction, the fall of meteorites, radioactivity, etc. The supply of heat from these sources could last only a few million years. The data of geology, however, particularly the recent work on sedimentation and on the radioactivity of rocks, are decidedly opposed to a short time scale for the sun and earth. Mr. Shapley cites a large amount of recent astrophysical evidence in behalf of the belief that the ages of the stars are probably several hundred times as great as was assumed in the older physical astronomy. Obviously existing hypotheses concerning the source of the energy radiated from the sun and stars need revision to bring them into agreement with the evidence in favor of an exceedingly prolonged life for these bodies."

"The latest official figures, giving our war losses in dead and wounded, show that we lost 116,492 dead and 205,690 wounded, a total of 322,182. This includes army and marine losses on all fronts during the war and from the Armistice to Sept. 1, 1919. Of this total 35,585 were killed in action and 14,472 died of wounds, making a total of 50,057. Disease accounted for 58,073, and 8,092 died of accidents and other causes."

"That we are on the verge of entering a nearly horse-less age does not seem apparent to the public because the change is being made gradually and we are so used to motor vehicles in practically all of our cities and towns. There are recent happenings, however, that indicate this in a positive manner. A prominent metropolitan architect has stated that in more than 80 per cent of the suburban homes he had designed so far this year, a garage for one or two cars was included in the specifications."

"Most motorists do not consider automobiling as exercise, providing there are no tires to change en route, and one frequently hears the opinion that the augmenting use of motor vehicles has materially reduced the opportunities for exercise that is so necessary to our physical well-being. A well-known writer on scientific subjects, Dr. Henry Smith Williams, takes exception to this general view and states that automobiling is beneficial and shows accruing benefits under three heads—physical, mental and volitional. He proceeds to point out that in addition to the exercise the motorist has been in the open air, buffeting the winds, inhaling ample quantities of oxygen to meet the increased needs of the accelerated currents of blood corpuscles; and that digestion and assimilation are thereby facilitated and the toxic products accumulated through former inaction progressively are in increased measures oxidized and eliminated. Dr. Smith supports his conclusions in part as follows: 'It is the muscles of the arms, together with those of the chest and abdomen, that preeminently and habitually suffer. When you drive a car 40 or 50 miles over average American roads, or a fraction of that distance in the city, you give your arms and torso a course of purposeful calisthenics that redounds directly to the benefit of your muscles, arteries and heart and indirectly, but no less significantly, to the benefit of your digestive apparatus and organs of elimination as well as the nervous system.'"

SCIENTIFIC AMERICAN

OCTOBER, 1869: "The expedition under the command of Major Powell, the Colorado explorer, has returned to Chicago, having successfully traveled through the entire Grand Cañon, from Green River to the point where the Colorado debouches into the open plain in the territory of Arizona. From the point where Major Powell's last letter was written the expedition descended the river about 400 miles, between walls almost vertical, ranging from 500 to 1,500 feet high, the exterior of the cañon being from 2,500 to 4,000 feet above the bed of the river. More than 200 waterfalls and cascades, emptying themselves over the walls of the cañon into the main river, were seen in this distance, with almost every variety of natural scenery. The geological formation of the cañon consists principally of limestone and sandstone; granite is found at only three places and in a limited amount. No discoveries of precious metals were made, and there were no indications of gold or silver found in the bed of the river. One section of the cañon was found to consist of a very fine, beautifully polished marble, which at present is entirely inaccessible. The country traversed was barren beyond description and is pronounced by Major Powell as not susceptible of cultivation, even by irrigation."

"The latest advices with regard to the progress of the Suez Canal are to the effect that the Bitter Lakes have been brought up to the level of the Mediterranean, and that M. de Lesseps, the engineer, has gone through the whole length of the canal in a steamer. The completion of the rest of the works in time for the proposed opening on the 17th of November is still considered in some degree uncertain."

"The Earl of Rosse is making a series of experiments by means of a thermopile of four elements and a three-foot telescope to determine, if possible, what proportion of the moon's heat consists of (1) that coming from the interior of the moon, which will not vary with the phase; (2) that which falls from the sun on the moon's surface and is at once reflected regularly and irregularly; (3) that which falling from the sun on the moon's surface is absorbed, raises the temperature of the moon's surface and is afterward radiated as heat of low refrangibility. The chief result arrived at up to the present moment is that a deviation of 90° for the full moon appears to indicate an elevation of temperature equal to 500° Fahrenheit. The relative amount of solar and lunar radiation was found to be 89,819 : 1."

"The contractor for the erection of the railroad bridge over the Missouri River, which is intended to connect the Missouri and Iowa railroads directly with the Union Pacific, is said to have received notice from the Irish laborers of that locality that he will not be allowed to employ Chinamen on the work. He has nevertheless made contracts in California to obtain Chinese laborers, and he intends to bring them to Omaha soon."

Measurement display spots trends in the commodity market. Stops bullets from ruining the 6 o'clock news. Takes the pain out of learning impedance.

Charting futures in pork.
Consider the problems of a broker in futures — precious metals, wheat or pork bellies. Imagine the seasonal shifts, or changing daily demands, which could radically alter his view on cocoa in the morning.

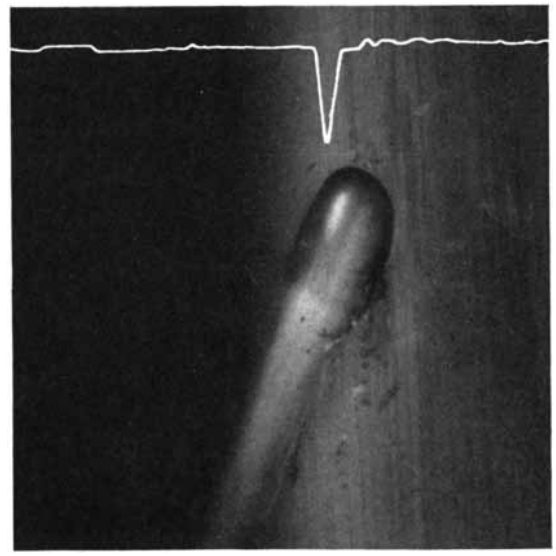
A large securities house may have the time, staff and possibly a computer to follow the action of slower trading. The commodities man needs an answer now. Fortunately, he can produce his own charts overnight with the new Hewlett-Packard 9100A Computing Calculator and its 9125A X-Y Recorder.

He inserts a wallet-sized magnetic card already programmed for high,

low, close. Percentage loss or gain. Extended logarithmatic average. Possibly a "Nervousness Indicator" developed out of his own experience.

He punches in today's reports. In seconds the plotter starts drawing curves. He can even continue a chart started yesterday. And draw his own conclusions. Privately. Smoothly.

The 9100A Calculator can also handle such problems as coordinate geometry, network analysis, statistical distribution, strain loadings or gear design; the 9125 X-Y Recorder plots the results. Cost: $4400 for the calculator, $2475 for the recorder. Write today for our illustrated brochure on the 9100A Computing Calculator and its accessories.



Bouncing echoes off bullet holes.

The nation's highest TV transmitter, 1500-feet tall, was set up to improve TV pictures over a vast area of Texas. It had scarcely been put into use when there were complaints about more bad pictures. When engineers inspected the tower, they found that marksmen were using it for target-practice. The only answer was to find each hole or dent in the cable.

They could have inspected the cable inch by inch. Instead they used HP's new time domain reflectometer that plugs into our 180A Portable Oscilloscope. This device acts much like a miniature radar to pinpoint breaks in transmission lines within a quarter inch. The reflectometer marks the transmission of a pulse with a step in the sweep on an oscilloscope. Any disturbance in the path reflects some energy which is sampled by the reflectometer and easily recognized on the scope. The distance can be read off in nanoseconds or feet of travel. The first hole is a big one, causing a major reflection 35 feet 3¾ inches up, the second a dent in the outer conductor, causing a capacitive change 70 feet 4½ inches up, and so on.

The HP 1815A Time Domain Reflectometer obviously has other applications than on the Texas range. It can locate faults in the maze of cables on aircraft, in buried cables, in cables on production lines, or in cable connectors. It operates with frequencies up to 12.4 gigahertz (12.4×10^9 Hz). Reflectometer, sampler and step generator cost $3150. If you need only inches of resolution rather than millimeters, a less expensive system sells for $2125. Of course, you'll need the HP 180A Portable Oscilloscope, at $825.

If you have an interest in fault finding —TV or otherwise — simply ask for Data Sheets 1815A and 180A.

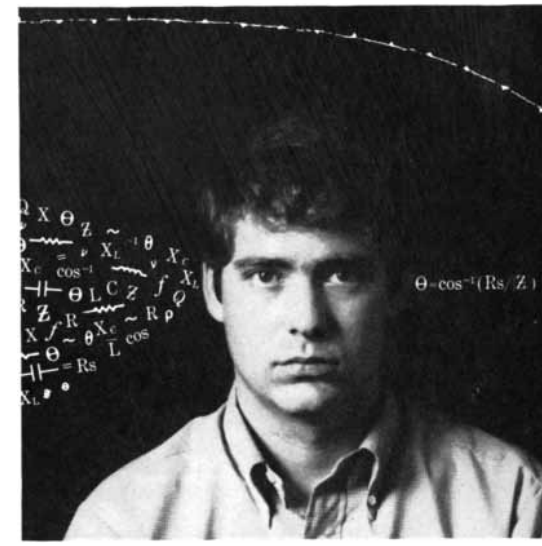
Demonstrating the dynamics of $\vec{Z}$.

To undergraduate students of physics, some theories are absolutely Greek. For example, take the behavior of a simple electrical circuit faced with alternating currents of different frequencies. No longer is resistance simply a matter of E=IR; now the student is involved with the Zeta and Theta of impedance, inductance and capacitance.

With all the calculations required, demonstrating the effect of frequency in the laboratory is next to impossible. Spot measurements with bridge, ac generator, ac voltmeter or oscilloscope can hide rapid changes of impedance with changes in frequency. They can also obscure the construction errors of the student, even if all his calculations are correct.

A happy way out of this hang-up is the use of a Hewlett-Packard Model 4800A Vector Impedance Meter. Two meters on the face indicate directly the magnitude and phase angle of complex impedance (Zeta and Theta), regardless of how often the frequency is changed. The meter is just as responsive when the frequency is electronically swept over a range from 5 hertz to 500 kilohertz. And the student can readily plot curves which demonstrate that inductive reactance and capacitive reactance are, as a matter of fact, directly and inversely proportional to frequency. (The HP 4815A Vector Impedance Meter will do the same job for frequencies between 500 kilohertz and 108 megahertz.)

The cost of the meters may seem expensive for the undergraduate institution ($1650 for the HP 4800A and $2650 for the HP 4815A), but they compare favorably with the signi-



ficant advantage of greater student confidence in the utility of basic concepts.

A complete discussion of the teaching technique is found in AMERICAN JOURNAL OF PHYSICS, Volume 37, Number 1, January 1969. Detailed descriptions of the instruments are available from Hewlett-Packard for the asking.

If there's something we can do to help you solve a problem with a new approach to measurement display, give us a call. Hewlett-Packard, 1503 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

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THE AUTHORS

ARCHIBALD S. ALEXANDER ("The Cost of World Armaments") is a lawyer who served until recently as assistant director of the U.S. Arms Control and Disarmament Agency in charge of the Economics Bureau. He was graduated from Princeton University in 1928 and the Harvard Law School in 1931 and practiced law in New York until 1949 except for service with the Army during World War II. After the war he devoted an increasing amount of time to politics and public service. He was Democratic candidate for the U.S. Senate from New Jersey in 1948 and 1952, Assistant Secretary of the Army in 1949 and Under Secretary of the Army from 1949 to 1952. In 1954 and 1955 he was treasurer of New Jersey. During the presidential campaign of 1956 he served as national director of Volunteers for Stevenson-Kefauver. Alexander has served on the board of a number of organizations, among them Rutgers University, where he was chairman of the Board of Governors for several years.

MASAYASU NOMURA ("Ribosomes") is professor of genetics at the University of Wisconsin. Born in Japan, he received his Ph.D. in microbiology from the University of Tokyo in 1957. For the next three years he worked as a postdoctoral fellow in the laboratories of Sol Spiegelman at the University of Illinois, James D. Watson at Harvard University and Seymour Benzer at Purdue University. He then returned to Japan and served for three years as assistant professor at the Institute for Protein Research of the University of Osaka. He took up his affiliation with the department of genetics at Wisconsin in 1963 and became professor in 1966.

ALEXANDER F. METHERELL ("Acoustical Holography") is a research scientist in the Douglas Advanced Research Laboratories of the McDonnell Douglas Corporation. He received a diploma in technology from the Kingston Technical College in England in 1961 and his Ph.D. in engineering from the University of Bristol in 1964. He then spent a year at the University of Minnesota, continuing his thesis work on the damping of structural vibration. "It was here," he writes, "through contacts with the University of Minnesota Medical School, that I became interested in applying my engineering training to some of the fundamental problems in biology and medicine. In particular, I became interested in the mechanics of pulsatile blood flow and in the force-generation mechanism in muscle. It is these interests in biophysics that most occupy my attention outside of the present work in acoustical and optical holography."

WILMOT HESS, ROBERT KOVACH, PAUL W. GAST and GENE SIMMONS ("The Exploration of the Moon") have been involved in the planning of Apollo missions and (except for Kovach) in the analysis of lunar samples from *Apollo 11*. Hess is director of the research laboratory of the Environmental Science Services Administration. He was graduated from Columbia College in 1946, took his master's degree at Oberlin College in 1949 and obtained his Ph.D. at the University of California in 1954. Kovach, who is associate professor of geophysics at Stanford University, was graduated from the Colorado School of Mines, obtained his master's degree at Columbia University and received his Ph.D. at the California Institute of Technology. Gast is professor of geology at Columbia University, where he obtained his master's degree in 1954 and his Ph.D. in 1957. He was graduated from Wheaton College in 1952. Simmons, who is professor of geophysics at the Massachusetts Institute of Technology, was graduated from Texas A. & M. University and received his master's degree at Southern Methodist University and his Ph.D. at Harvard University.

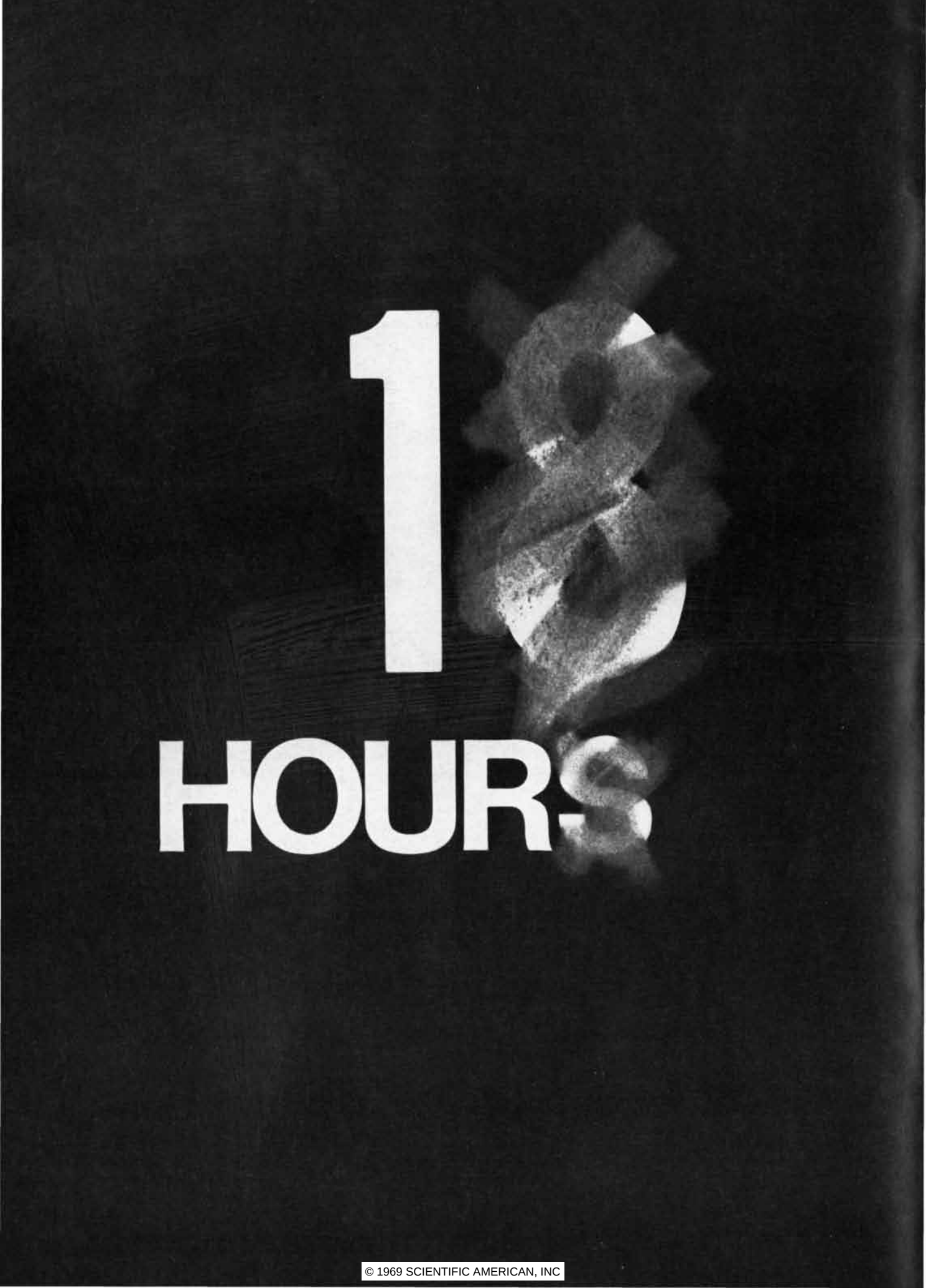
WILLIAM F. WINDLE ("Brain Damage by Asphyxia at Birth") is research professor of rehabilitation medicine and director of research at the Institute of Rehabilitation Medicine at the New York University Medical Center. In addition he is editor of the journal *Experimental Neurology*, which he founded. Windle has conducted studies in fetal physiology and the development of behavior and has written articles on neuroembryology, neurohistology and regeneration in the central nervous system. He was graduated from Denison University in 1921 and received his Ph.D. from the Northwestern University Medical School in 1926.

OLIVER E. OVERSETH ("Experiments in Time Reversal") is professor of physics at the University of Michigan. He writes: "Did my undergraduate work at the University of Chicago, receiving B.S. in 1953. Graduate work at Brown University; received Ph.D. in 1958 for work in nuclear physics. After gradua-

tion I taught at Princeton University and there switched to high-energy physics. Since 1961 I have been at the University of Michigan. I continue work similar to that discussed in the article and currently am analyzing two experiments studying the decays of strange particles. I am a jazz enthusiast and am compiling a discography of Sidney Bechet."

DANIEL S. FERTIG and VAUGHAN W. EDMONDS ("The Physiology of the House Mouse") are respectively assistant professor of zoology at California State College at Los Angeles and teacher of biology at Millikan High School in Long Beach, Calif. Fertig obtained his bachelor's and master's degrees at the University of Florida in 1960 and 1962 respectively and received his Ph.D. from the University of Southern California last year. He was a teaching assistant at Southern California from 1963 to 1968 and a research associate there from 1968 until he took up his work at California State this year. Edmonds was graduated from Kansas State Teachers College in 1942 and obtained his master's degree at Colorado State College in 1951. He has taught at high schools in California since 1946. He and Fertig met at Southern California, where Edmonds has done work toward his Ph.D.

OSCAR LEWIS ("The Possessions of the Poor") is professor of anthropology at the University of Illinois. His study of poverty has ranged over several cultures and many years. "For example," he writes, "in 1947 I published an article, 'Wealth Differences in a Mexican Village,' in *The Scientific Monthly,* and in the same month W. E. B. Du Bois published an editorial on my article in *The Chicago Defender.*" The editorial commented that the study provided the kind of factual base needed for dealing with a vexatious question: "Why is it that the great majority of the people of the world in this heyday of civilization... are desperately and, it seems to most of us, inexcusably poor?" Lewis' work received widespread recognition following the publication of his books *The Children of Sánchez: Autobiography of a Mexican Family* (1961) and *La Vida, a Puerto Rican Family in the Culture of Poverty: San Juan and New York* (1966), which won the National Book Award for nonfiction in 1966. Lewis was graduated from the City College of New York in 1936 and received his Ph.D. in anthropology from Columbia University in 1940. Before going to the University of Illinois in 1948 he taught at Brooklyn College and Washington University.



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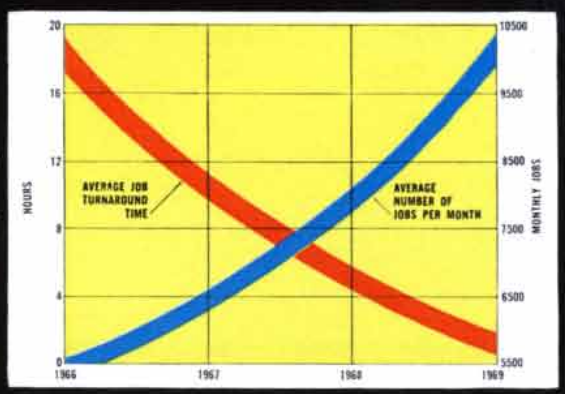

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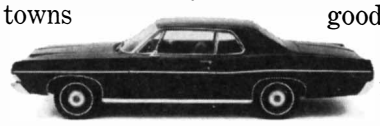

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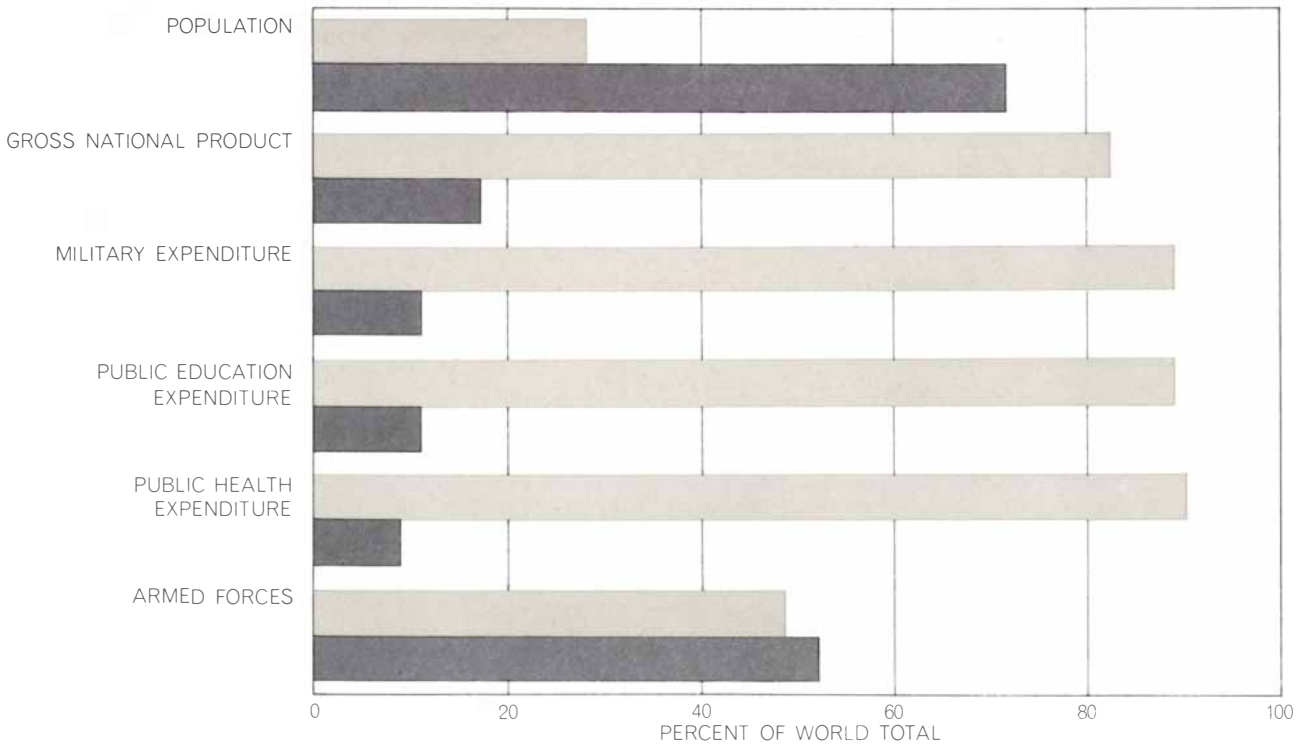
The Cost of World Armaments

A survey of 120 countries by the U.S. Arms Control and Disarmament Agency shows a continuing rise in military expenditures. The rate of increase is higher than it is for population and gross product

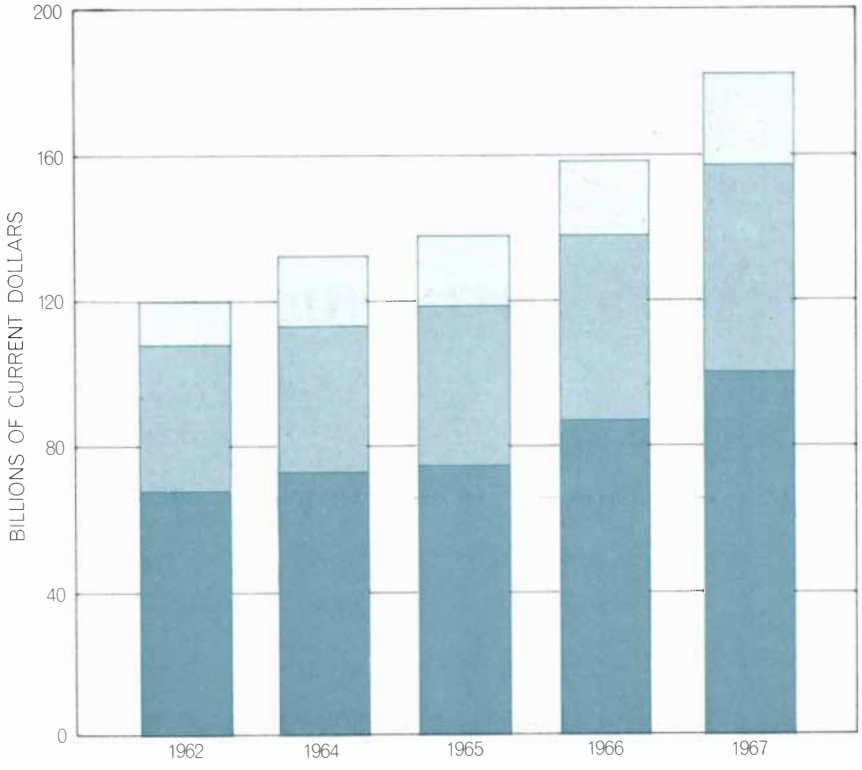
by Archibald S. Alexander

In the year 1967 (the latest year for which comprehensive data are available) the military expenditures of the world's nations totaled $182 billion—an average of $53 for every man, woman and child on the earth. This was an increase of $50 billion over the annual expenditure four years earlier. Military budgets have continued to rise since 1967. If the recent rate of increase in military spending continues, the arms race will consume $4 trillion over the next 10 years.

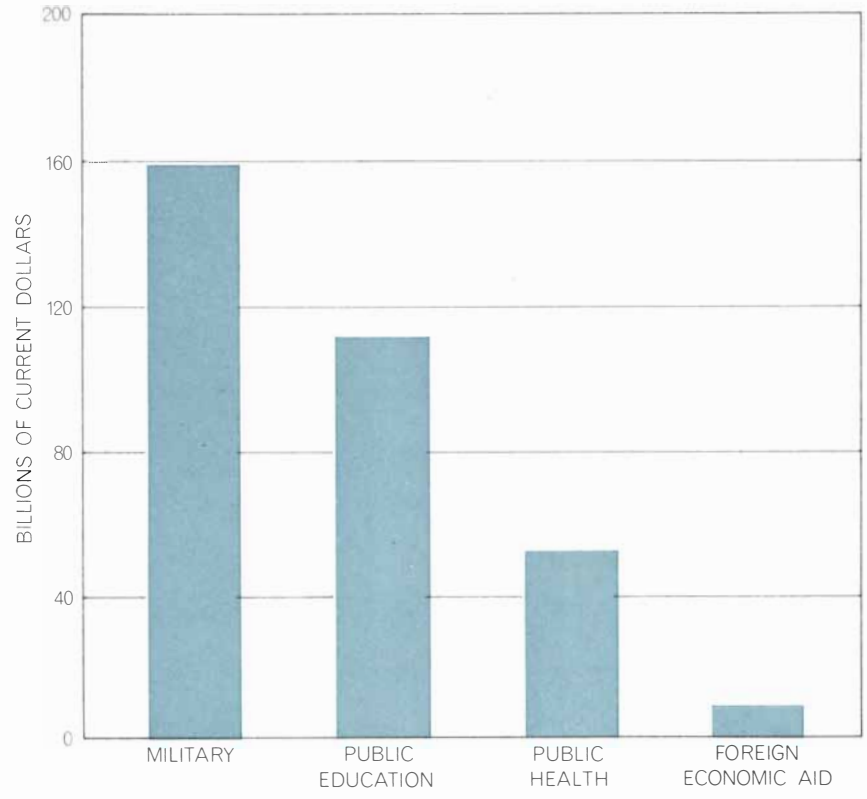
The magnitude or meaning of this sum is difficult to imagine. It far exceeds the total valuation of all U.S. land, buildings, machinery, businesses and cash. Military spending has reached a level at which—quite apart from the risk of mass destruction—it endangers mankind's economic and social well-being.



CONTRASTING SHARES of the world total of population and certain major categories of expenditure are shown for 27 developed countries (*color*) and 93 less developed countries (*gray*). Latter account for most of population but only a fraction of expenditures.



RECENT TREND of military expenditures by members of the North Atlantic Treaty Organization (*dark color*), by nations of the Warsaw Pact group (*medium color*) and by all other nations (*light color*) is upward. The unit of measurement is billions of current dollars for the years given. Currencies of other nations have been converted to the dollar.



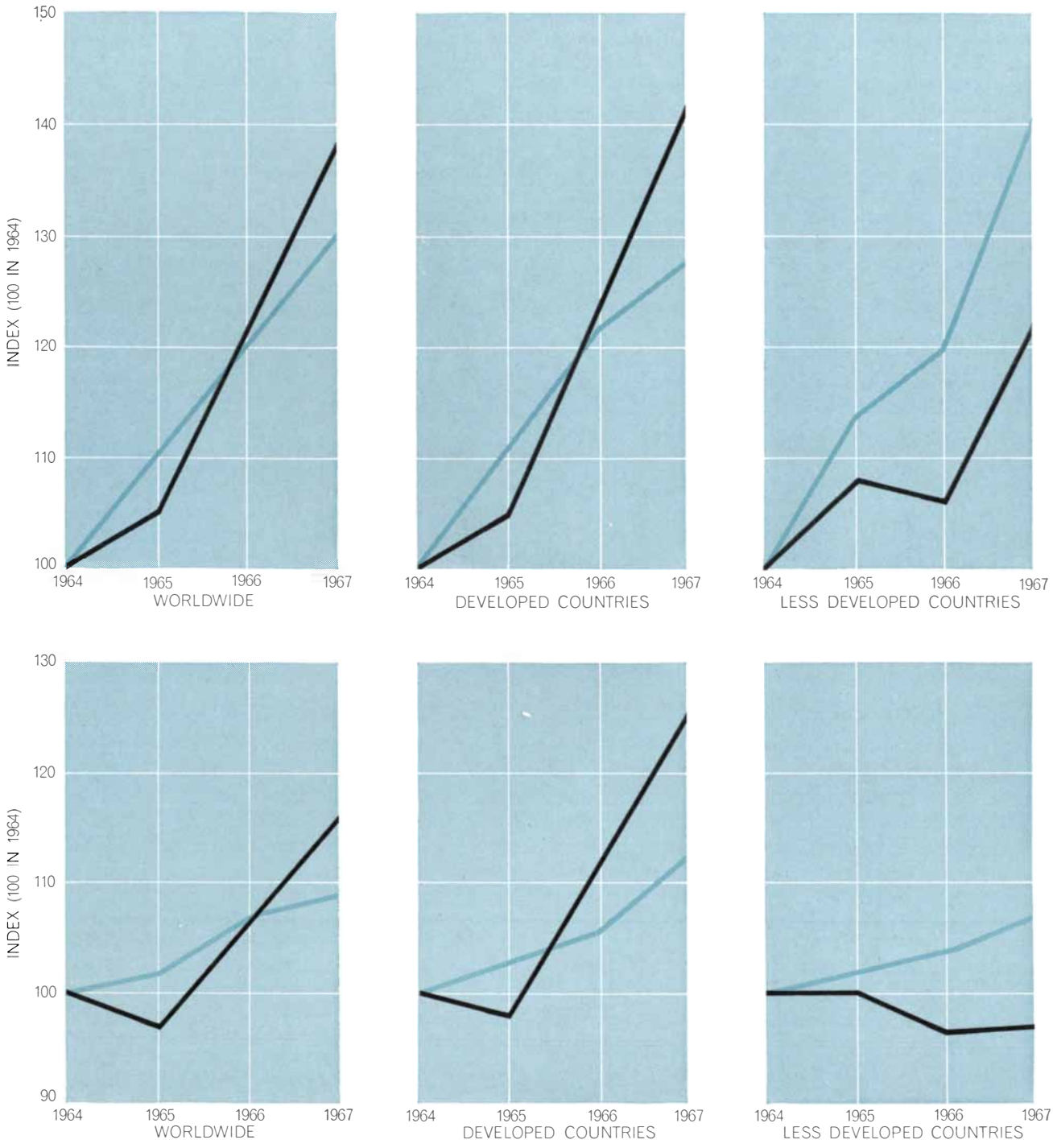
MILITARY AND CERTAIN MAJOR NONMILITARY EXPENDITURES throughout the world are compared for 1966. Figures for public education and public health include all levels of government. On the average, developed countries spend a significantly higher proportion of their gross national product on public education than less developed countries.

These are some of the things to be learned from the size and trend of military spending as reflected in the findings of the third and latest worldwide survey conducted by the Economics Bureau of the U.S. Arms Control and Disarmament Agency. These findings have recently been published under the title "World Military Expenditures, 1966–67." Staff members who participated in the project at different times under my general supervision were Ruth Sivard, who supervised the three studies, Daniel Gallik, Roscoe Lewis, William Sprecher, Bruce Stram and Lynda Zengerle. The backing and encouragement of William C. Foster, director of the Arms Control and Disarmament Agency for its first seven years, were of special importance.

During the past few years several of the agency's economists and statisticians have been compiling a continuing account, from available sources of information, of the annual military expenditures by the nations of the world. The work has covered 120 countries, including the major powers and impoverished small countries, the highly developed industrial nations and those that are struggling to emerge from a relatively primitive agricultural economy. For each country information was collected on the amount of the military budget in relation to the country's gross national product and to its expenditures for two of the nonmilitary functions that are essential for its internal viability and development, namely the functions of public education and public health.

Publication of the three successive annual reports marks the first time a government has presented comprehensive data of this kind. The Arms Control and Disarmament Agency has had assistance in compiling the figures from other agencies of the U.S. Government such as the Agency for International Development and from international organizations such as UNESCO and the World Health Organization.

There were two special difficulties encountered, over and above the profusion of the figures and the tediousness of the checking: first, the inadequacy of published data, resulting both from nondisclosure and from nomenclature or differences in accounting concepts and practices, and second, the technical problem of converting foreign figures into U.S. currency in such a way as to make fair comparisons between different countries. For example, the legal rate of exchange, which is set primarily for foreign-trade purposes, frequently does not provide a realistic basis for translating



FOUR-YEAR TREND in military expenditures (*color*) and gross national product (*black*) is expressed in terms of billions of current dollars (*top*) and per capita in constant 1967 dollars (*bottom*). In each chart the base year, with an index figure of 100, is 1964.

the value of other nations' budgets and expenditures into dollars.

The results arrived at, notwithstanding these difficulties, offer a fair basis for comparison between countries and for an evaluation of global and national trends. There is a degree of imprecision in the figures, but after three years of public exposure of the results, and of efforts to improve the methodology, the information seems basically valid.

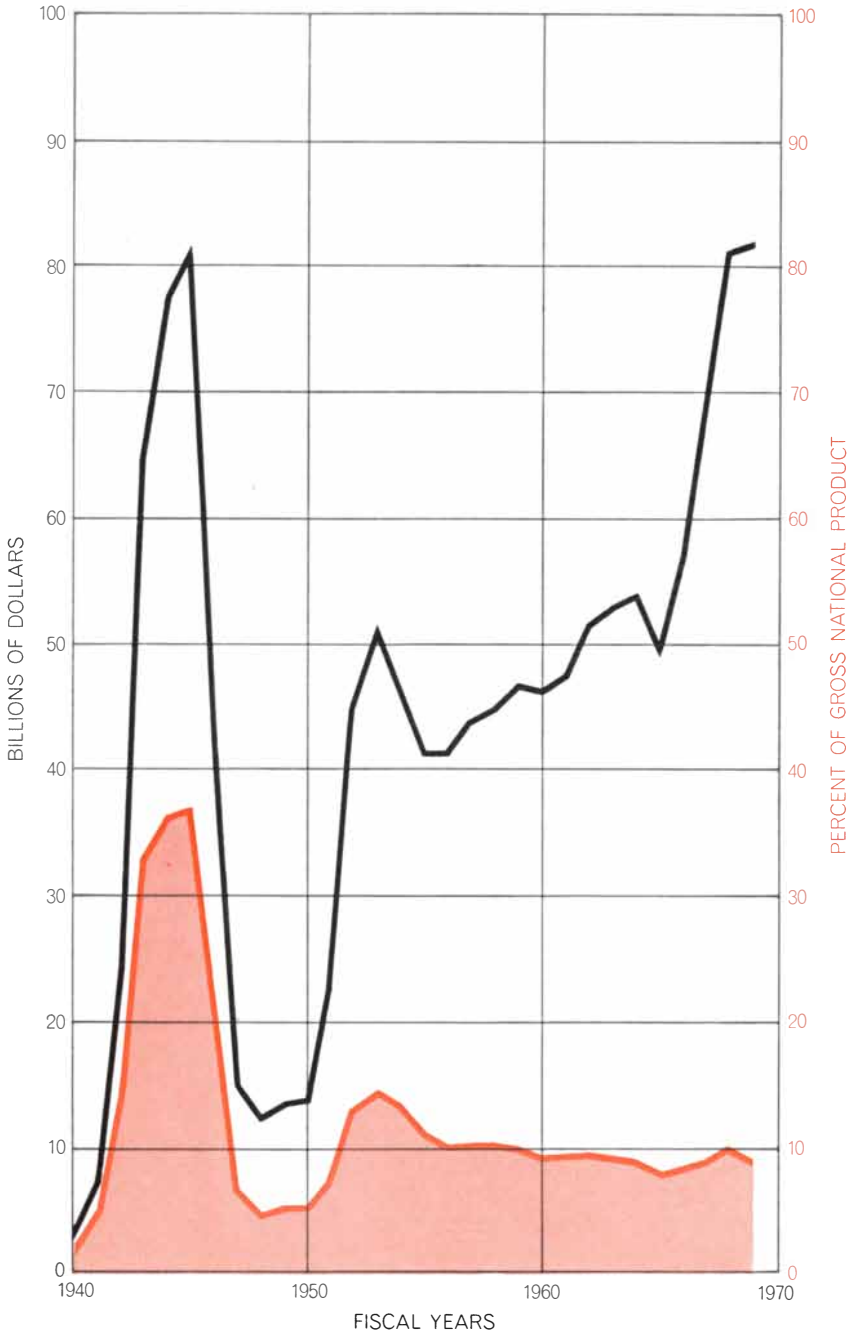
I shall summarize the trends first for the world as a whole, then in terms of the developed and the less developed countries and finally in terms of some individual countries.

In the world as a whole military expenditures have risen steadily since 1950. The rate of military spending in current dollars per capita has at least doubled. The data show that it is now undergoing its sharpest rise since the Korean war; the world military expenditures jumped by $44 billion (an increase of almost a third) from 1965 to 1967, and judging from known recent increases in military budgets we can deduce that the world total continued to climb in 1968 and 1969. Allowing for the inflation of prices, we find that the world military outlay, expressed in constant dollars, increased by nearly 24 percent in the four-year period 1964–1967 [*see illustration above*]. During that period military spending increased more rapidly than the growth in

world population (7 percent) and more rapidly than the growth of the gross world product (16 percent in constant dollars). It is evident that the burden of military expenditures is becoming ever larger, both overall and per person.

In 1967 military costs consumed 7 percent of man's entire production of goods and services. This was equal to the total annual income of the one billion people living in Latin America, South Asia (including India and Pakistan) and the Middle East. The manpower absorbed in military service and production—in the world's active armed forces and military-connected employment—totaled some 50 million persons.

The world as a whole is spending about 40 percent more on military programs than on public education; in 1966, compared with $159 billion for military budgets, the governments of the world spent $111 billion for public education [*see bottom illustration on page 22*]. Military expenditures exceed those for public education in about half of the countries of the world, including the U.S. In the field of public health the world's total expenditure in 1966 was only about a third as large as the military outlay.



RELATION IN U.S. of military expenditures (*color*) and gross national product (*black*) is charted for 30 years. Military expenditures are shown in billions of dollars at the prices prevailing for each year. Bottom curve expresses the level of military spending as a percentage of the gross national product. The years are fiscal years, which begin July 1.

So much for the gross world figures. Data for regions and individual countries reveal significant differences from the general pattern. The relative positions of the developed and the less developed countries, or what are commonly called the "have" and the "have not" nations, are of special interest.

The less developed countries as a group did not escalate their military expenditures as much as the developed nations in the period 1964–1967. Discounting price inflation, which has been particularly severe in many of the have-not countries, we find that the total military expenditure of the less developed nations did not change significantly, in constant prices, between 1964 and 1967. In 1967 the 93 less developed countries in the survey, with 72 percent of the world population, accounted for only 11 percent of the world's total military expenditure; their average military outlay per capita was $8 (as against an average of $170 in the developed countries), and their military spending averaged 4 percent of their gross national product (compared with 8 percent in the developed countries).

The figures might seem to suggest that their military burden is not great. Such comparisons with developed countries, however, give no valid measure of the actual burden military expenditures represent for the have-not countries. In the less developed nations, living barely above the subsistence level on an average per capita G.N.P. (roughly equivalent to per capita annual income) of $186, even a diversion of $8 per capita to military use cuts deep into the standard of living. Whereas large G.N.P. increases in the developed countries have made it easier for such nations to pay for their increase in military outlays, in the less developed countries the G.N.P. growth rate per capita has been modest (only about half that in the developed countries). The burden of military spending in the have-not countries is compounded by the fact that it depletes savings that could be used for the investment required to advance their development and standard of living.

Modest as their proportion of the

world's military expenditures is, the less developed countries are devoting more than twice as much to this expense as they are receiving in economic aid from the wealthier nations. Military spending, for which the example is set by the developed countries, is one of the factors contributing to the lag of the developing countries behind the developed countries in economic growth. Its hampering effects show up clearly in the available statistics. In 1966 the 93 less developed nations as a group spent more on their military budgets than on government-supported education and public health combined: $17 billion for the armed forces, $11 billion for public education, $5 billion for public health. Their $16 billion total for public education and public health, for 72 percent of the world population, represented only about 10 percent of the total world outlay for public education and public health. The average expenditures per person in the have-not countries were about $5 per year for public education and $2 for public health, as against average per capita expenditures in the developed countries of $100 for public education and $50 for public health. Elimination of military spending would not by any means fill the gap for the less developed countries, but the figures graphically demonstrate how ill those countries can afford that use of their scarce resources. There is the further unhappy consequence that their military establishments not only absorb desperately needed funds but also divert their scarce skilled manpower from the civilian economy.

The military factor looms considerably larger in some of the individual countries than it does for the less developed group as a whole. In 1966 the military budget for mainland China was estimated to be 8.1 percent of its G.N.P., for Taiwan 11.2 percent, for Laos 18.5 percent, for North Vietnam 20 percent, for South Vietnam 14.5 percent, for the United Arab Republic 9.1 percent and for Jordan 11.7 percent. In most of these countries the G.N.P. was less than $200 per capita and the expenditure for public education was a small fraction of the military outlay. In 1966 a populous Latin-American country, with two out of five of its people illiterate, was spending only half as much on education as on defense. An African country, with four out of five illiterate, spent $103 million on military programs and $99 million on public education ones. In either case a transfer from military to welfare expenditures could bring about a qualitative

RANKING OF MAJOR COUNTRIES according to gross national product (*gray*) and military expenditures (*color*) in 1966 is indicated on a logarithmic scale in 1966 dollars or the equivalent in purchasing power. Dot for military expenditures beginning with Argentina and going to the bottom of the list means military spending of less than $1 billion.

improvement in the latter and in time have a beneficial effect on the overall development of the country.

What of the developed countries? How well can they afford their military expenditures?

The 27 developed countries, comprising 28 percent of the world population, account for 89 percent of the world total of military spending, and for nine-tenths of the jump in this spending that took place in the period from 1965 to 1967. Most of these countries are members, on one side or the other, of the two major military alliances: the North Atlantic Treaty Organization (NATO) and the Warsaw Pact. The NATO group increased its military expenditures by 35 percent in the 1965–1967 period; the Warsaw Pact countries, by 29 percent. The two principal contributors to these increases were the U.S. and the U.S.S.R. Their military expenditures constitute almost three-fourths of the world total, and these two nations accounted for $35 billion of the $44 billion increase in world military spending in 1965–1967. Devoting a sizable part of their resources to the military sector, the U.S. and the U.S.S.R. account for a considerably larger share of the world's military spending than of its gross product, although they are also the leaders in G.N.P. by a great deal [*see illustration on preceding page*].

In 1967 the developed nations as a group had an average per capita G.N.P. of $2,141, nearly 12 times the average for the less developed countries. Since 1964 the developed countries' military outlay, however, has risen twice as rapidly as their G.N.P. Thus a growing proportion of their total product has gone into weaponry, armed forces and military engagements. These countries are on a military treadmill in an economic sense. As the weapons grow in sophistication, costs escalate. Because of increasing emphasis on research and development, weapons become obsolete almost as fast as they are produced, and they are replaced by still more costly ones.

The developed countries spend a substantially higher proportion of their G.N.P. on education than the less developed countries: 5 percent by the developed countries, on the average, as against 3 percent by the less developed ones. Nevertheless, most of the developed nations are devoting a much larger share of their resources to the military budget than to public education, according to the latest available figures (for 1966). Exceptions among the relatively affluent countries include Japan (spending more than four times as much on education as on military services), Canada (twice as much), Italy, Sweden, the Netherlands, Switzerland, Denmark, Belgium and Norway. In the U.S., even if the estimated $7 billion spent for private education is added to the public expenditure of $34 billion (in Federal, state and local educational outlays), the

REGION AND COUNTRY	GROSS NATIONAL PRODUCT		MILITARY EXPENDITURES		FOREIGN ECONOMIC AID	
	BILLIONS OF DOLLARS	DOLLARS PER CAPITA	BILLIONS OF DOLLARS	PERCENT OF G.N.P.	RECEIVED BILLIONS OF DOLLARS	GIVEN BILLIONS OF DOLLARS
WORLD TOTAL	**$2,311.1**	**$687**	**$159.0**	**6.9%**	**$7.1**	**$7.9**
NORTH AMERICA	800.9	3,696	64.9	8.1	0	4.2
UNITED STATES	747.6	3,796	63.3	8.5	0	4.0
EUROPE	1,037.3	1,455	76.5	7.4	.6	3.1
EUROPEAN NATO	466.6	1,570	21.3	4.6	.3	2.5
WARSAW PACT	478.5	1,434	52.3	NA	0	.4
SOVIET UNION	357.0	1,531	47.0	NA	0	.3
OTHER EUROPEAN	92.2	1,123	2.8	3.1	.3	.1
NATO TOTAL	1,267.5	2,466	86.2	6.8	.3	6.8
LATIN AMERICA	102.4	415	2.1	2.1	1.4	0
FAR EAST	218.7	185	9.4	4.3	1.2	.4
CHINA, MAINLAND	80.0	104	6.5	8.1	0	.1
JAPAN	97.5	986	.9	1.0	0	.3
SOUTH ASIA	54.2	83	1.9	3.5	1.9	0
INDIA	36.9	74	1.4	4.0	1.3	0
NEAR EAST	24.8	284	1.9	7.5	.4	•
AFRICA	42.5	171	1.1	2.5	1.3	•
OCEANIA	30.6	2,153	1.2	3.9	0	.1

REGIONAL SUMMARY is given of military expenditures and related data for 1966. The amounts are in U.S. dollars at 1966 prices and exchange rates. Table includes figures for 93 countries classified as less developed, a category that embraces all Latin America,

total for education is less than two-thirds the size of the military budget.

The military burden of the U.S. has become so heavy that it is coming under increasingly critical scrutiny by Congress. There have also been a proliferation of protesting organizations and growing concern on the part of the public at large. The nation's $63 billion military budget in 1966 amounted to 8.5 percent of the gross national product. The average annual cost to the population was about $320 per person—$1,280 for a family of four.

Since 1966 the expenditures have increased. Two elements in the U.S. military budget have been singled out for questioning in Congress and by the public. These are the costs of the Vietnam war and of new strategic weapons. The Vietnam war, although its cumulative cost is now approaching $100 billion, has not cost as much as the several hundred billions spent so far on the stockpile of strategic weapons. The new generation of weapons (anti-ballistic-missile systems, "MIRV" systems, new nuclear submarines and others) now under development or being considered is likely to entail a very high level of spending for strategic forces.

The Council of Economic Advisers in its latest annual report estimates that, assuming the end of the Vietnam war and no "new defense programs," the defense budget for fiscal year 1972 might amount to about $73 billion. Assuming growth of the G.N.P. to $1,100 billion by that year, the council calculated that a "dividend" of some $22 billion would be available annually for new economic and social programs—in welfare, education, health and other aspects of national improvement. This is barely half the amount required for projects that various official task forces have listed as urgent national needs. If the arms race is not brought under control, the hope of obtaining even a $22 billion dividend for civilian needs will not be realized.

Because the percentage of the G.N.P. devoted to military spending has remained fairly constant (at about 9 or 10 percent) over the past 15 years as the G.N.P. grew, it is argued in some quarters that the U.S. can "afford" to allocate this proportion of its resources to military defense. This contention seems to me highly questionable on two grounds. First, the theory that the enormous military outlays have advanced the nation's security remains unproved as long as there are unexplored arms-control possibilities; indeed, most students of the matter appear to agree that the arms race has only served to make the world, including the U.S., more insecure than ever. Second, we have seen abundant evidence in recent years that "military security" is not a synonym for "national security." National security requires not only international peace but also peace and fulfillment for the people within the national society.

Although the G.N.P. of the U.S. has been growing at a high rate, it is quite evident that we are not allotting a large enough share of our national income to our economic and social needs. The decay of our cities, the pollution of our environment, the inadequacy of our schools, housing, medical care, hospitals and transportation facilities, the unacceptable lot of large portions of our population compel us to reorder our priorities. A further need for release of more of our resources from defense uses exists, of course, in the field of foreign economic assistance. Money alone will not solve our problems, but without money we cannot do what we should and must do. Since our resources are not limitless, it is imperative that we find a way to devote a greater share to constructive rather than to unproductive uses.

In the first half of the 20th century the world spent $4 trillion and millions of lives in wars and preparations for wars, including the two world wars. Humanity may now be on the verge of launching military programs costing $4 trillion in just one decade, with an attendant threat of destruction not merely to millions but to most, perhaps to all, of mankind. One can think of better ways to spend the $4 trillion.

For the peoples of the earth, to say nothing of taxpayers, the most significant and welcome news of the decade would be a beginning in the control and reduction of military spending. This could be initiated by an agreement between the U.S. and the U.S.S.R. to arrest their race in the production of strategic weapons.

PUBLIC EDUCATION EXPENDITURES	PUBLIC HEALTH EXPENDITURES	POPULATION MIDYEAR	ARMED FORCES	
BILLIONS OF DOLLARS	BILLIONS OF DOLLARS	MILLIONS	MILLIONS	PERCENT OF POPULATION
$110.8	**$52.2**	**3,363.4**	**20.3**	**.6%**
37.3	13.7	217.0	3.2	1.5
34.3	12.2	196.9	3.1	1.6
58.5	33.5	712.9	7.9	1.1
18.8	6.1	297.1	2.9	1.0
36.3	25.5	333.7	4.2	1.3
30.6	21.0	233.1	3.2	1.4
3.4	2.0	82.1	.8	1.0
56.1	19.8	514.0	6.1	1.2
2.5	1.6	246.9	.8	.3
8.0	1.5	1,180.6	5.9	.5
2.8	1.1	772.0	2.5	.3
4.1	.1	98.9	.2	.2
1.3	.2	655.8	1.4	.2
1.0	.2	501.6	1.0	.2
1.0	.6	87.2	.7	.8
1.2	.5	249.1	.3	.1
1.0	.5	14.2	.1	.6

the Near East and South Asia; all the Far East except Japan; all Africa except South Africa, and, in Europe, Albania, Bulgaria, Greece, Portugal, Spain, Turkey and Yugoslavia.

RIBOSOMES

They are the organelles that conduct the synthesis of proteins in the living cell. Their structure and functioning are studied by taking them apart and seeing how they reassemble themselves

by Masayasu Nomura

It is one thing to discover the basic principles of a life process and quite another to know in detail the chemical mechanisms that underlie it. In order to genuinely understand a cellular function one must study the machinery that performs it, and in many cases that means studying a highly organized cellular element, or organelle, that provides the machinery. One must first determine the organelle's structure and learn how it operates and then find out how the organelle itself is generated in the cell. In this article I shall relate how the structural and functional description of the ribosome, the organelle that conducts protein synthesis, has been attempted and is even now being achieved.

The story of the ribosome goes back to the discovery some years ago that the capacity of various types of cell to synthesize proteins was correlated with the cells' content of ribonucleic acid (RNA), and that most of the cellular RNA was in the form of small particles (then known as microsomes) in the cytoplasm of the cell. This suggested that the particles must play some role in protein synthesis, but the real importance of ribosomes emerged only after intensive biochemical investigation.

The pioneer work was done by Paul C. Zamecnik and his collaborators at the Massachusetts General Hospital in the 1950's [see "The Microsome," by Paul C. Zamecnik; SCIENTIFIC AMERICAN, March, 1958]. They homogenized rat-liver cells, added amino acids labeled with atoms of the radioactive isotope carbon 14, fortified the homogenate with adenosine triphosphate (ATP) to provide chemical energy and were able to detect the formation of small amounts of protein. By a process of elimination they established that several cellular organelles, including the nucleus and the mitochondrion, were not necessary for protein synthesis but that the microsomes were essential. They were able to identify other cellular components required for protein synthesis, including the small RNA molecules called transfer RNA and enzymes that attach amino acids to transfer-RNA molecules. These early test-tube assembly systems, however, made only very small amounts of protein. Then in 1961 Marshall W. Nirenberg and J. Heinrich Matthaei of the National Institutes of Health found that in order to obtain intensive synthesis of protein in cell-free extracts of the bacterium *Escherichia coli* it was necessary to include a third type of RNA, called messenger RNA, that had been postulated by François Jacob and Jacques Monod of the Pasteur Institute in Paris.

Once a complete cell-free protein-synthesizing system could be assembled it was possible to study the functioning of its several components. One of the most interesting of these was the ribosome. It was now clear that this particle coordinates the translation of the genetic information in the sequence of nucleotide bases in the messenger RNA (transcribed from the DNA molecule, the gene) to the sequence of amino acids in each protein manufactured by the cell [*see illustration on page 30*]. The first systematic studies of ribosomes were initiated about 1957 by several groups, notably one at Harvard University led by Alfred Tissières and James D. Watson and one in the Carnegie Institution of Washington that included Ellis T. Bolton, Roy Britten and Richard B. Roberts. (I should add that my association with Watson's group at that time, although it was brief, had a great influence on my later research on the ribosome.) The initial studies were done mainly on *E. coli* ribosomes, which consist of two subunits of unequal size that are designated 30*S* and 50*S*. The size is determined by the rate, measured in Svedberg units (*S*), at which a particle sediments when it is spun at high speed in an ultracentrifuge. Together these particles constitute the functional unit in protein synthesis: the 70*S* ribosome. (The reason the two S values are not additive is that the shape of a particle influences its rate of sedimentation.) In each of these subunits proteins represent about a third of the total mass; the rest is RNA. The 50*S* ribosome subunit contains a 23*S* RNA molecule and a 5*S* RNA molecule. The 30*S* ribosome subunit incorporates one 16*S* RNA molecule. In 1961 J. P. Waller and J. I. Harris of Harvard observed that the ribosome contains different kinds of protein molecules, indicating that its structure must be quite complex. Subsequent experiments conducted by many workers, including those in my own group at the University of Wisconsin, show that the 30*S* ribosomal subunit includes either 19 or 20 different protein molecules and that the 50*S* subunit apparently has more than 30 protein molecules.

As the early work on the structure of the ribosome was proceeding, a general picture of its functional properties had begun to emerge. The existence of specific ribosomal binding sites for transfer and messenger RNA was demonstrated, forcing the conclusion that the ribosome plays an active role in protein synthesis and is not merely an inert workbench on whose surface amino acids are assembled. The observed physical complexity of the ribosome must therefore reflect the complexity of its function. What we needed to establish was the relation between structure and function. Yet as far as the actual roles of the RNA and proteins and their critical interrelations were concerned, the ribosome was still a mysterious "black box." How was one

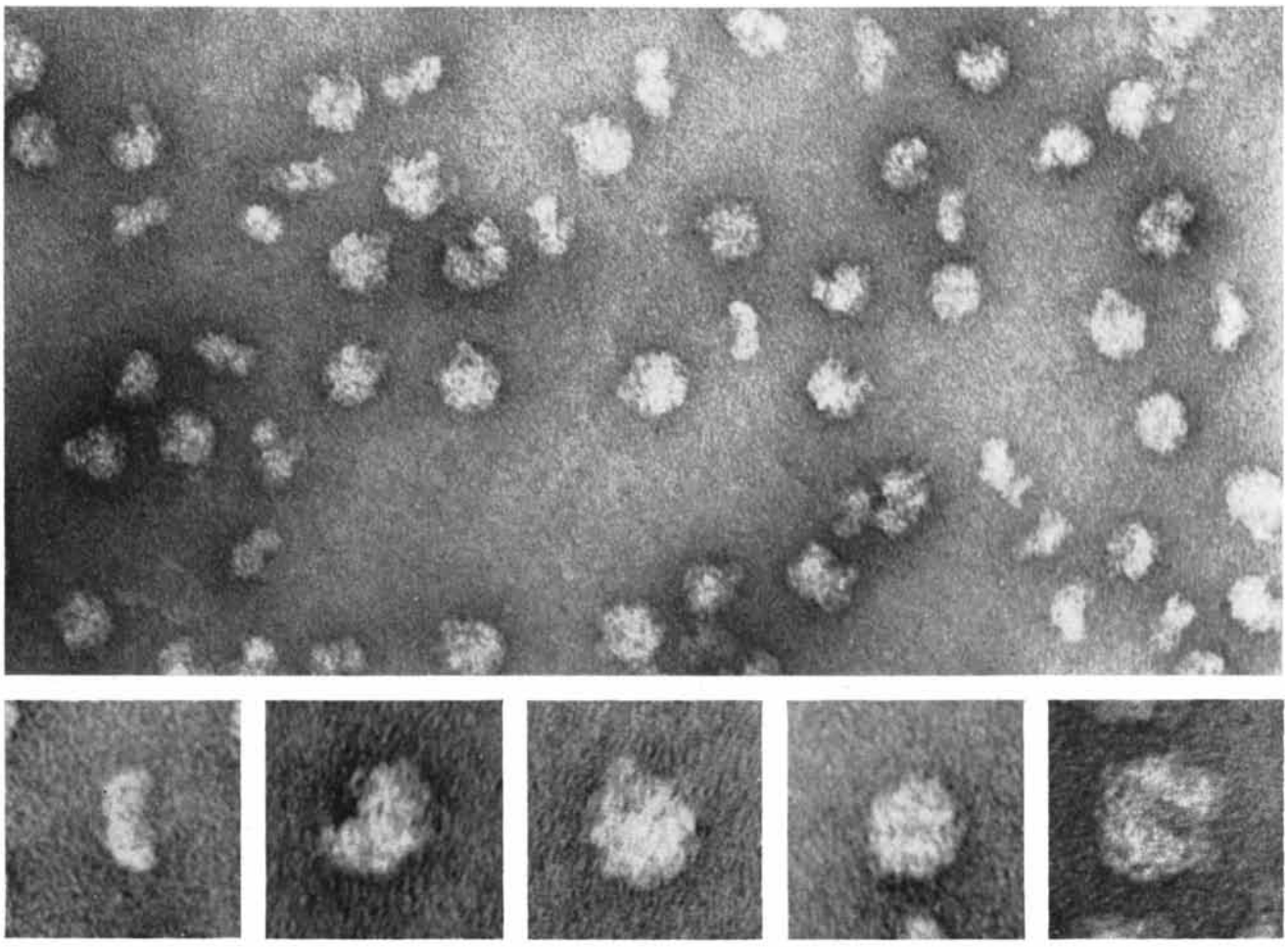
to understand this complicated piece of machinery? One could take it apart and try to reassemble it, but what tools were delicate enough to avoid destroying the machine in the process?

In 1961 Jacob, Sidney Brenner and Matthew S. Meselson, in a paper describing the classic experiments that proved the messenger-RNA theory, noted the presence of two kinds of ribonucleoprotein particle in mixtures that were centrifuged in a solution of the salt cesium chloride, which forms a density gradient in the centrifuge cell. (Density-gradient centrifugation, originally developed by Meselson, Franklin W. Stahl and Jerome R. Vinograd at the California Institute of Technology, separates large molecules on the basis of their different buoyancy in such a solution.) When they centrifuged bacterial extracts containing ribosomes, they observed two bands containing ribosomal particles. The lighter band (the *B* band), corresponding to a density of 1.61, contained messenger RNA as well as proteins being synthesized; the heavier band (the *A* band), corresponding to the density of 1.65, did not.

The presence of the *A* band was not relevant to the main theme of the paper, and no reason was given for its presence. At the time the paper was published I was working at the University of Osaka on both ribosomes and messenger RNA, and I was quite curious about this phenomenon. We knew then that the 30*S* and 50*S* subunits and their aggregate, the 70*S* ribosome, all have the same chemical composition: 65 percent RNA and 35 percent protein. Since the buoyancy of complex molecules in solution usually reflects their chemical composition, why should density-gradient centrifugation reveal two kinds of ribonucleoprotein particle?

In the summer of 1962 I had an opportunity to visit Meselson's laboratory at Harvard to look into the question. When we recovered the particles from the two bands, we found that the *B* band contained undegraded 50*S* and 30*S* ribosomal subunits. The denser *A* band, however, consisted of a mixture of smaller 40*S* and 23*S* "core" particles that had been created from the usual ribosomal subunits by the splitting off of about 40 percent of the protein during the density-gradient centrifugation; the split proteins could be found in a protein fraction at the top of the gradient. The explanation for the *B* band was apparently that in crude bacterial extracts some of the ribosomes are resistant to this splitting, perhaps because they are stabilized by messenger RNA and growing protein chains.

On returning to Osaka I continued experiments with Robert K. Fujimura to characterize these core particles. Initially we prepared 40*S* and 23*S* particles (the latter are not to be confused with 23*S* RNA molecules) by respectively centrifuging purified 50*S* and 30*S* ribo-

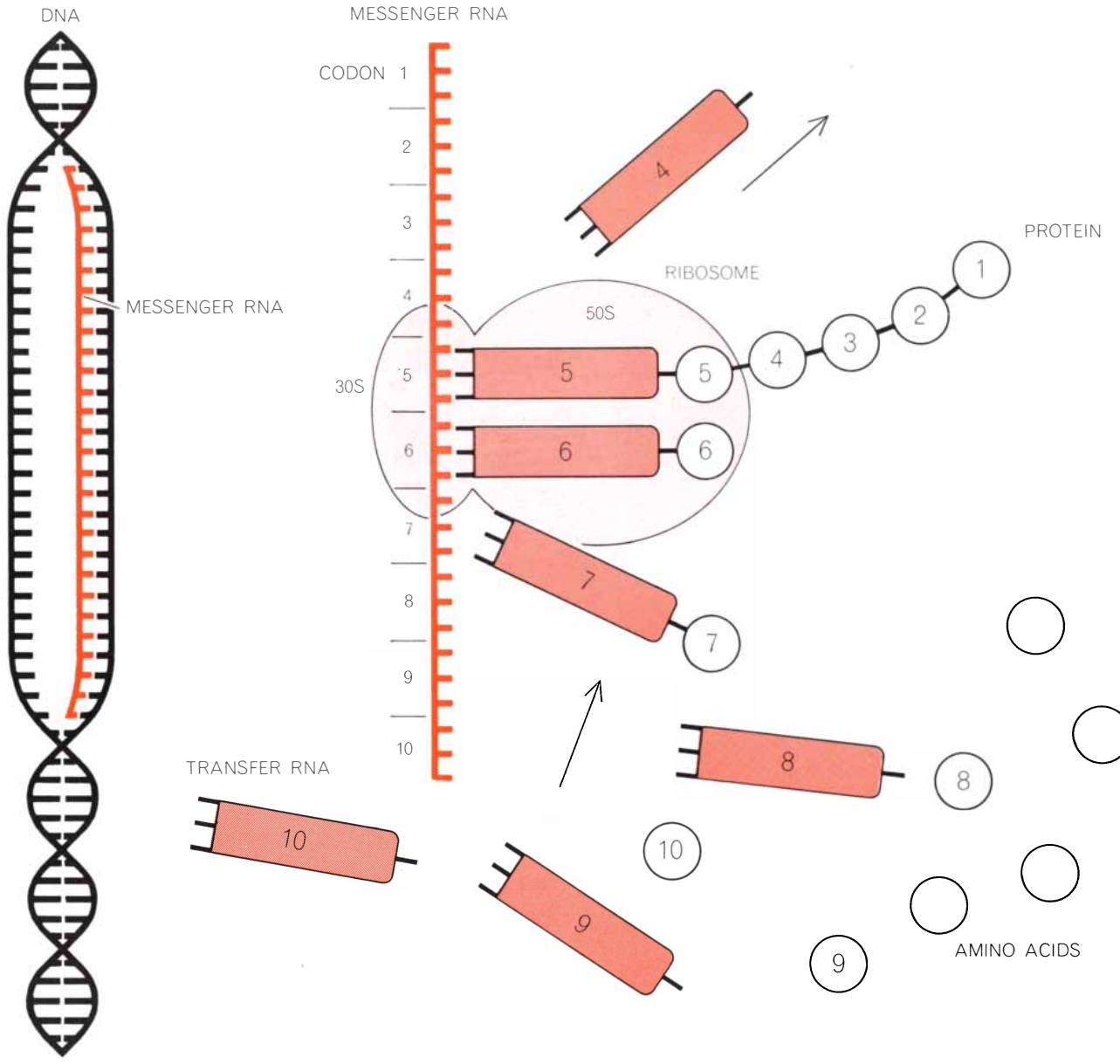


RIBOSOMAL SUBUNITS are enlarged 450,000 diameters in an electron micrograph (*top*) made by Martin Lubin of the Dartmouth Medical School. To prepare them, intact (70*S*) ribosomes were dissociated in solutions with a low magnesium concentration and the subunits were negatively stained with uranyl formate. Individual particles are enlarged 800,000 diameters (*bottom*). The smaller of the two subunits is the 30*S* (*left*). The larger is the 50*S*, seen in three different views characterized by a kidney shape (*second from left*), a "nose" (*third from left*) and a groove (*fourth from left*). The two subunits join to form a 70*S* ribosome (*right*).

somal particles in cold cesium chloride solution for 36 hours and then recovering the core particles from the band in the middle of the centrifuge cell [*see middle illustration on opposite page*]. This procedure was troublesome, however, and unsuitable for large-scale preparation of the particles. We therefore tried omitting the centrifuge step. Reasoning that it was surely the particular salt solution and not the physical centrifugation that disrupted the subunits, we simply kept 50S subunits in the solution for 36 hours, expecting that irreversible splitting of the protein would take place, yielding the 40S core particles we wanted to study.

When we removed the cesium chloride and examined the products, however, we found to our surprise that the recovered particles behaved just like the original 50S ribosomal subunits. Why had there been no splitting of the proteins? We immediately realized the important implication of this experimental observation: The splitting of the 50S unit is reversible; the reaction is pushed in the direction of dissociation only by separation in the centrifuge. To test this supposition we prepared core particles and split proteins by the usual centrifugation method. Then we mixed them together and removed the cesium chloride. We found complete conversion of the core particles to intact ribosomal particles. In this way we succeeded in reconstituting the 50S ribosomal subunit from the 40S core and split proteins that had been derived from the 50S, and also in reconstituting the 30S subunit from the 23S core and the homologous split proteins.

In order to prove that the reconstituted ribosomal particles really had the

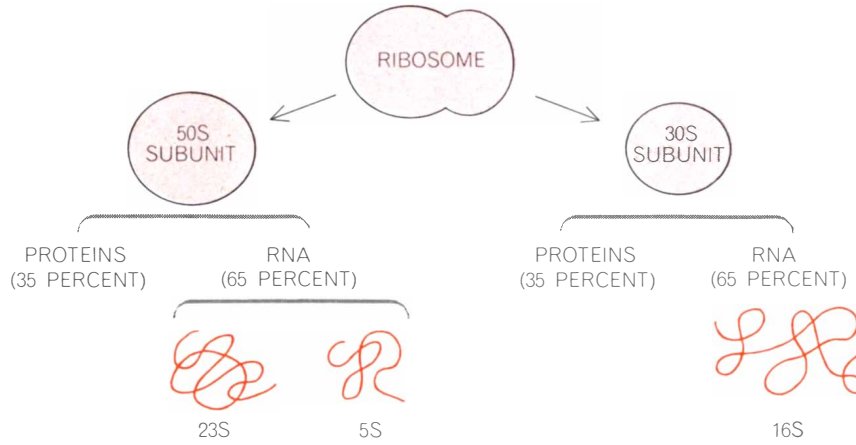


RIBOSOMES conduct protein synthesis. Genetic information is encoded in the sequence of bases (*horizontal elements*) in the double helix of DNA (*left*). This information is transcribed into a complementary sequence of RNA bases to form messenger RNA (*dark color*). Each group of three bases in the messenger RNA constitutes a codon, which specifies a particular amino acid and is recognized by a complementary anticodon on a transfer-RNA molecule (*lighter color*) that has previously been charged with that amino acid. Here amino acid No. 6, specified by the sixth codon, has just been bound to its site on the ribosome by the corresponding transfer RNA. It will bond to amino acid No. 5, thus extending the growing peptide chain. Then the ribosome will move along the messenger RNA the length of one codon and so come into position to bind transfer RNA No. 7 with its amino acid.

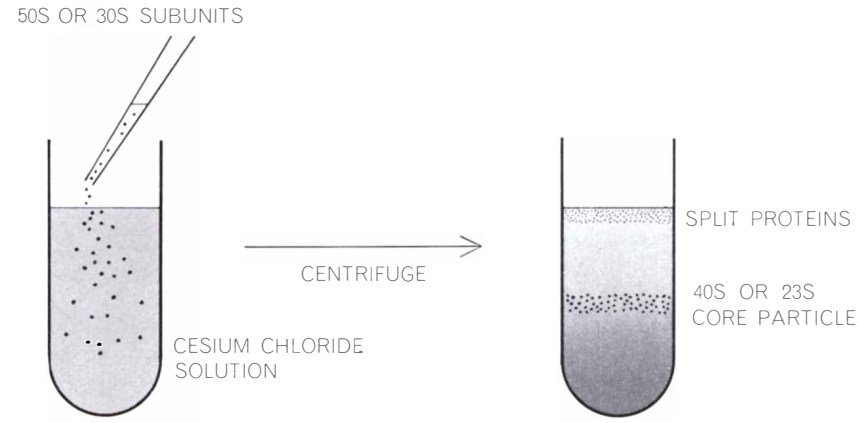
same specific structure as the original ones, we had to demonstrate the functional integrity of the reconstituted particles. Before we could succeed in such experiments I left Osaka and moved to the University of Wisconsin. There Keiichi Hosokawa and I were able to show in 1965 that, whereas neither the 23S nor the 40S cores have any activity in a cell-free protein-synthesizing system, reconstituted 30S and 50S particles have activities comparable to the original intact 30S and 50S ribosomal subunits. At the same time Theophil Staehelin and Meselson, who were taking a similar approach at Harvard, independently succeeded in demonstrating the reconstitution of the ribosomal subunits from core particles and split proteins. The functional capabilities of the reconstituted particles can be assayed in various ways. For example, the function of 30S particles is usually assayed by measuring the rate of protein synthesis directed by messenger RNA in the presence of intact 50S subunits and other necessary components. One can also test the subunits' ability to bind several different transfer RNA's in the presence of various messenger RNA's and the ability to bind messenger RNA itself.

The success in reconstitution, although it involved the dissociation and reassociation of only some of the ribosomal proteins (the split proteins), had several important implications. First, the experiment showed that at least part of the ribosome assembly in the test tube is spontaneous; no extraribosomal template or enzyme is required. Second, it provided a system in which the functional roles of individual split proteins could be analyzed. The 30S split-protein fraction consists of seven proteins. By column chromatography we separated the proteins into five pure protein components and one fraction containing two proteins, and we showed that the five proteins differ from one another in amino acid composition. Then we determined the functional need for each of the purified proteins by omitting one of them at a time in reconstitution experiments. We found that three of the five purified proteins are essential for reconstitution, and that the omission of either one of the others has only a partial effect. From this type of experiment we could conclude that all five of the purified proteins are chemically and functionally distinct, and that some of them are absolutely required whereas others are not (although they are required for full activity in protein synthesis).

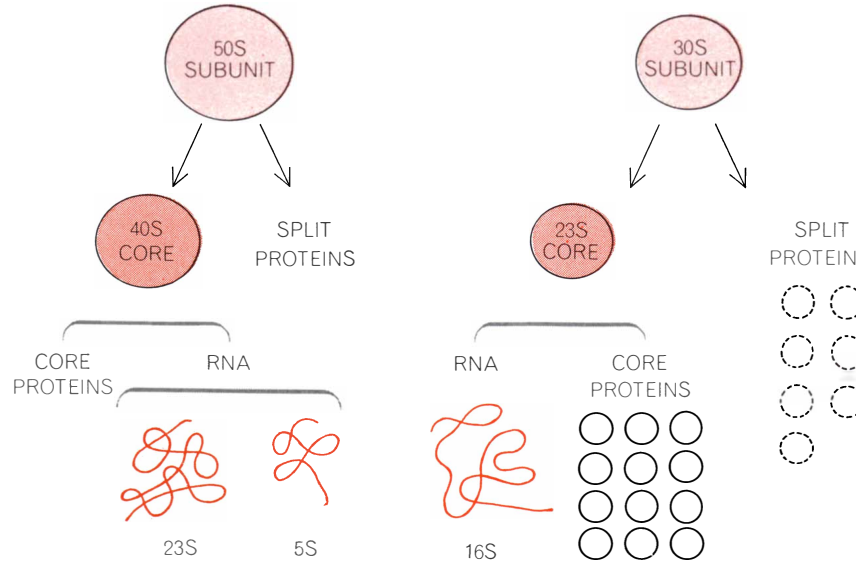
The partial-reconstitution system was a first step toward the functional analy-



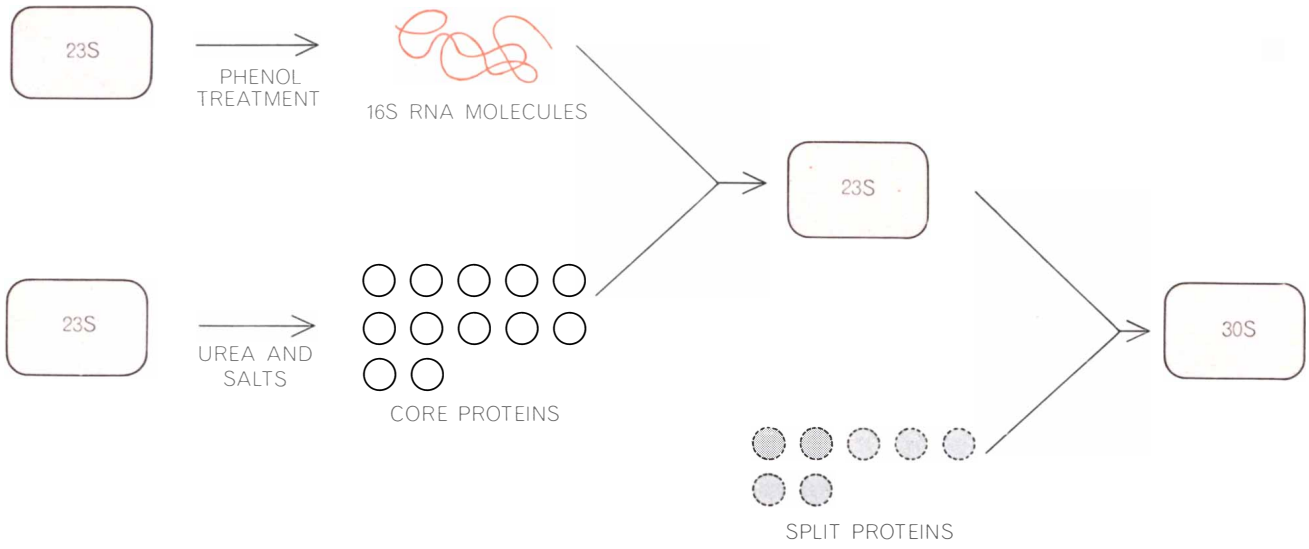
TWO SUBUNITS of a ribosome can be separated by spinning ribosomes in a centrifuge because the subunits are different sizes and move through the centrifuge cell at different rates. Both subunits are about 35 percent protein and 65 percent RNA. The 50S subunit contains a 23S and a 5S RNA molecule and the smaller 30S subunit has a 16S RNA molecule.



FURTHER CENTRIFUGATION of the subunits breaks them down. The subunits are added to a cesium chloride solution (*left*). Centrifugation establishes a stable density gradient in the solution (*right*), within which the subunit components form layers according to density. Some proteins split off, leaving "core" particles of RNA and other proteins.



DISSOCIATION of the 50S subunit yields a 40S core particle and split proteins, dissociation of the 30S subunit a 23S core particle and split proteins. In the case of the 30S subunit there appear to be seven split proteins, with about 12 proteins remaining in the core.

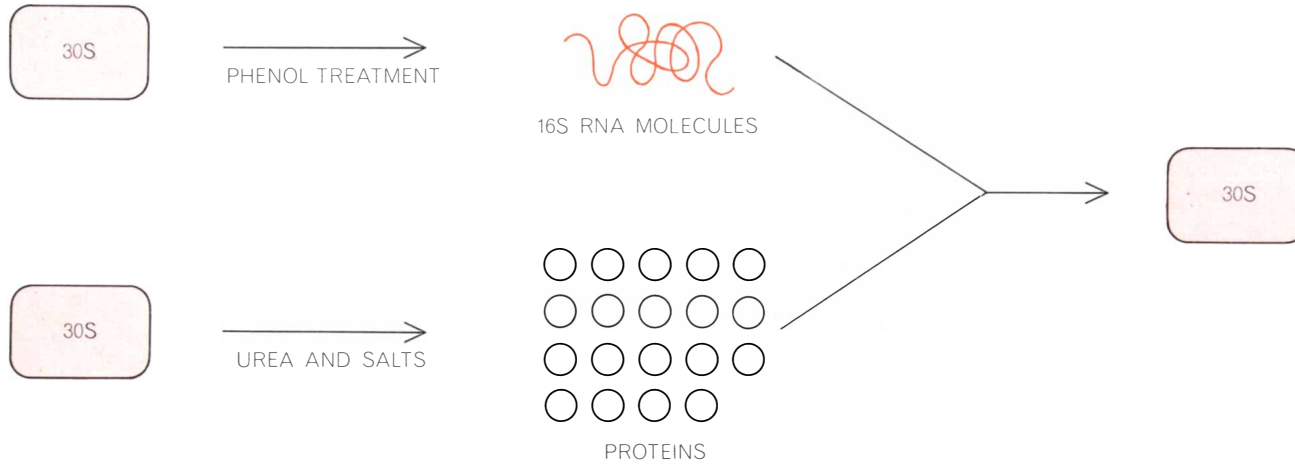


RECONSTITUTION of subunits was first accomplished as shown here. Core particles were treated with phenol to prepare 16S RNA and with urea and salts to yield the core proteins. The RNA and proteins were combined at 37 degrees Celsius to form 23S core particles. Then the reaction was completed by the addition of the split proteins, and in this way the 30S subunits were formed.

sis of the ribosome, but the information that could be provided by such a system was limited. To accomplish complete analysis we needed a way to reconstitute ribosomes entirely from free RNA and completely separated proteins. In 1967 Peter Traub and I began systematic attempts at complete reconstitution with the 30S subunit.

We assumed that we must do the reconstitution in two steps, first making 23S cores from 16S RNA and proteins and then making complete 30S subunits from the 23S cores and the split proteins. We therefore prepared 16S RNA by treating 23S cores with phenol. We separated proteins from other 23S cores by treating the core particles with urea and a high concentration of lithium chloride. We mixed these core proteins with the 16S RNA under several different conditions, hoping to obtain 23S core particles. Then we added the split proteins to the reaction mixture, recovered the particles by centrifugation and assayed the activity of the recovered particles in a cell-free protein-synthesizing system. As typical enzyme chemists, we felt it was essential to protect the ribosomal proteins and any sensitive intermediates from inactivation by heat, and so we performed all these operations in a cold room and kept everything on ice.

Our initial attempts were failures. We could find only very slight protein-synthesizing activity. It seemed that the reaction might not be possible. Then we realized that living *E. coli* cells multiply most rapidly at 37 degrees Celsius (body temperature) and not at all at freezing temperatures, and that multiplying cells must certainly be assembling ribosomes quite efficiently. We also recognized that the cytoplasm of living *E. coli* contains a rather high concentration of salts; the salts might discourage nonspecific RNA-protein aggregation and thereby promote the specific RNA-protein assembly reaction. We therefore attempted the reconstitution at 37 degrees and with a high concentration of a salt, potassium chloride. Success! The 30S ribosome could be self-assembled [*see illustration above*]. We found, indeed, that the reconstitution of 30S subunits from RNA and proteins is independent of the order of addition of proteins, whether they are core proteins or split proteins. By simply mixing all the proteins prepared directly from the 30S subunit with 16S RNA and incubating them in an optimal ionic environment at about 40 degrees C. for 10 minutes we were able to convert almost all



CORE AND SPLIT PROTEINS need not be assembled separately. Reconstitution can be accomplished by mixing all ribosomal proteins from 30S subunits with 16S RNA in the correct ionic environment and incubating at 37 to 40 degrees C. for 10 to 20 minutes.

the 16S RNA in the mixture into 30S particles [*see bottom illustration on opposite page*]. In protein-synthesizing activity, in protein content and in sedimentation behavior the reconstituted particles were almost identical with the original 30S particles.

From this point one could proceed in many directions. One basic goal was to determine the functional role of the 16S RNA and of each 30S ribosomal protein. With regard to the RNA, we first considered the specificity requirements. For example, is an RNA molecule that is merely similar in size to *E. coli* 16S RNA competent to reconstitute a physically and functionally intact 30S subunit? No. Neither 16S ribosomal RNA from yeast cells nor *E. coli* 23S RNA degraded to a 16S-sized fragment was active in reconstitutions with *E. coli* 30S proteins. In fact, the inactive products of such combinations did not even resemble 30S ribosomes physically, judging by their sedimentation behavior. This finding certainly came as no surprise; one would expect the requirements for a functional ribosome to be stringent. How stringent? When we performed the reconstitution with 16S RNA from one bacterial species and 30S ribosomal proteins from another species that is distantly related, we found that in many cases such "artificial" ribosomes were as active as the respective homologous RNA-protein combinations. We conclude from this that although there is definitely a specificity requirement for the RNA, the requirement is not absolute.

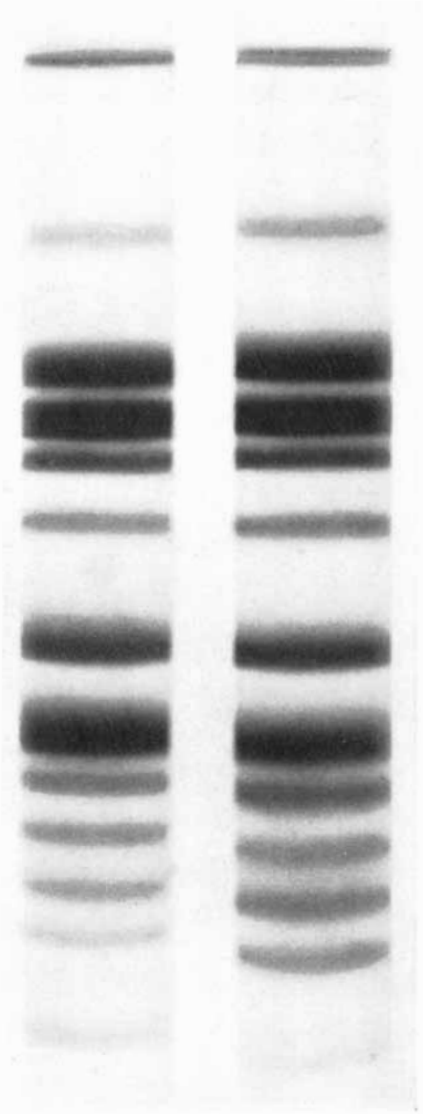
In determining the roles of the various ribosomal proteins our basic approach was to perform the reconstitution with one component omitted or specifically modified and then see if physically intact 30S particles were formed and, if so, whether or not they were functionally active. We first had to separate the 30S protein mixture into each of its 19 components. The fractionation of 30S ribosomal proteins had already been achieved by research groups at the University of Geneva, the Max Planck Institute for Molecular Genetics in Berlin, the University of Wisconsin and the University of Illinois. We employed methods similar to theirs, relying mainly on various types of column chromatography.

We then did the reconstitution with 16S RNA and 19 purified proteins rather than with the unfractionated protein mixture used in our earlier experiments. The extent of the reconstitution was not as good as it was with unfractionated proteins (and we therefore could not exclude the possibility that there are some ribosomal components other than the RNA and 19 protein molecules), but the reasonably high efficiency of the reconstitution made it possible to undertake the functional analysis of the separated protein components.

The first protein we studied in detail was the one responsible for sensitivity or resistance to the antibiotic streptomycin. Earlier studies had indicated that the drug's primary site of action is the bacterial ribosome, specifically the 30S subunit. When streptomycin is added to a cell-free system containing ribosomes from a streptomycin-sensitive strain, it inhibits protein synthesis. Streptomycin also causes the misreading of certain synthetic messenger RNA's, that is, it induces the incorporation into proteins of amino acids other than the ones dictated by the genetic code. This misreading effect of streptomycin was discovered first by Julian E. Davies, Walter Gilbert and Luigi Gorini at Harvard [see "Antibiotics and the Genetic Code," by Luigi Gorini; SCIENTIFIC AMERICAN, April, 1966].

Bacteria can become resistant to streptomycin through mutation, and streptomycin does not inhibit synthesis or cause misreading of messages in a cell-free system if 30S ribosomal particles from streptomycin-resistant mutants are used. Traub and I showed that the component altered by the mutation was not the RNA but had to be in the protein fraction; 30S particles reconstituted from the protein of a resistant mutant and the RNA of a susceptible strain were resistant to streptomycin in cell-free protein-synthesizing systems, whereas the reverse combination produced 30S particles that were susceptible to streptomycin. Makoto Ozaki and Shoji Mizushima took over the job of identifying the altered protein. We purified 30S ribosomal proteins from both susceptible and resistant bacteria, systematically substituted single proteins from a resistant strain in a mixture of proteins from a susceptible strain [*see illustration on next two pages*] and assayed the reconstituted ribosomes for their response to streptomycin. In this way we established that a single protein, one we had designated *P*10, determines the susceptibility of the entire 30S ribosomal particle to the inhibitory action of streptomycin, its susceptibility to streptomycin-induced misreading and its ability to bind the antibiotic.

Having learned how an alteration in a given protein can affect the function of the ribosome, we investigated what happens to the ribosome when this protein is simply left out. Is the ribosome still able to assemble itself and, if so, how are its functional capabilities altered? We found that in the absence of *P*10, RNA and the other ribosomal proteins can still assemble into particles that sediment at 30S. These *P*10-deficient particles have several interesting properties, however. Under the conditions of the assays these particles show high activity when a synthetic messenger RNA is used as a template, but their



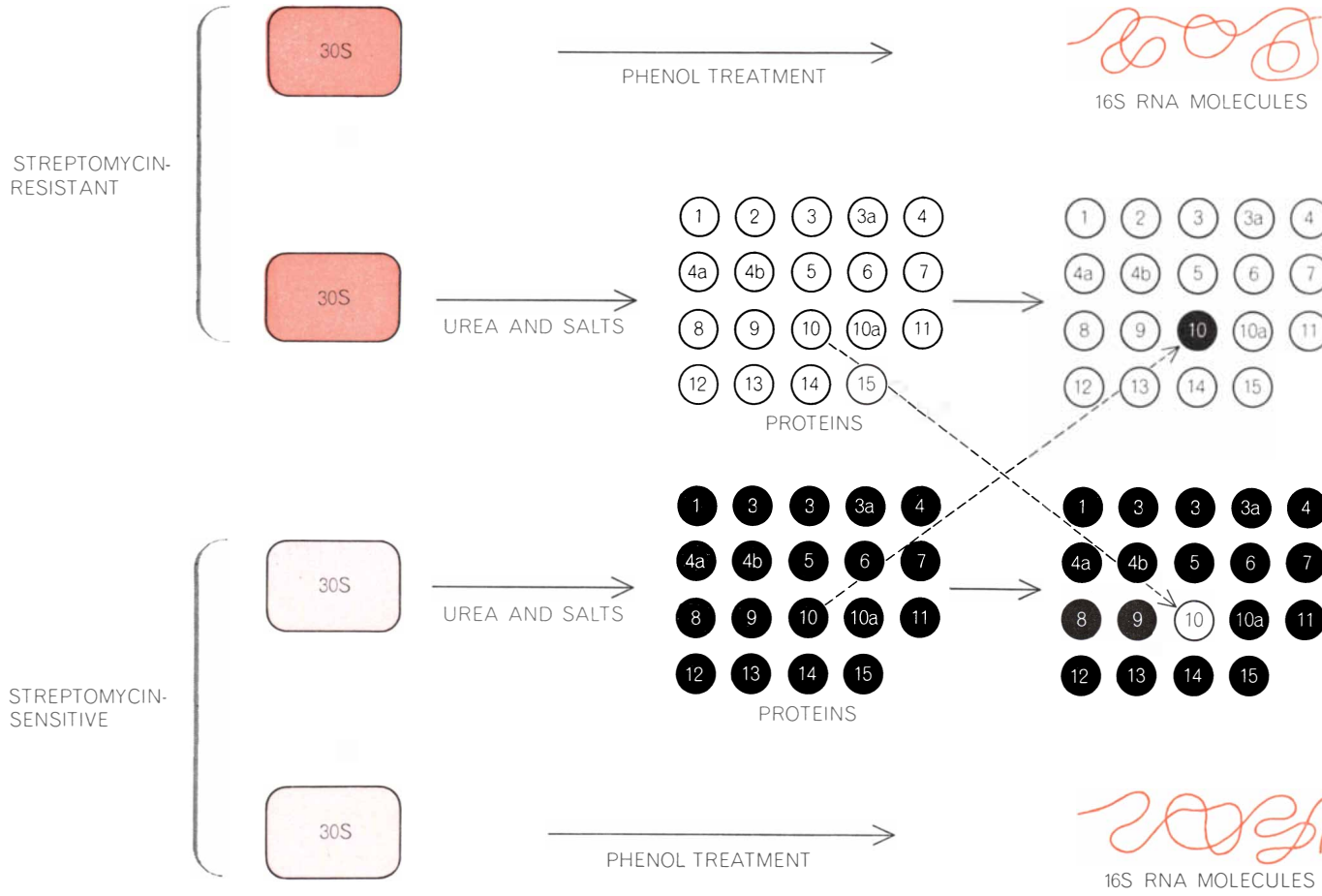
ALL THE PROTEINS normally found in a 30S subunit are found in a reconstituted 30S subunit, as shown by a comparison of electrophoresis results for the natural (*left*) and the reconstituted (*right*) particles. The protein mixtures are layered onto the top of a polyacrylamide gel column. When an electric current is applied, the proteins migrate down the column, each protein forming a band that moves at a different rate depending on the charge and the size of the molecule. Staining visualizes each protein.

activity is weak when directed by RNA from a natural source. It is known that a special mechanism for initiating protein synthesis is needed in the system directed by natural messenger RNA's but not in the system directed by synthetic messenger RNA's [see "How Proteins Start," by Brian F. C. Clark and Kjeld A. Marcker; SCIENTIFIC AMERICAN, January, 1968]; the *P*10-deficient particles cannot carry out this special initiating function.

The other interesting finding is that the frequency of translation errors with the *P*10-deficient particles is much reduced not only in the presence of streptomycin but also in the presence of certain other antibiotics, of ethyl alcohol or of high concentrations of magnesium ions, all of which are known to induce translation errors. In fact, the deficient particles read synthetic messenger RNA more accurately in the presence of error-inducing agents than normal ribosomes do even in the absence of such agents. In other words, it appears that protein *P*10 plays a role in increasing the frequency of errors in the translation of the genetic message. The inherent ability of ribosomes to make mistakes may be advantageous to bacterial cells, as Gorini suggested, since it can suppress the effects of harmful mutations. On the other hand, the property may simply be an unavoidable consequence of the complexity of the machinery.

Although we have not yet completed similar detailed analyses of all the proteins, preliminary experiments with them lead to certain general conclusions. Omitting any one of several proteins affects a number of known 30*S* ribosomal functions. Conversely, several different 30*S* ribosomal functions are affected by the omission of any of a number of proteins. That is, these functions seem to require the presence of more than one protein component, and so one can say that the 30*S* ribosomal proteins function cooperatively. We have also found that the omission of some proteins drastically affects physical assembly. Particles formed in the absence of one of these proteins are deficient in several other proteins, including some that were present in the reconstitution mixture. In other words, the presence of certain proteins is essential for other proteins to be bound. In this sense the assembly process itself is cooperative.

One of the most effective tools that are available for the study of a reaction is chemical kinetics, the study of the rate at which a reaction proceeds. Most chemical reactions have a distinct kinetic mode, or "order," which is determined experimentally from the reaction rate's dependence on the concentration of the reactants. Since the 30*S* reconstitution reaction involves at least 20 components, one might expect the rate to have a very high order of dependence on their concentration—so that doubling the concentration would increase the rate by as much as 2^{20}, or more than a million times! To be sure, this would be an absurdity, since it would mean that it was necessary for all the components to collide simultaneously in order to form a complete subunit, and subunit formation



ONE PROTEIN in the 30*S* subunit is responsible for the effect of streptomycin on ribosome functioning. Proteins and RNA are separated from subunits derived from bacterial cells that are resistant to streptomycin and from other cells that are susceptible to its effect. The proteins are isolated. When the protein designated *P*10 from susceptible cells is combined with all the other proteins from resistant cells and with the RNA from resistant cells, the 30*S* ribosomes that result turn out to be susceptible to streptomycin. On the

would be an incredibly rare event. As a matter of fact, most chemical reactions, even those involving a number of reactants, turn out to have a first-order or second-order dependence on reactant concentration (that is, doubling the concentration doubles or quadruples the reaction rate). The reason is that most complex reactions proceed in steps, with one unimolecular rearrangement or bimolecular interaction being slower than the others and hence determining the overall rate.

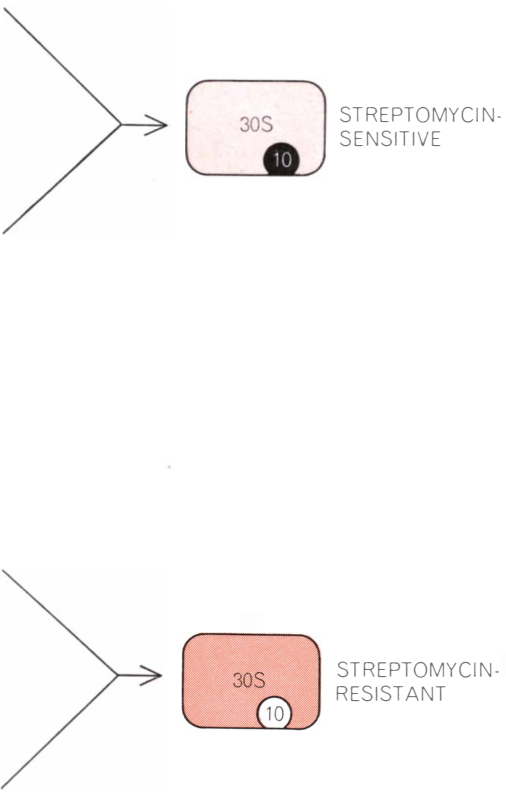
This generalization, however, has in the past applied to reactions involving far fewer components than are needed for reconstitution, and so we expected to find a somewhat higher order of reaction. We were rather surprised to observe that our assembly was in fact a first-order reaction; whether we double or halve the concentration of the reactants, the time it takes for all the components to assemble themselves into completed ribosomes is roughly the same—about five minutes under optimal conditions in the test tube. When one observes first-order kinetics in a reaction involving more than a single component, one can conclude that there is an intermediate step, involving a relatively slow rearrangement of a single component, that must take place before the reaction can be completed. This is exactly what we observe in the reconstitution reaction. The slow step in the assembly process may be occurring at any time before the binding of the 20 proteins to the RNA molecule is complete—after none of them or only some of them are bound—or after all are bound; in any case, our observation would be the same.

We had noted with interest that the reaction is extremely dependent on temperature. It turned out that a considerable amount of heat energy is required to effect the rearrangement of the unknown intermediate product—about 40,000 calories per mole of ribosomes. On the other hand, many of the proteins attach themselves in an ice-cold solution. We were therefore able to isolate the intermediate, activate it by warming the solution and then observe the almost instantaneous binding of the rest of the proteins to form a completed ribosomal subunit. And so we can describe the general nature of the pathway of self-assembly: a rapid binding of some of the proteins to the RNA, a slow structural rearrangement of this intermediate that requires thermal energy and then a rapid binding of the rest of the proteins.

After obtaining all this information on assembly in the test tube, one comes to an obvious question: Do the same principles operate in the living cell? The problem of ribosome synthesis in living cells was being attacked long before test-tube assembly was even seriously considered. The early work was done by the group including Britten, Brian J. McCarthy and Roberts at the Carnegie Institution, and they were followed by a number of groups, notably Shozo Osawa's in Japan and David Schlessinger's at Washington University. In a series of intricate experiments they delivered short pulses of radioactive components to growing bacterial cells and monitored the flow of the labeled components into ribosomes. It was possible in this way to postulate the presence of several classes of precursor particles, but it was difficult to isolate and analyze them. The obvious limitations of such an experimental approach encouraged investigators to seek other directions. One was genetics. Genetics has been a powerful tool for identifying the flow of intermediates in numerous biosynthetic pathways because one of the easiest ways to find out how something works is to see what happens when it does not work. For example, it should be possible to isolate mutants that are defective in a specific step in the biosynthesis of ribosomes; the step reveals itself by the accumulation of the precursor whose conversion is blocked by the mutational defect.

What was needed was a systematic method of isolating mutants defective in ribosome assembly. The trouble is that since ribosomes are essential for growth such mutants are ordinarily inviable and cannot be cultured. They can be isolated only as "conditionally lethal mutants": cells with defects such that the organism is inviable under one condition but functions normally under some other condition. As I have mentioned, in our detailed study of the test-tube reaction we had been struck by the remarkable dependence of the reaction rate on temperature. If the same principle operated in living cells, we reasoned, then many mutational defects in ribosomes or in related components should manifest themselves more severely at lower temperatures, and so some assembly-defective mutants should be conditionally lethal—viable at high temperatures but inviable at lower temperatures. They could therefore be isolated as cold-sensitive mutants.

Our reasoning proved to be correct. Christine Guthrie, Hiroko Nashimoto and I have isolated a large number of cold-sensitive mutants of *E. coli,* a significant fraction of which appear to be defective specifically in ribosome assembly. (Independently John L. Ingraham and his co-workers at the University of California at Davis have found abnormal ribosome biosynthesis at low temperatures in cold-sensitive mutants of the related bacterium *Salmonella typhimurium.*) By sucrose-gradient sedimentation we have already identified three distinct classes of particles, from three different mutants, that accumulate in cells grown at 20 degrees C. Two of these particles appear to be precursors of 50S subunits; the third appears to be a 30S precursor. While proceeding with the biochemical characterization of these particles we are also conducting genetic analyses of the various mutants in the hope of obtaining information on the genetic organization and genetic control of the ribosome and of ribosome assembly. We hope that through the coupling of genetic techniques with the biochemical techniques of test-tube reconstitution this sophisticated and complex cellular instrument will soon be understood on a truly molecular level.



other hand, when *P*10 is derived from resistant cells and all the other components are taken from susceptible cells, the resulting subunit is resistant to streptomycin.

ACOUSTICAL HOLOGRAPHY

By "illuminating" an object with pure tones of sound instead of with a beam of coherent light one can create acoustical holograms that become three-dimensional pictures when viewed by laser light

by Alexander F. Metherell

Optical holography, the technique for making three-dimensional pictures with the aid of laser beams, has given rise to a new form of holography in which sound waves instead of light waves are used to create the initial hologram. A laser beam is then employed to reconstruct, or translate, the acoustical hologram into a recognizable pictorial image. In other words, acoustical holography makes it possible to create an optical wave-field analogue of an acoustical wave field. Since sound waves can penetrate opaque objects ranging from living tissues to metal structures, the new imaging technique has promising applications in many areas of medicine and technology.

Optical holography, sometimes called the wave-front reconstruction process, became practical with the development of the laser, which provides an intense light source whose waves are coherent, or in step. An optical hologram is formed by directing a laser beam at an object and recording on a photographic plate the interference patterns produced when the light waves reflected from the object interact with a portion of the undisturbed laser radiation, which serves as a reference beam. Although the hologram produced in this fashion appears to be a meaningless jumble, it actually contains in coded form all the information the eye would intercept if it were located at the position of the photographic plate. The code can be broken by illuminating the hologram with another laser beam, which reconstructs the original scene.

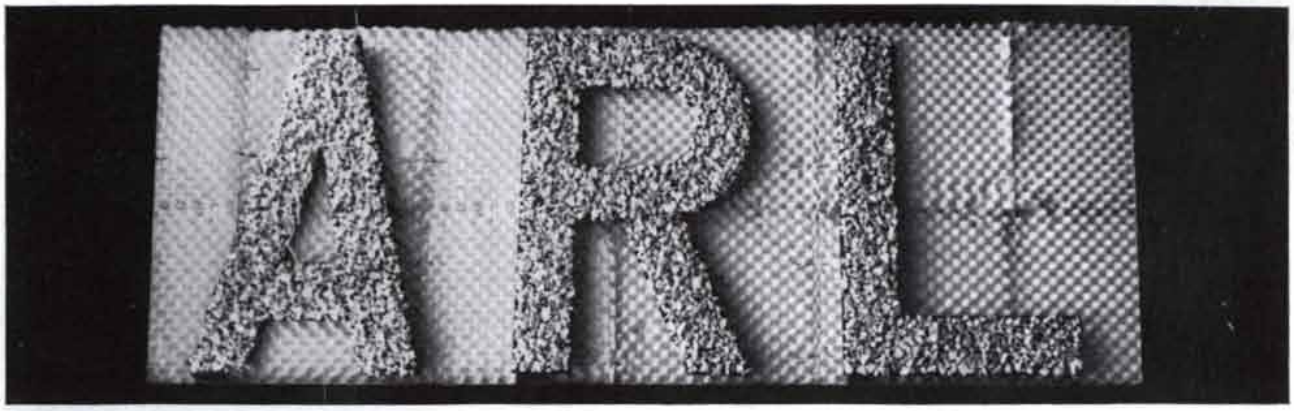
In order to produce an acoustical hologram the scene to be recorded is "illuminated" with a pure tone of sound instead of a laser beam. The objects in the scene disturb the sound waves and produce interference patterns analogous to those produced by light waves. As we shall see, it is not always necessary to use a reference beam in acoustical holography, and the hologram pattern can be recorded in various ways. Once recorded, the acoustical hologram can be reconstructed with a laser beam exactly as if it were an optical hologram.

What are the advantages of using sound instead of light? The interaction of sound with solids and liquids is different from the interaction of electromagnetic radiation. Sound can travel a considerable distance through dense, homogeneous matter and lose little energy, and yet it will lose a significant amount of energy when it passes through an interface. This loss is due to reflection at the interface. In contrast, electromagnetic radiation such as X rays will lose a significant amount of energy passing through matter and yet lose a negligible amount at an interface. Therefore sound can be singularly effective in medical diagnosis, in nondestructive testing and in seeing underwater and underground because it is mostly the discontinuities of internal organs, tumors, flaws, submerged objects or subterranean strata, rather than the bulk matter, that is of interest to the observer.

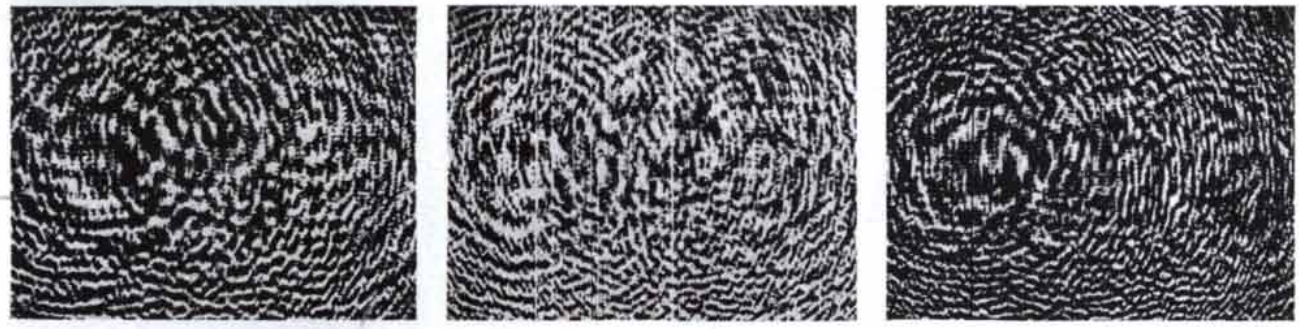
Acoustical imaging is of course not new; there are sonar devices that produce pictures similar to those on a radar screen. This type of imaging is currently employed in prospecting for oil and minerals. Similar scanning methods are also being used by physicians for the detection of brain tumors and for examining the unborn child. In these applications the sound usually has a frequency of between one million and 10 million cycles per second. Another conventional acoustical imaging technique employs what may be best described as an acoustical camera. In this method sound waves bounced off an object are focused with an acoustical lens onto an image converter that translates the pattern of sound intensity into a pattern of visible light.

The limiting feature of both of these conventional sound-imaging methods is that the images show only two dimensions. They are two-dimensional because the methods detect only the intensity (the square of the amplitude) of the sound waves in the sound images. What these methods are unable to record is phase information, that is, the arrival time of the crest of the wave from the object with respect to the arrival time of the crest of a reference wave of the same frequency. The most powerful feature of holography is that phase information as well as intensity information is retained in the hologram and can subsequently be "played back" in the optical image, with the result that the optical image is three-dimensional. Thus in acoustical holography there is a total transfer of information from the acoustical wave field to the visible optical wave field.

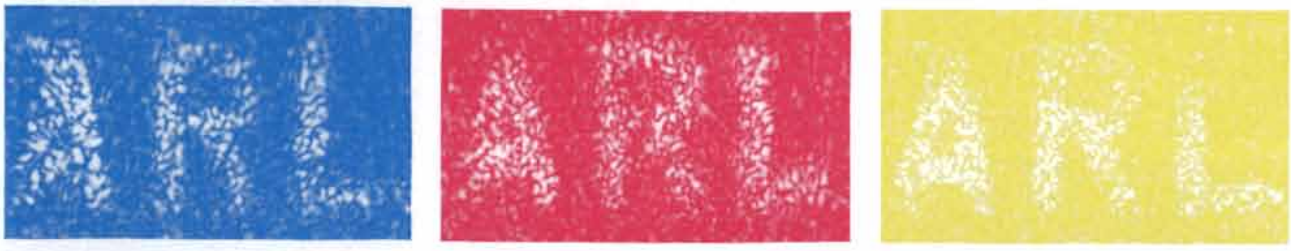
The simplest way to understand how a hologram works is to think of it as a coded diffraction grating. Consider first of all a simple point object that is illuminated by a plane wave produced by a coherent source at infinity [*see illustration on page 40*]. The point object scatters part of the wave, which then radiates spherically away from the point object. Both the spherical (object) wave and the plane (reference) wave fall on a plane that is perpendicular to the direction of propagation of the reference wave. At some points on the plane the object wave is in phase with the reference wave, so that the two waves constructively interfere with each other and are therefore added together to increase the wave amplitude. At other points on the plane the object wave is out of phase



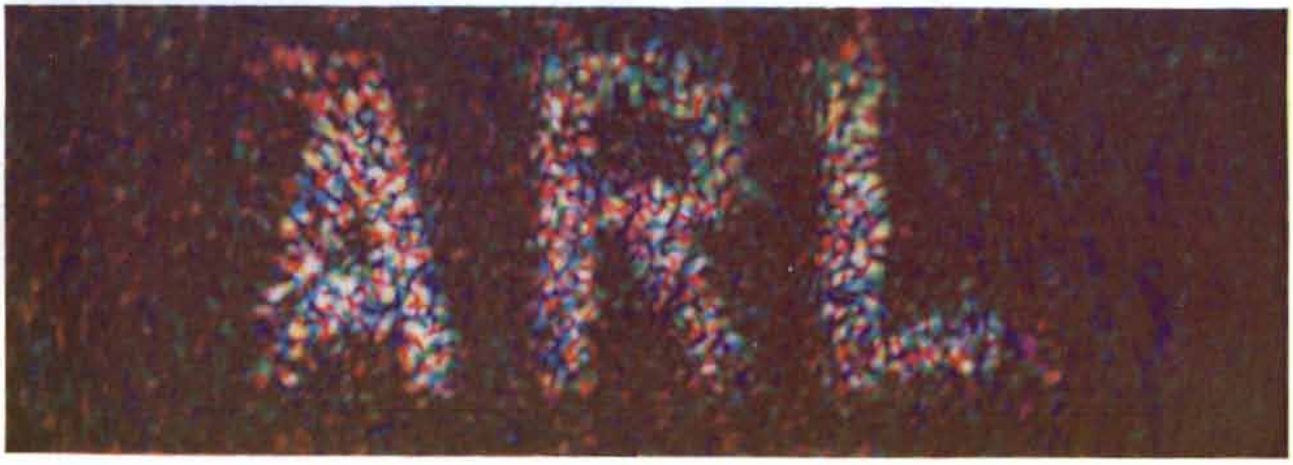
SUBJECT OF ACOUSTICAL HOLOGRAM, reconstructed in three colors at the bottom of the page, was a group of three letters formed from pebbles of various sizes. The holograms (*below*) were made by sound waves of 15,000, 18,000 and 21,000 cycles per second.



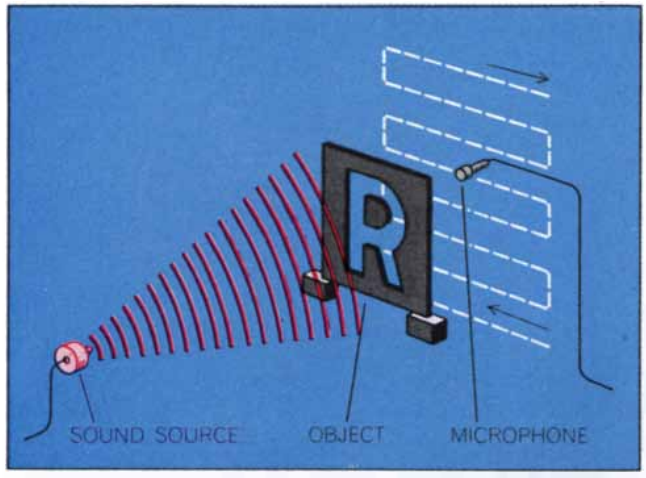
ACOUSTICAL HOLOGRAMS, one for each wavelength, are the electronic analogues of the reflected interfering sound waves as they appear on a cathode ray tube. A three-color montage of these three images is on the cover of this issue of SCIENTIFIC AMERICAN.

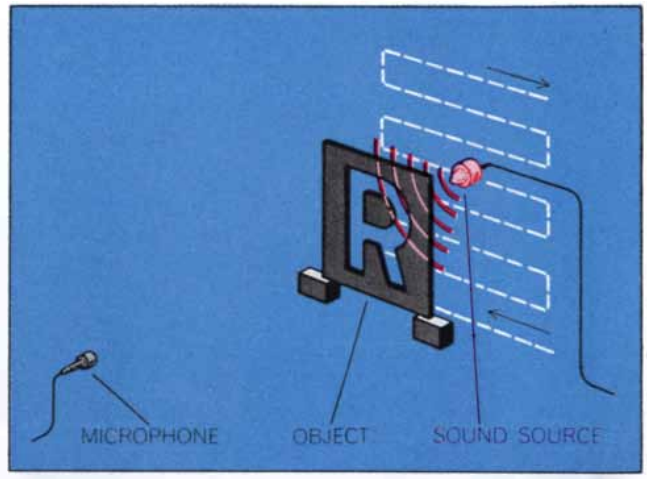


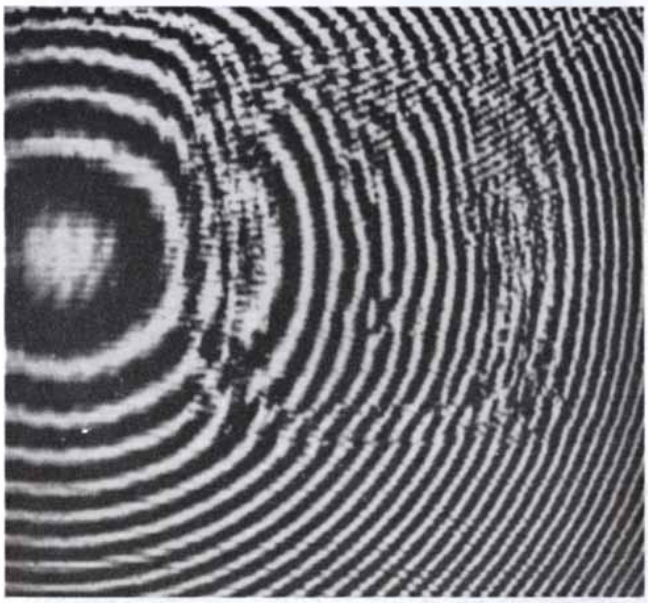
RECONSTRUCTED IMAGES FROM HOLOGRAMS are made by shining a coherent beam of laser light through black-and-white transparencies of the holograms. Here the reconstructed image of the hologram made with sound of 15,000 cycles is printed in blue ink, the one made with sound of 18,000 cycles is printed in red and the image made with sound of 21,000 cycles is printed in yellow.

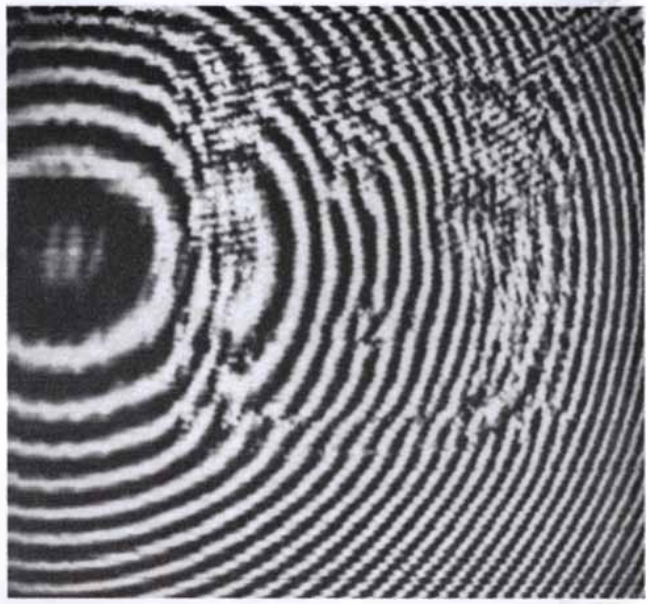


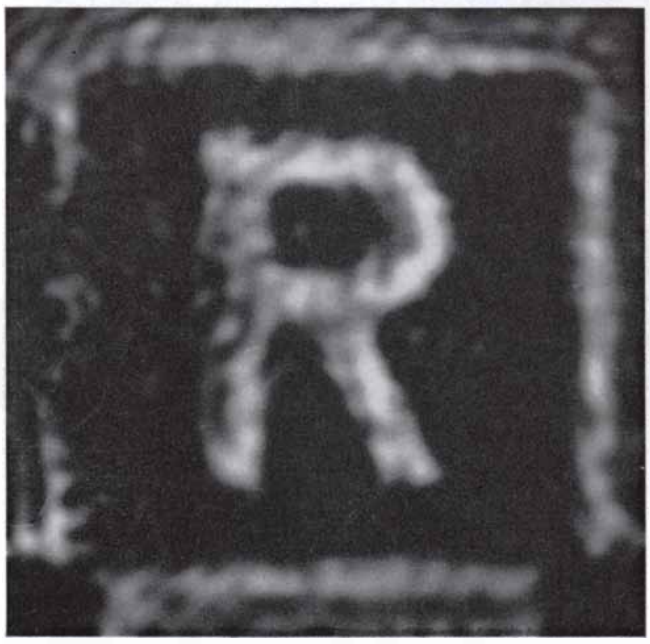
FINAL THREE-COLOR RECONSTRUCTION of the pebble pattern is made by superposing the blue, red and yellow reconstructed images. The hard surfaces of the pebbles reflected the three wavelengths of sound about equally. The letters stand for Advanced Research Laboratories of the McDonnell Douglas Corporation, where these images were made by the author, Sidney Spinak and E. J. Pisa.

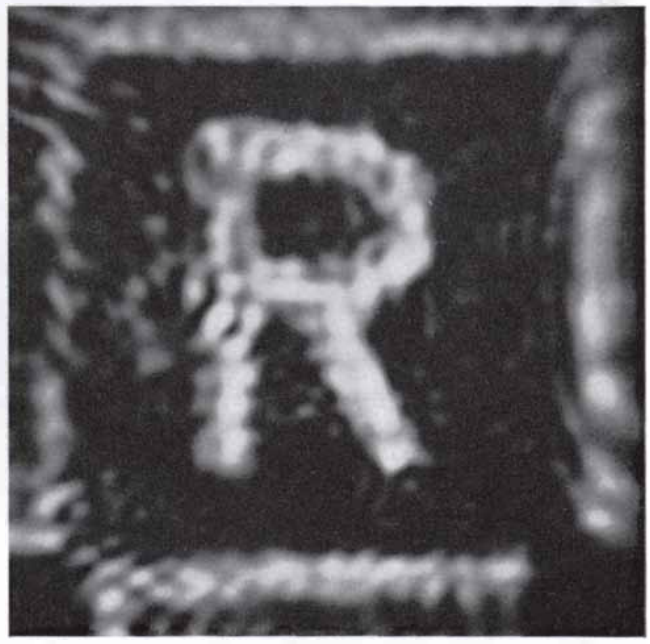












EQUIVALENT HOLOGRAMS and reconstructions are obtained whether the microphone is moved in a raster pattern while the source is stationary (*left column*) or whether the sound source is moved while the microphone is held stationary (*right column*). The object scanned in both cases is a cutout of the letter *R* in a panel four feet on a side. The acoustical holograms are the two images in the middle of the page; the laser-beam reconstructions are at the bottom. The experiment was done by the author and Spinak.

with the reference wave, so that the two waves destructively interfere, thereby canceling each other and decreasing the wave amplitude. If we record the amplitude (intensity) in the plane as variations of density on a photographic plate, the resulting pattern will be a continuous set of concentric circles centered on the point on the plane that is obtained by projecting a line from the light source through the point object onto the plane. This pattern closely resembles a Fresnel zone plate, an optical device in which a round bull's-eye is surrounded by concentric rings of regularly decreasing thickness. In the point-object hologram, however, the density of the rings varies outward from the center in a sine-wave pattern, and simultaneously the frequency of the sine wave increases.

A well-known property of a zone plate is that the diffraction effects of the rings will cause the plate to act as a lens. When illuminated with a wave, the zone plate will focus the wave. However, it acts simultaneously as if it were both a positive and a negative lens. If the holographic zone-plate pattern is illuminated by the plane (reference) wave alone, the negative-lens effect of the zone plate will cause a diverging spherical wave to emerge from the plate, thereby producing a "virtual" image of the point in the same position the point object originally occupied. At the same time the positive-lens effect will create a converging wave that will produce a real image of the point.

Hence the wave that emerges from a hologram has three components. First there is the attenuated part of the illuminating wave that passes right through the hologram. This is called the zero-order wave. Second there is the diverging spherical wave that appears to come from the virtual image of the point. This is a first-order diffracted wave that is the true reconstruction of the original spherical wave that radiated from the point object when the hologram recording was made; it is called the true reconstructed wave. Third there is the converging spherical wave that forms the real image of the point. This too is a first-order diffracted wave, but because it is opposite in curvature to the diverging wave it is called the conjugate wave.

The two images the hologram produces are normally such that one is a virtual image located where the original object used to be and the other is a real image formed on the other side of the hologram. Under certain circumstances, however (by illuminating the hologram with a spherical wave instead of a plane parallel beam), both images can be virtual or both can be real. Therefore it is confusing to name them the virtual and the real images. To avoid this confusion one is called the true image (resulting from the true reconstructed wave) and the other is called the conjugate image (resulting from the conjugate wave).

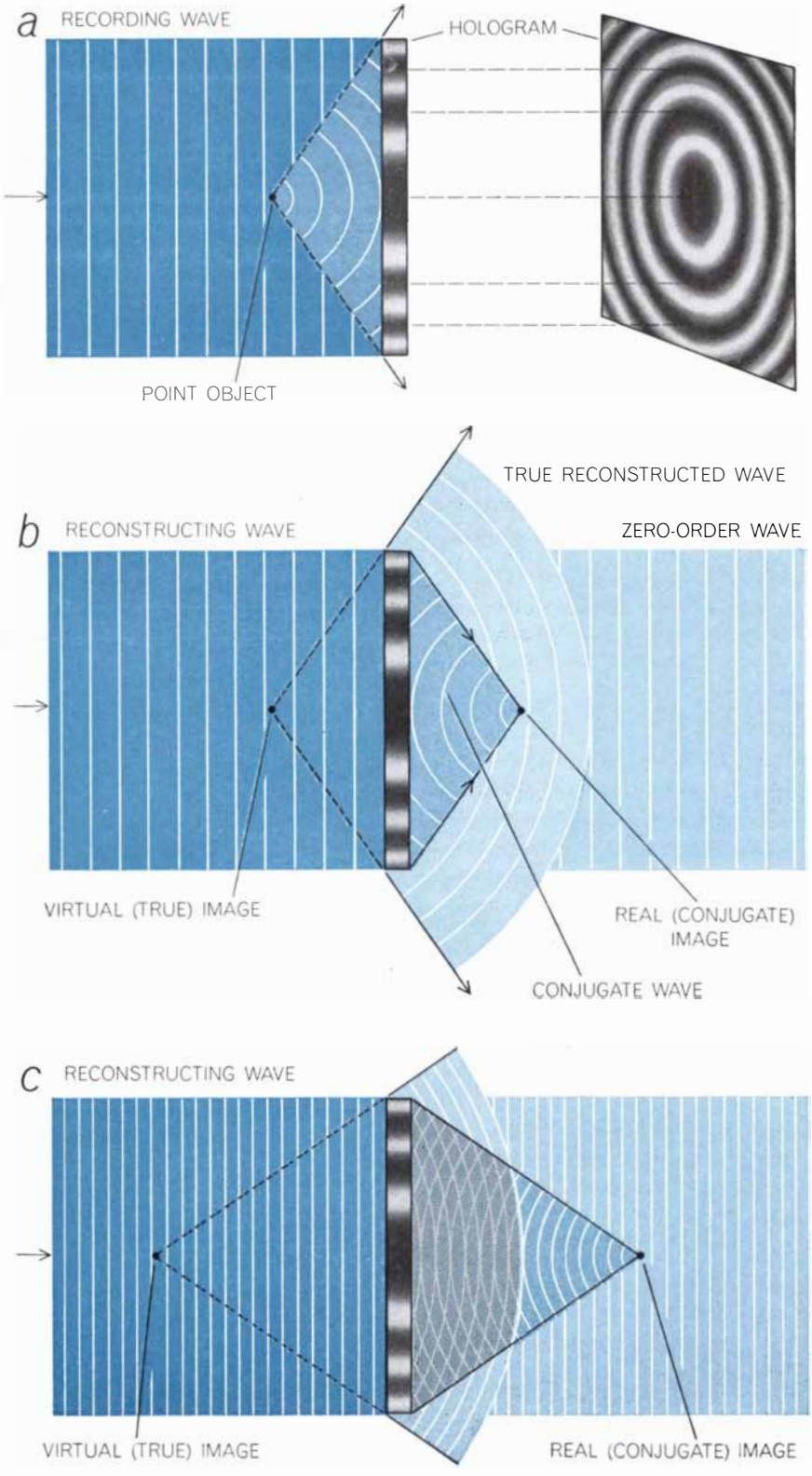
Let us now consider what happens when the hologram is illuminated with a beam whose wavelength is shorter than the wavelength used to record the hologram zone-plate pattern. In diffraction the angle of the diffracted wave increases or decreases as the ratio of the wavelength to fringe (ring) spacing increases or decreases. If the hologram is illuminated with a wavelength shorter than the recording wavelength, the result is a decrease in the diffracted angle of the emerging diffracted wave fronts. The true and conjugate waves diverge and converge more slowly and therefore form their true and conjugate images farther away from the hologram, but they are still formed on the axis that passes through the center of the hologram zone-plate pattern.

So far I have discussed only the hologram created by a simple point object. The holography of complicated objects, such as the figurines and chessmen commonly used to demonstrate optical holography, can be as easily understood by thinking of their complicated surfaces as being made up of a large number of point objects. Each point on the surface of the complicated object forms its own hologram zone-plate pattern superposed on all the other zone-plate patterns from all the other points on the object. The resulting hologram then has the appearance of an unintelligible mass of broken fringes and grainy blobs, but in reality each zone-plate component acts independently of all the others in the reconstruction process to reproduce its individual point on the surface of the object image.

Inasmuch as a hologram can be recorded at one wavelength and reconstructed with a different wavelength, it follows that a hologram can be recorded using single-frequency acoustical waves and reconstructed with laser light. The main effect of this is that the resulting visual image is distorted because of the difference in wavelength between the sound used to record the hologram and the light used to reconstruct it. The illustration on page 41 shows how a simple arrangement of three points is stretched out in one direction (along the axis of the recording beam) when the reconstructing wavelength is shorter than the recording wavelength. The stretching out, or longitudinal magnification, is equal to the ratio of the recording wavelength to the reconstructing wavelength. When the recording wavelength is sound at a million cycles per second in water and the reconstructing wavelength is the red light from a helium-neon laser, the image will be stretched out some 500 times. This results in an apparent (but not actual) loss of the three-dimensional effect that is so dramatic when an observer views the reconstruction of a conventional optical hologram. The longitudinal distortion has led some people to consider that the images obtained from acoustical holograms are two-dimensional. This is not true. One can still focus on different planes in the image and perform optical data-processing operations (such as spatial filtering) to improve the images. A number of methods have been suggested for eliminating the distortion but none is completely satisfactory.

The three-dimensional perception obtained in viewing the true virtual image in a conventional optical hologram is largely due to the parallax effect obtained when the viewer moves his head from side to side and looks through different parts of the optical hologram. In each viewing position the image seen is formed by an area on the hologram represented by the diameter of the viewer's pupil. Hence from each viewing position only a small part of the total hologram area is used. This works well enough with an optical hologram because the resolution, or image quality, obtained with an aperture equal to the pupil diameter is perfectly acceptable since the optical hologram was recorded at optical wavelengths. Image resolution is directly related to the ratio of aperture to recording wavelength.

Since the wavelengths used to record acoustical holograms are so large compared with the aperture of the eye, the image resolution provided by an acoustical hologram would be completely unacceptable if one simply viewed it with the unaided eye. Accordingly (disregarding the longitudinal image distortion problem) it may never be feasible to use the parallax effect in viewing the reconstructed image from an acoustical hologram. To obtain acceptable image quality in the reconstruction the viewing aperture must approach the size of the entire hologram. As a result the observation of the reconstructed images from an acoustical hologram will most probably always be done by using the entire hologram and observing the real image as it is focused on a screen. The ob-



OPTICAL HOLOGRAM OF POINT is a series of concentric rings (*a*) representing the intensity pattern that results when the waves scattered from the point are summed with the crests or troughs of the plane recording wave, which acts as a reference wave. The hologram is reconstructed (*b*) by illuminating it with the reference wave alone. The diffraction effect of the hologram fringes causes two first-order diffracted wave fronts to emerge in addition to the attenuated zero-order wave. One is the true reconstruction of the original object wave, which forms a virtual (true) image of the point at its original position. The other wave front is the conjugate reconstructed wave, which forms a real (conjugate) image of the point. If the hologram is illuminated with a wave that has only half the length of the original wave (*c*), the reconstructed images are shifted to twice their normal distance.

servational benefit of the third dimension in the image comes from being able to move the screen throughout the depth of the image.

The methods available for recording acoustical holograms are numerous because of the many different methods that are available for recording sound. In optical holography a photographic plate is normally used to record the hologram. To record an acoustical hologram it is necessary to have an acoustical equivalent of the photographic plate. A natural first approach is to see if sound can be recorded directly on photographic film. It can be. A piece of photographic film that has been exposed to light can be placed in a weak fixing solution. If, while the film is in the fixing bath, it is exposed to high-intensity sound, the regions of high sound intensity speed up the fixing process. Subsequent development of the differentially fixed photographic film yields an image corresponding to the sound levels at its surface. This method has been used to record acoustical hologram interference-fringe patterns. The method has serious limitations, however, because the recording sound must be very intense indeed (about one watt per square centimeter), and even then exposures typically run to 30 minutes.

Another method involves placing a starch plate in an iodine solution. Exposure to sound causes the iodine to stain the starch, thereby recording the sound pattern. Here again high intensity levels and long exposure times are required.

If a high-frequency sound source, for example a piezoelectric transducer vibrating at a frequency of five million cycles per second, is placed in a tank of water and aimed toward the surface, the water will bulge up where the sound hits the surface. If two such high-frequency sources are submerged and pointed toward the surface, the acoustical beams will interfere and the resulting interference pattern will reveal itself as a stationary ripple pattern. If an object is now placed in one of the beams, the ripple pattern on the surface will be the hologram of the object.

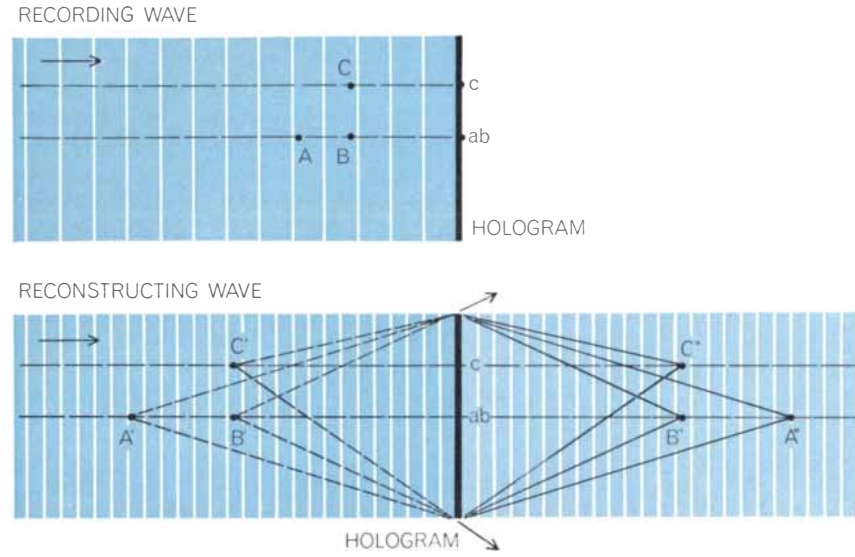
Such an image can be reconstructed by two methods. The first is a "real time" method that merely involves illuminating the surface with a laser. The ripple pattern acts much as an optical phase hologram; the true image of the object appears below the surface and the conjugate image appears as a real image above the surface. The longitudinal distortion, which is due to the difference

between the acoustical and the optical wavelengths, causes the reconstructed images to appear much farther from the surface than the actual object is. The second method is to photograph the ripple pattern, thereby obtaining a hologram that can be reconstructed in the usual manner.

When the first method is used, the longitudinal distortion introduced by the disparity in length between sound waves and light waves will ordinarily shift the reconstructed image so far from the surface that it must be viewed with a telescope. The need for a telescope can be avoided, however, by placing an acoustical lens between the object and the surface in such a way that the three-dimensional image formed by the lens is projected onto the surface. The reference wave remains as before but the hologram is now a focused hologram, so that on reconstruction the reconstructed image appears in the surface [*see illustration on next page*]. In early experiments acoustical lenses created serious aberrations in the holographic image, but recent work with liquid-filled acoustical lenses has led to quite satisfactory results.

Two major problems arise from the use of a water surface. First, the surface is very sensitive to unwanted vibrations and to larger-scale motions that break up the ripple pattern. Second, the object beam and reference beam must be reasonably well balanced in intensity at the surface. Otherwise streams form on the surface, and they also break up the hologram ripple pattern. This limits the usable area of the water surface, which in turn limits the aperture and hence the quality of the final reconstructed image. The technique has been improved by covering the water surface with a thin membrane and placing an oil film a few millimeters thick on top of the membrane so that the ripple pattern forms on the oil surface instead of on the water. When the oil-film method is combined with the newer types of acoustical lens, and when the sound is pulsed in short bursts, the practicability of the ripple technique is greatly enhanced.

Recently this method has been used to record some of the best reconstructed images obtained so far. A group under the direction of Byron B. Brenden at the Pacific Northwest Laboratory of the Battelle Memorial Institute has produced a motion-picture film that shows the real-time acoustical holographic image of a goldfish made with sound at a frequency of nine million cycles per second. The skeleton of the fish and its denser internal organs are clearly visible [*see top illustration on page 43*]. The motion of the internal organs, the opening and closing of the fish's mouth and the raising and lowering of its dorsal fin are all vividly represented. Such a real-time system, which allows the observer to follow the motion of the object and thus assists in its interpretation, has great merit. Image interpretation can prove to be difficult if the observer is viewing a stationary image. These and other results demonstrate beyond doubt that acoustical holography can be of significant value in medical diagnosis.



LONGITUDINAL DISTORTION occurs in acoustical holography because the reconstructing light waves from a laser are much shorter than the acoustical waves used for recording. Here the depth separation between two points, *A* and *B*, is magnified twofold because the reconstructing wave is only half the length of the recording wave. In actual reconstructions of acoustical holograms the longitudinal distortion often exceeds 500 times.

There are other methods for recording the holograms produced on or immediately below a liquid surface. These include mechanical scanning of a detector below the liquid surface and the electronic scanning of a piezoelectric transducer. These methods, however, offer no significant advantages over the method I have described. I shall therefore pass on to an experimental technique for scanning acoustical images formed in air that has been used by our group at the Douglas Advanced Research Laboratories of the McDonnell Douglas Corporation. There are no obvious praetical applications for the air-scanning method because the wavelengths employed are some 20 to 100 times longer than those readily generated in water, with the result that resolution is much inferior. (The wavelengths in air lie between 29 and 14 millimeters, corresponding to sound frequencies between 12,000 and 25,000 cycles per second.) Nevertheless, the air-scanning method has proved to be a flexible laboratory tool for investigating different aspects of acoustical holography.

In a typical experiment the object to be scanned is a letter of the alphabet cut out of a sheet of Masonite a few feet square. The sound source is placed on one side of the sheet and the scanning microphone is moved through a raster pattern on the other side. The output of the microphone modulates the intensity of a spot on a cathode ray tube, and a time exposure of the face of the tube provides the hologram.

One might wonder what would happen if the microphone were held stationary and if the sound source were moved through the raster pattern. One can appreciate that when the sound source is stationary the interference pattern of sound waves on the far side of the object is "frozen" in space. The role of the microphone is to sample a particular plane of this frozen pattern. If, however, the microphone is fixed and the source is moved, the interference pattern in the plane in which the microphone is now located must change from moment to moment.

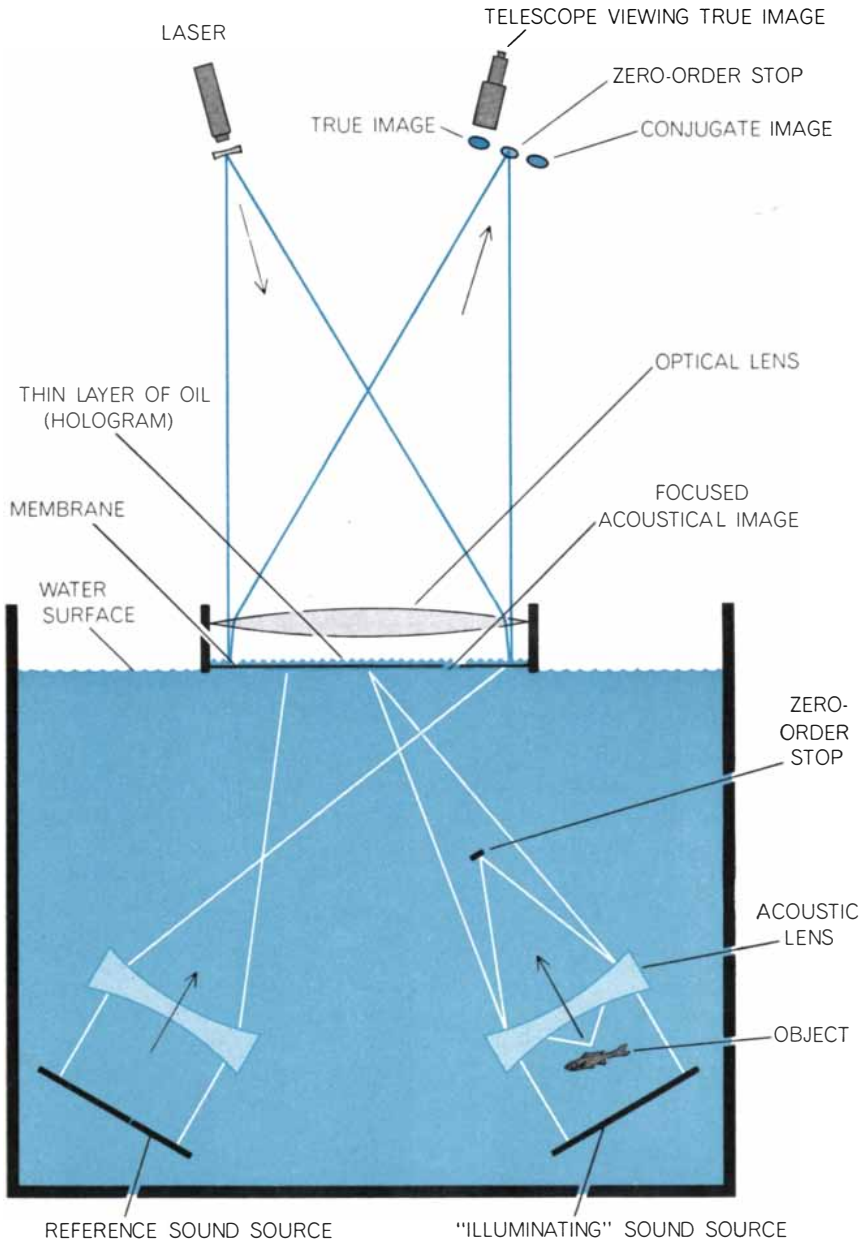
Will the hologram recorded under these constantly changing conditions resemble the one created when the microphone travels through the frozen pattern? Surprisingly (although there is really no reason for surprise), the two pat-

terns are identical, as are the images reconstructed from them [*see illustration on page 38*]. This experiment shows that when a single-point source is used to illuminate an object acoustically and a single-point detector is used to scan the resulting hologram, there is a reciprocal relation between the source and the detector. That is to say, the detected phase and the amplitude will remain unchanged if the source and the detector are physically transposed.

In another series of experiments we scanned the wave pattern not transmitted by an object but reflected from it to produce the hologram. Here the object was the three letters *A*, *R* and *L* (standing for Advanced Research Laboratories). Each letter consisted of a mosaic of pebbles of various sizes and was about four feet tall. We wanted to see how the holograms would differ if we illuminated the letters with sound of three different wavelengths. In order to make these differences apparent we planned to print each of the reconstructions in a different color and so obtain, when the images were superposed, a single reconstruction in three colors.

To make the sound-to-color analogy complete we chose wavelengths of sound that bear the same relation to one another as the wavelengths of the primary colors blue, green and red. The approximate dominant wavelengths for these three colors are 420, 525 and 630 nanometers, and they are in the ratio 4:5:6. Accordingly we selected sound wavelengths of about 16, 20 and 24 millimeters, corresponding to frequencies of 21,000, 18,000 and 15,000 cycles per second.

As we had expected when we planned the experiment, a target consisting of hard pebbles acts as a "white" reflector of sound, with the result that the holograms at each wavelength are very similar and the letters in the final three-color reconstruction contain roughly equal amounts of each color [*see illustration on page 37*]. In three-color printing the primary colors red, green and blue are reproduced by mixtures of their complementary colors: cyan ("blue"), magenta ("red") and yellow. To create the pattern on the cover of this issue of *Scientific American* the three acoustical holograms were superposed and printed in colors corresponding to the wavelengths of the sound that produced them. If the pattern on the cover were reproduced in the form of a color transparency and were illuminated with a coherent beam of white light (in the form of a balanced mixture of coherent red, green and blue light), the letters *ARL* in the resulting reconstruction would appear white.



LIQUID-SURFACE ACOUSTICAL HOLOGRAPHY provides interference patterns that can be reconstructed instantaneously. The focused acoustical image of the object forms diffraction fringes with a reference beam at the surface of an oil film, after being transmitted through the water and a membrane. The acoustical image of the object coded in the oil "hologram" is decoded continuously by a laser beam and viewed through a telescope.

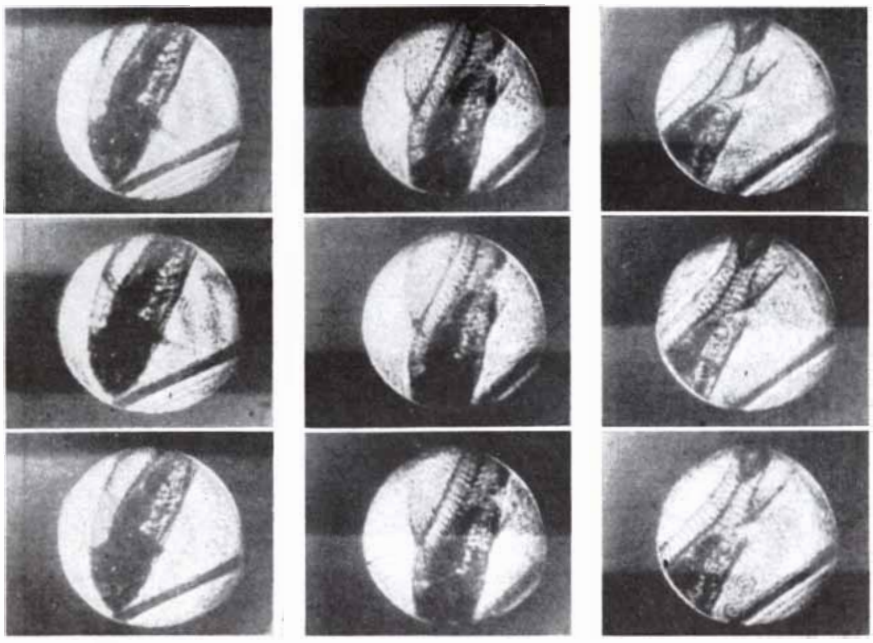
In early experiments with acoustical holography the methods used were straightforward acoustical analogues of optical methods. It gradually became apparent, however, that entirely new techniques could be introduced that have no equivalent in optical holography. For example, when electronic detection is used, the output from the detector (microphone) is an electrical signal of the same frequency and phase as the acoustical signal. Therefore, instead of mixing the acoustical object wave with an acoustical reference wave and sensing the sum of the two, the reference wave can be simulated electronically by detecting the acoustical object wave alone and adding the electrical output from the detector to an electrical reference signal. This signal is taken directly from the electronic signal generator used to power the illuminating sound source. The electronic summation then corresponds to the interference between the object wave and the reference wave. Electronic simulation of the reference wave is now almost invariably used.

Another major advantage of this kind

of detection is that one can perform operations on the detected object signal before it is added to the electronic reference signal. We have performed such operations in investigating the relative importance of the two components in the object wave that are normally recorded in a hologram: phase and amplitude. This has led to the recording of phase-only acoustical holograms. The phase-only hologram is made by taking the electrical object wave, whose amplitude and phase vary as the detector scans, and setting the amplitude at a constant value (no matter how much the acoustical amplitude varies) but retaining the phase of the object wave. The resulting phase-only hologram is recorded by summing this constant-amplitude object signal with a constant-amplitude reference signal. The phase-only hologram differs in appearance from the conventional hologram only in that the contrast of the interference fringes is constant over the hologram plane instead of varying in contrast. (The variations in the conventional acoustical hologram correspond to variations in amplitude of the object wave.) The reconstructed images from phase-only holograms are generally sharper at the edges than reconstructions from conventional acoustical holograms [*see upper illustration on next page*]. Moreover, the relative acoustical brightness scale in the object is retained in some cases.

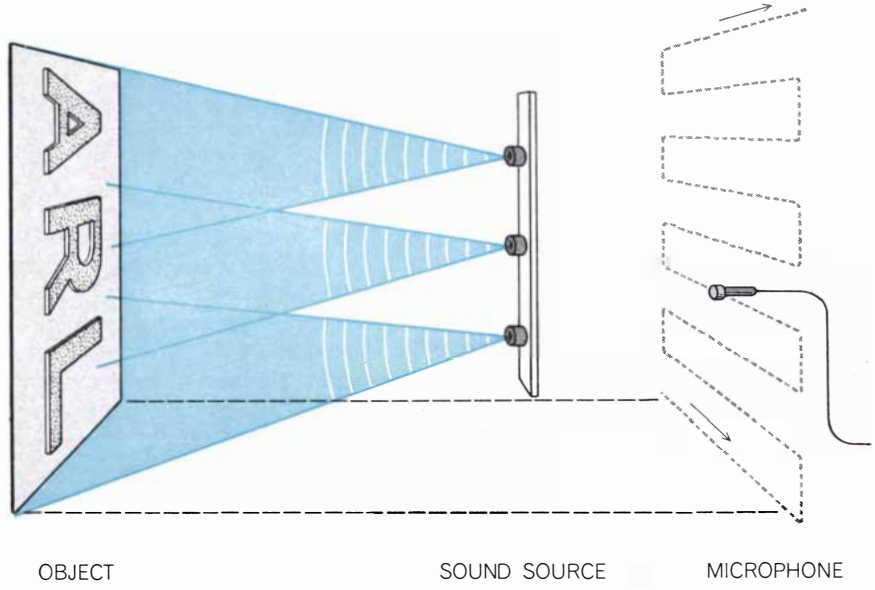
Another trick that is possible with sound waves but not with light waves has led to the development of a new technique called temporal reference holography. As the term indicates, the object wave is recorded with respect to the time at which the recording is made rather than with respect to a reference wave. This is done by recording the pressure potential of the acoustical object wave at some selected instant within the acoustical cycle. The main advantage that temporal reference holography has over conventional acoustical holography is a much higher recording speed, which provides more satisfactory images of moving objects.

The Douglas Advanced Research Laboratories are now working on a technique suitable for medical diagnosis in which temporal reference acoustical holograms generated by sound waves with a frequency of one million cycles per second can be recorded in half a millionth of a second. The technique applies a new form of optical interferometric holography called subfringe interferometry, a term indicating that the displacements recorded are less than one optical wavelength. This is in contrast to conventional interferometry, where the displacements are many optical wavelengths.

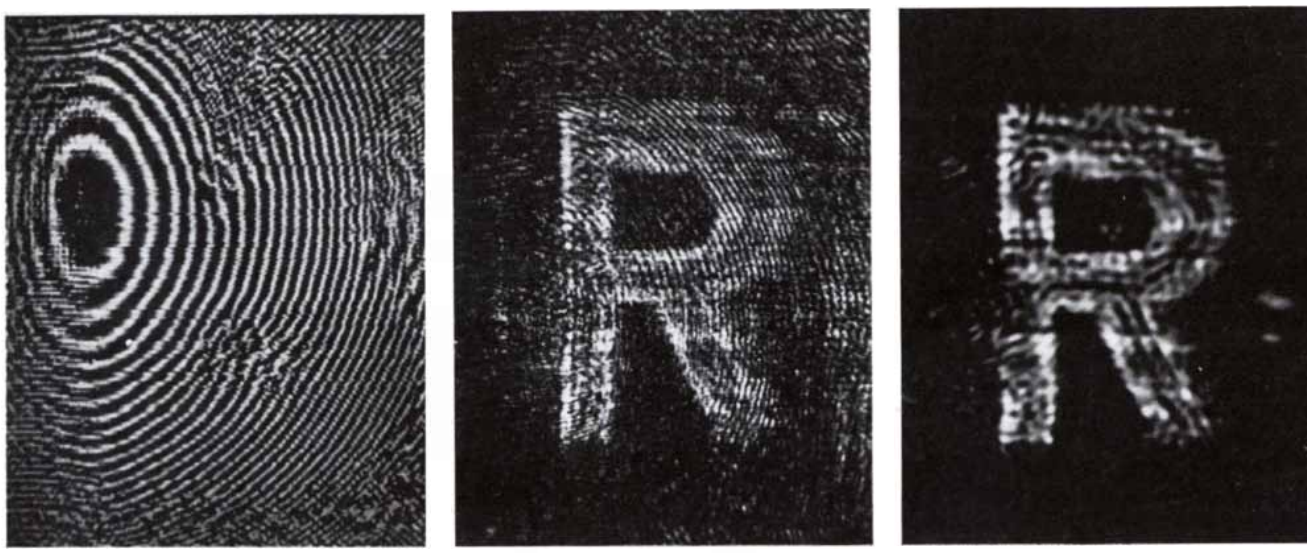


ACOUSTICAL VIEW OF GOLDFISH was provided by the liquid-surface method of holography illustrated on the opposite page. The 16-millimeter movie camera that recorded these reconstructions of the holograms as they were displayed on a television screen was not quite synchronized with the television frame rate, hence the light and dark bands. The system was developed by Byron B. Brenden and Gary Langlois at the Pacific Northwest Laboratory of the Battelle Memorial Institute. The work was sponsored by the Holotron Corporation.

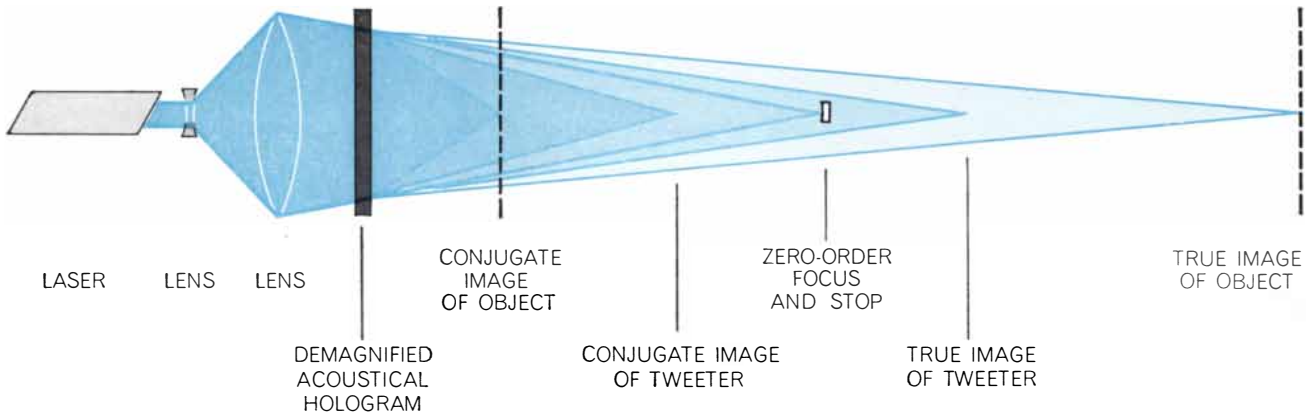
Briefly, the method works as follows. The acoustical object wave is allowed to fall on a surface, causing it to vibrate with an amplitude much less than an optical wavelength. This surface is slightly deformed by the acoustical wave striking it. The deformation is recorded by shining a pulsed laser on the surface and making an optical hologram of it on a photographic plate. After half an acoustical cycle has passed (that is, half a mil-



HOLOGRAPHIC PATTERN IN AIR was scanned to make the holograms reproduced on page 37. The letters *ARL*, formed of pebbles, were "illuminated" by three "tweeters," all operating in phase at the same frequency. The pattern of the reflected sound waves was scanned by a microphone and processed in a circuit that provided the electronic equivalent of a reference beam. The summed output wave was then displayed on a cathode ray tube and photographed. Holograms were recorded at 15,000, 18,000 and 21,000 cycles. The method of reconstructing the holograms is depicted in the lower illustration on the next page.



CUTOUT OF LETTER *R* was "illuminated" with a tweeter operating at 18,000 cycles per second, using the arrangement shown on page 38. In this case, however, the intensity of the holographic pattern was held constant electronically and only the phase information was recorded, producing a phase-only hologram (*left*). The reconstruction in the middle shows what happens when the out-of-focus image of the tweeter and the out-of-focus conjugate image are both allowed to reach the plane where the true image of the *R* is in focus (*see diagram below*). At the right the two out-of-focus images have been blocked off, leaving only the true image of the letter.



OPTICAL RECONSTRUCTION SCHEME used for decoding the hologram of the letter *R* with a laser shows where the various images come to a focus. Because the tweeter used as a sound source in this experiment was "visible" to the microphone through the openings in the letter *R*, it is recorded in the hologram and one can therefore view it in sharp focus in the reconstruction if one wishes.

lionth of a second later), a second pulsed laser, which is lined up on the same axis as the first, records a second hologram of the deformed surface on the same photographic plate. Between the two exposures, however, the path length of the optical reference wave is decreased by a quarter of an optical wavelength. When the two-component optical hologram is reconstructed, the reconstructed image of the surface exhibits brightness variations that are proportional to the acoustically induced displacement, or deformation, that occurred between the two pulsed-laser exposures. The reconstructed image of the surface obtained in this way is a temporal reference acoustical hologram of the acoustical-wave field impinging on the surface.

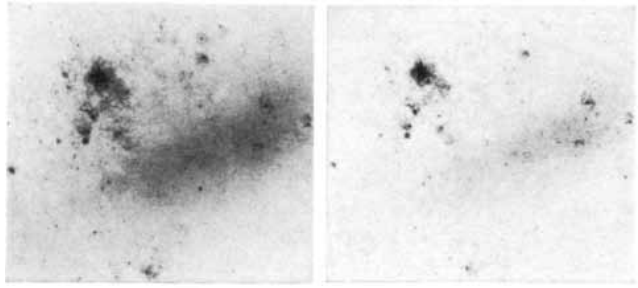
The technique has several important advantages. First, the aperture of such a hologram is limited only by the power available from the laser for illuminating the surface. A pulsed laser can readily illuminate a surface three feet square, thereby providing the resolution and image content needed to make acoustical holography a useful tool. Second, the use of an optical means for area detection eliminates the serious engineering problems that would be involved in trying to build large-aperture arrays of electronic detectors. Third, the extremely high recording speed means the system is little affected by object motion.

The liquid-surface technique and the technique for optical recording of temporal reference acoustical holograms, both of which are currently under development, show great promise as being truly practical systems for operation at high ultrasonic frequencies. Such frequencies, which lie in the megacycle range, will be required in medical diagnosis and in the nondestructive testing of materials. The acquisition of high-quality images of the human body showing the soft-tissue structures of organs and vessels will make new clinical information available to the physician. Such a system will be a valuable complement to present pulse-echo methods and X-ray techniques. Acoustical holography for imaging objects below the surface of the sea and below the surface of the earth is under development but appears to be somewhat farther off.

We want to be useful ...and even interesting

Kodak

Does this help any?



This past February, Bart J. Bok (University of Arizona) compared the new KODAK Special Plate 098-01 (left) with the long-established KODAK Spectroscopic Plate, Type 103a-E on the Curtis-Schmidt Telescope (University of Michigan) at Cerro Tololo, Chile. Looking for 60 minutes at the 30 Doradus Nebula in the Large Magellanic Cloud, our new emulsion not only shows the Axis of the Large Cloud far better but also catches an $H\alpha$ nebulosity hardly shown by the other. An improvement in $H\alpha$ visualization is to an astronomer what a better harvesting machine is to a potato farmer.

Astrologers have been among the most influential of men. When the other savants turned on them and proclaimed them fakers, the surviving honest students of the stars fell far in influence. Through a long and patient recovery, they have won high respect from those of us with a more selfish life style.

It is hard to explain convincingly why we keep scraping the art of photographic emulsion-making to earn the approbation (and not a great deal more) of a group of customers, far from rich but very smart, all of whom could fit comfortably into a single lecture room of moderate size. The Working Group on Photographic Materials of the American Astronomical Society did exactly that this past summer. This was the occasion for the first issue of the periodical *AAS Photo-Bulletin,* which we are having printed for them under their own editor, with one of our own star-struck technical advertising men helping from his own home on his own time. We have lived in this servile awe of astronomers for at least 50 years, and it hasn't impeded our progress noticeably.

Man's most photosensitive scheme

Paul Gilman, as photographed by Bob Phillips

Bob Phillips, as photographed by Paul Gilman

Bob Phillips is the better photographer, but Paul Gilman does more for photography. This is as it should be, for Mr. Phillips is a senior man in our Photo Illustrations Division, while Dr. Gilman is a Research Associate of the Kodak Research Laboratories who specializes in those organic molecules that absorb photons and pass a resultant something to silver halide crystals. More specifically, he studies how the transfer is accomplished. Without that phenomenon and improvements effected over the years, photography would never have amounted to much, and astronomers might still be scrapping with astrologers, if for no better reason than to rest their eyeballs.

To tell *all* that Gilman and the others in his specialty do for photography would be not unlike buying a large fleet of expensive limousines and lining them up with doors open and motors running beside a sign reading, "Take a few. They're free."

On the other hand, no respectable scientist latching onto any fundamental information about man's most photosensitive device—which is what these dye molecules and their associated AgX crystals are—is willing to keep it a secret any longer than required to make sure he speaks the truth.

Lately, William West of our Laboratories and Gilman have devoted the open portion of their work to fluorescence and phosphorescence as indicators of possible mechanisms in the dye-to-AgX transfer. Much involved are the phenomena of supersensitization (which gave a mighty boost to our fortunes and to the art of photography and the motion picture when we popped it on the world in the early '30s) and of J-aggregation (a very special two-dimensional ordering of the dye molecules named in honor of the late E. E. Jelley of our Laboratories and subsequently found to have broad implications elsewhere, as in the detection of biological macromolecules).

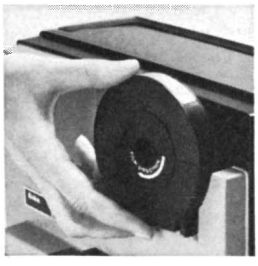
Under the title "Recent Observations on Spectral Sensitization and Supersensitization," a current summing-up of this securely fundamental work appears in the September-October '69 issue of Photographic Science and Engineering. *To dig out of it thoughts applicable beyond photography (or not beyond photography, for that matter) may prove no mean task. Reprint available from Senior Advertising Associate, Eastman Kodak Company, Rochester, N.Y. 14650.*

It isn't the film you want to see . . .

The user of movie film need never touch it again. Today's super 8 camera receives it hidden in a cartridge, and now the projector can take it hidden inside another cartridge. It can't get lost in a wrong carton. A reel you drop into the cartridge can't come unwound.

. . . it's what's on the film

Instead of threading the film through the projector, you simply slip the cartridge on. A mechanism reaches into the cartridge for the film and projection begins. At the end, the film withdraws by itself back into the cartridge. You don't have to turn the lights back on because with the KODAK EKTALITE Projection Screen you never had to turn them off.



Some new projectors backed by our trademark work like that. Apart from those, several other manufacturers have arranged to adopt the mechanism we invented.

The objective is to make super 8 film that much better a medium for teaching, for research, for reporting. And for the private joys of family history.

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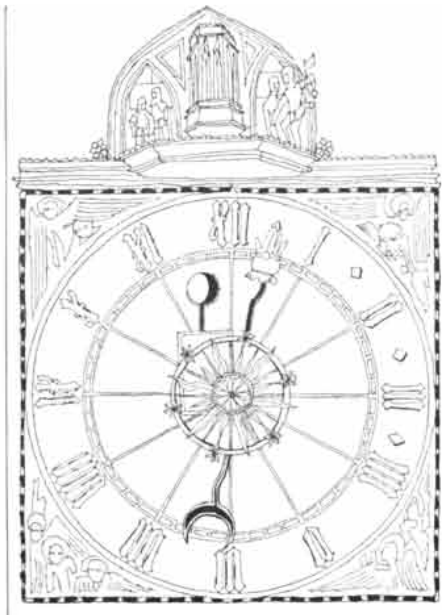
SCIENCE AND



The Assessment of Technology

The development of specific new institutions to assess the effects of technology on the environment and on the general welfare has been recommended by a panel of the National Academy of Sciences. As the speed and scale of technological change have increased, there has been growing concern over the harmful effects of technological innovations ranging from nuclear weapons to the indiscriminate application of DDT. In this context the concept of "technology assessment" has taken shape, and some 18 months ago Representative Emilio Q. Daddario of the House Subcommittee on Science, Research and Development asked the National Academy to study how that function is carried out now and how it might be improved.

An 18-member panel headed by Harvey Brooks of Harvard University submitted its report *Technology: Processes of Assessment and Choice* during the summer. The panel first considered the need for technology assessment. It identified as a central problem the fact that in considering whether or not to exploit a technological opportunity "individuals, corporations and public institutions attempt to project the gains and losses to themselves.... The difficulty is that self-interested analyses of this sort may ignore important implications of particular choices for sectors of society other than those represented in the initial decisions." For this reason opportunities that deserve exploitation may be passed up and technological paths that should be avoided may be pursued.

In order to institutionalize technology assessment, the panel recommended that new mechanisms for accomplishing it be established within the Federal Government. It urged that no attempt be made to form a centralized agency that could by fiat promote or suppress specific technological change and that the process of assessment be limited, at least initially, to Federal Government activities, but it also urged that the process of assessment be carried out close to the seat of political power.

Toward this end it recommended first of all 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. 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. The panel recommended that a parallel institution be created within Congress, either as a new Joint Congressional Committee on Technology Assessment or as a Congress-wide Technology Assessment Office something like the present General Accounting Office. It maintained that both the executive and the legislative institutions are necessary, the former to ensure a more professional and continuous operation and the latter to ensure adequate publicity and public representation. Finally, the panel urged that means be developed for including adequate assessment of classified military technology.

Bubble Computers

The Bell Telephone Laboratories have disclosed a new way to build electronic data-processing circuits by manipulating the flow of tiny magnetic "bubbles"—actually magnetic domains in the form of microscopic cylinders embedded in thin sheets of ferrite. The bubbles can be moved around with less energy than is needed to switch a transistor and, being only a few wavelengths of light across, they can be packed with a density of a million or more to the

square inch. The bubbles can be created, erased and shunted around to perform a variety of functions: logic, memory, switching and counting. Data rates of three million bits per second have been demonstrated in an experimental shift register, a type of circuit widely used as a high-speed storage unit in computers and data-transmission equipment.

The new technique is an outgrowth of basic studies with thin films of ferromagnetic materials going back many years. In 1967 Paul C. Michaelis of Bell Laboratories reported a way to control the propagation and interactions of isolated magnetic domains in thin films of certain anisotropic ferrites. In such ferrites the domains move more readily in one direction than another. Soon afterward a group headed by Andrew H. Bobeck described how cylindrical magnetic domains ("bubbles") could be manipulated in potentially useful devices. Bobeck's associates in this work were Umberto F. Gianola, Richard C. Sherwood and William Shockley. In these studies the bubbles were created in orthoferrites grown as single crystals and sliced into thin sheets. Being essentially isotropic, orthoferrites make it possible to move the bubbles with equal facility in any direction. The moving bubbles can be made visible by viewing the orthoferrite sheets under a polarizing microscope; the polarized light is rotated in one direction or the other depending on the direction of magnetization of the material through which it passes. The tiny domains show up because they are magnetized in a sense opposite to the magnetism of the supporting medium.

The creation and flow of bubbles can be controlled in a number of ways. For example, a gridwork of conductors can be printed on the surface of the orthoferrite; the bubbles will then move in response to magnetic fields generated by pulses of current through the grid. In another method the bubbles' direction of motion is controlled by an overlay pattern of a magnetically soft material (such as Permalloy).

The Shape of Insulin

Thirty-four years after Dorothy Crowfoot Hodgkin began to study the pancreatic protein insulin by means of X-ray crystallography her group at the Univer-

sity of Oxford has determined the three-dimensional structure of the insulin molecule. The announcement was made at the August meetings of the International Union of Crystallographers. Guy Dodson, a member of the group, has given an account of the research effort in the *New Scientist*.

The electrons in the orderly array of molecules within a crystal diffract X rays to form an image composed of many thousands of bright spots. From the position of these spots the location of the electrons can be calculated with the aid of a high-speed computer, and a map of electron densities reveals the arrangement of the molecule's atoms and thus its three-dimensional form. Successful X-ray analysis of such complicated molecules as proteins awaited the discovery by M. F. Perutz of the "isomorphous replacement" method, in which heavy-metal atoms are introduced into known sites in the protein crystal in order to modify its diffraction image. In the case of insulin it was particularly difficult to introduce heavy atoms. Only within the past two years were the Oxford workers able to collect diffraction data on crystals into which uranium, lead and mercury had been introduced, and this summer they calculated an electron-density map with a resolution of 2.8 angstroms.

The insulin molecule had been known to consist of an *A* chain of 21 amino acid subunits and a *B* chain of 30 such subunits. As Dodson describes insulin's form, the *B* chain is in the form of a distorted *U* and the *A* chain nests inside it. The *A* chain is folded in such a way, Dodson notes, that the three amino acids in it that differ most in insulin from various animal species have little effect on the shape of the molecule. This is consistent with the fact that pig insulin (which the Oxford group worked with), bovine insulin and sheep insulin are all more or less clinically effective in man. Detailed study of the molecule should add to the understanding of insulin's biochemistry and its mode of action, which is still unknown.

Undersea Oil for Japan?

Japan, which has never had a major oil supply of its own and has to import 99 percent of its petroleum requirements, may have discovered a substantial underwater oil field in the East China Sea. The discovery was made solely by geophysical techniques and remains subject to confirmation by more detailed surveys and finally by drilling. The potential field is in a large sedimentary basin on the Asian continental shelf between Taiwan and Japan; the average depth of the water in the area is about 200 feet.

A team led by Hiroshi Niino of Tokai University made the discovery. Its techniques included the use of a sparker and a magnetometer. A sparker system consists of banks of high-voltage capacitors that discharge into the water every few seconds, generating enough steam bubbles to simulate an explosion. The resulting sound signal goes through the water and into the sea floor, where seismic reflections are produced by geological structures as much as two miles below the floor. The reflected signals that return to the mother ship are recorded on moving paper tape, so that the investigator obtains a printed record that enables him to "see" formations characteristic of those that contain oil. A magnetometer detects variations in the earth's magnetic field. Oil is usually associated with specific sedimentary structures that can be inferred from the readings yielded by the magnetometer.

The Trillion-Volt Accelerator

Many physicists are convinced that new methods of acceleration will be needed to build a machine capable of accelerating nuclear particles to energies on the order of 1,000 billion electron volts (1,000 GeV), which is four times the energy of the largest accelerator now under construction (the one being built by the U.S. at Batavia, Ill.). A method receiving increasing attention in the U.S., the U.S.S.R. and western European countries is collective-ion acceleration, also termed electron-ring acceleration. In this method a proton or another kind of ion is tightly gripped by electric forces inside a cluster of electrons traveling in the form of a rotating ring. V. P. Sarantsev, a group leader in electron-ring studies at the Russian high-energy laboratory at Dubna, reviews the current status of collective-ion acceleration in a recent issue of the *CERN Courier*.

The advantage of the collective-ion approach is that the accelerating apparatus does not need to generate fields any stronger than those now found in many electron accelerators. The protons buried inside the electron rings, and thus carried along at the same velocity, acquire a much higher energy because of their greater mass. In fact, the energy of the proton is greater by approximately the ratio of the proton's mass to the electron's mass, or a factor of 1,800. Therefore it should be possible to achieve proton energies in the range of 1,000 GeV by accelerating rings of elec-

trons to an energy of no more than one or two GeV, after allowing for various losses.

The problems associated with collective-ion schemes are of two kinds. The first problem is to compress perhaps 10^{14} electrons into a small ring, to inject 10^{12} protons (initially present as hydrogen atoms) into the ring and then to begin accelerating them. The second task is to continue the acceleration to the desired level while keeping the rings intact. Physicists at both Dubna and the University of California at Berkeley have designed "compressors" capable of producing satisfactory rings. Extraction of the rings for further acceleration has proved to be more difficult. Nevertheless, electron rings have been successfully pumped out of the Dubna compressor at a third of the speed of light. The Dubna group has also produced rings containing atomic nuclei much heavier than protons, for example mercury atoms from which up to 10 electrons have been removed.

For accelerating the rings Sarantsev's group is studying alternating magnetic-field gradients combined with a system of accelerating cavities. Physicists at Berkeley are designing an alternative system in which acceleration is accomplished by linear induction in a sequence of pulsed cavities. Such a system requires switching elements that can be timed with an accuracy of 10^{-10} second. Still other approaches are being studied at the University of Karlsruhe and at the University of Munich. Sarantsev predicts that "the efforts of many physicists will eventually result in the construction of the first accelerator to operate on the principle of collective acceleration."

Firm Squeeze

A procedure first developed in order to apply ultrahigh pressures to small samples of matter in the laboratory may now have a heavy impact on die extrusion, the manufacturing process that annually squeezes out thousands of miles of metal in the form of wire, rod, tubing and various complex cross-sectional shapes. The new process applies hydrostatic pressure to the extrusion. Although the concept was patented in 1893, it was not until the 1940's, when P. W. Bridgman of Harvard University applied some of his ultrahigh-pressure techniques to die extrusion, that the advantages of the hydrostatic process became apparent.

In conventional extrusion a billet of the metal to be extruded is placed in a cylinder with massive walls. A ram then

forces the billet against a die, the billet is deformed under great pressure and the metal emerges from the die with a different diameter or cross section. In the process some metals lose mechanical strength because of the high temperatures generated by the deformation. Moreover, conventional extrusion is a "small batch" process: the maximum length of a billet is seldom more than four times its diameter.

In hydrostatic extrusion the ram does not touch the billet but instead exerts pressure on a fluid (often castor oil) that in turn squeezes the billet from all sides instead of from one end. Because the fluid is an effective lubricant between the billet and the die, and because friction between the billet and the walls of the surrounding cylinder is eliminated, hydrostatic extrusion can be accomplished at substantially lower pressures and with less generation of heat than conventional extrusion. These advantages yield substantially greater "working reductions." Moreover, because the billet is free to rotate within the cylinder during extrusion, the ratio of length to diameter is far less limited. With a spiral billet the ratio can be as much as 20 to one; by using a coiled billet for extruding wire the ratio can be increased to several thousand to one.

Reviewing recent progress in the field, including the extrusion of such novel shapes as spiral-finned uranium rods for nuclear reactors, Hans Kronberger of the United Kingdom Atomic Energy Authority summarizes its prospects in *Proceedings of the Royal Society*. Where common metals are concerned, he foresees a demand for the process whenever considerations of surface finish, dimensional accuracy or enhanced mechanical properties are of particular importance. He also expects that with the new alloys and stronger metals hydrostatic extrusion will prove cheaper and will allow the production of more complex forms.

Interfering with Tumors

Interferon is the substance produced by animal cells that interferes with the reproduction of viruses. At least some malignant tumors are now believed to be caused by viruses. Might interferon therefore inhibit the growth of such tumors? Several groups of workers have recently had interesting results along these lines.

Ion Gresser and his colleagues of the Institut de Recherches Scientifiques sur le Cancer in France report in *Proceedings of the National Academy of Sciences* that treatment with mouse interferon isolated from blood serum and brain tissue appears to prolong the life of mice inoculated with tumor cells. Tumors normally appear within a few days after such inoculation, yet of the 103 experimental mice, 101 survived beyond 22 days and 16 survived more than 60 days. Only seven of 188 control animals survived for 22 days and none lived more than 60 days.

At least two major obstacles confront Gresser and other investigators working with isolated interferon. The substance is difficult to produce and purify in large quantities, and some forms of it appear to be highly unstable. Samuel Graff and Robert L. Kassel of the Columbia-Presbyterian Medical Center in New York have circumvented one of these problems by stabilizing mouse interferon with horse blood serum. How the serum stabilizes the interferon, which is produced in large batches in tissue cultures, is not known. It is known, however, that blood-serum interferon is stable whereas tissue-culture interferon is not. Graff and Kassel took the logical step of treating tissue-culture interferon with blood serum. They have been administering massive doses of their preparation to AKR mice with viral leukemia and to Paris RIII mice with viral mammary carcinoma. The results have been encouraging.

Certain substances stimulate the production or release of interferon in the body, and some investigators have taken this route to investigate the antitumor effects of antiferon without isolating it. One of these substances is polyinosinic-polycytidylic acid (poly I-C), a form of RNA whose interferon-stimulating effect was discovered by Maurice R. Hilleman of the Merck Institute for Therapeutic Research. Hilton B. Levy of the National Institute of Allergy and Infectious Diseases and L. W. Law and Alan S. Rabson of the National Cancer Institute have found that poly I-C reduces the size of mouse tumors and sometimes even eliminates them. Moreover, when these workers administered poly I-C to rats and mice, it protected the animals from 12 of 14 different kinds of transplanted tumors, several of which are not virus-induced. Levy believes that poly I-C may have antitumor effects in addition to the stimulation of interferon production or release. It may act as a chemotherapeutic agent that destroys the tumor cells directly, and as a stimulant to the immunological system that somehow evokes the production of antibodies against tumor-cell proteins.

Levy and his colleagues have begun experimental trials of poly I-C on human patients; so have Irwin H. Krakoff and Charles Young of the Memorial Sloan-Kettering Cancer Center, using material provided by Hilleman. Both groups are proceeding cautiously because large doses of poly I-C given to animals have produced serious side effects.

Brownstone Dinosaur

The Triassic rocks of the Connecticut River Valley are famed among fossil-hunters both for the abundance of dinosaur footprints preserved in them and for the occasional skeletal remains of these animals. Among quarrymen they are equally well known for their yield of brownstone, a building material that was much in demand before World War I. This summer a mystery that originated when these two interests came into conflict 85 years ago seems to have been solved.

In October, 1884, a quarryman in Manchester, Conn., spotted evidence of fossil bone in a freshly exposed block of brownstone. Word reached the pioneer American paleontologist Othniel Charles Marsh, who visited the quarry and found that the block contained the rear end of a new species of dinosaur. By then, however, the brownstone that presumably contained the front end of the specimen had been used in the construction of a bridge a few miles away.

Marsh was not able to recover the missing brownstone, and with the passage of time it was forgotten which of the bridges near Manchester contained it. Then in 1967 John H. Ostrom, a paleontologist at Yale University, surveyed the area and selected as the bridge most likely to contain Marsh's lost brownstone a 40-foot span across Hop Brook, south of Manchester. Early this year Ostrom learned that the bridge was scheduled for demolition in a program of highway improvement. With the cooperation of the State Highway Department, he saw to it that a team including himself, Joe Webb Peoples of Wesleyan University, Peter Galton of the University of London and several students and volunteers was present for the wrecking.

As the bridge came down in August, the investigators carefully examined more than 100 brownstone blocks. Toward the end of the second day they came on two that showed signs of including fossil bone. The two blocks will not be studied in detail for some months, but the odds favor their containing some or all of the rest of Marsh's dinosaur. In one of the blocks the cross section of a femur is visible; one of the femurs recovered by Marsh was incomplete.

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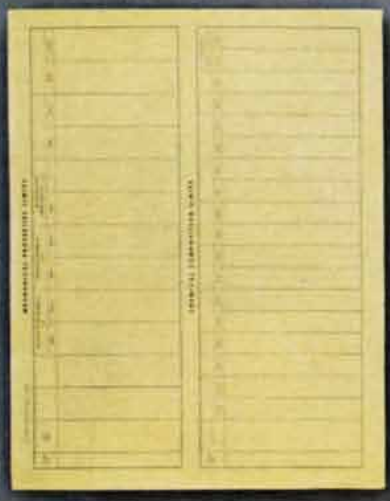
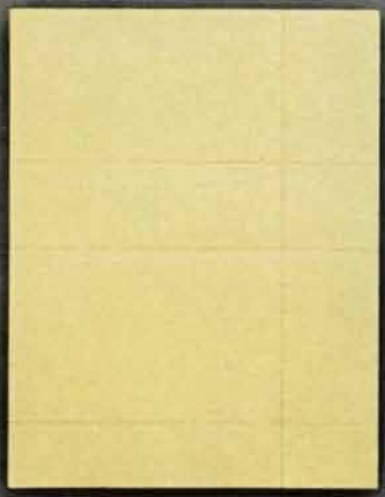
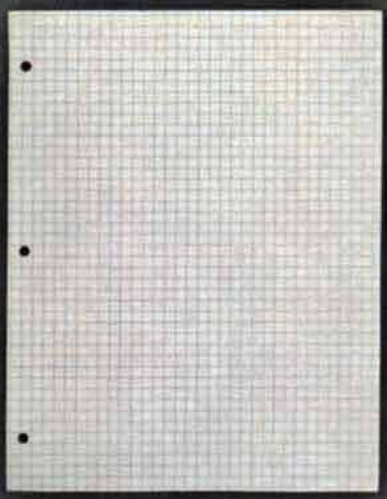
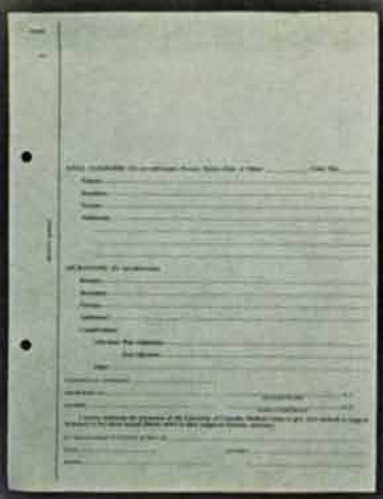
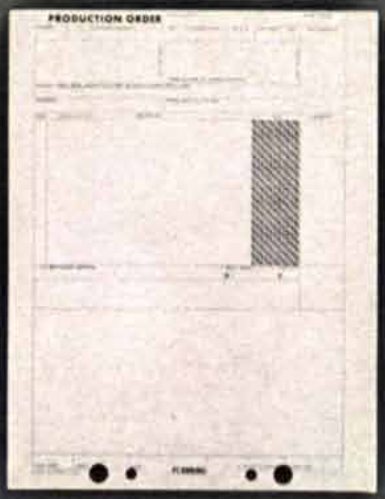


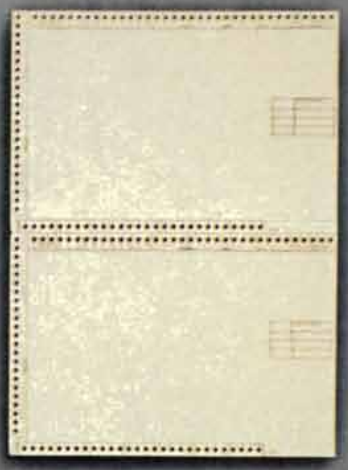


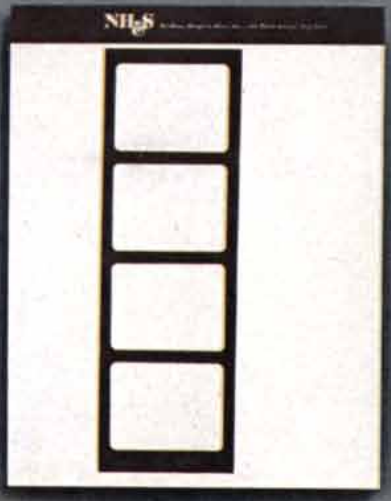


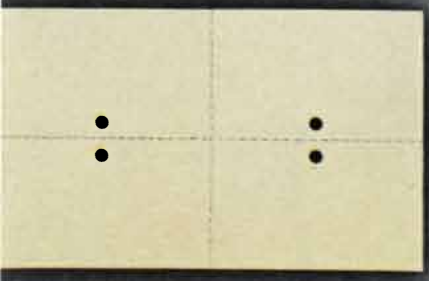




machines can copy on. But this is a start.







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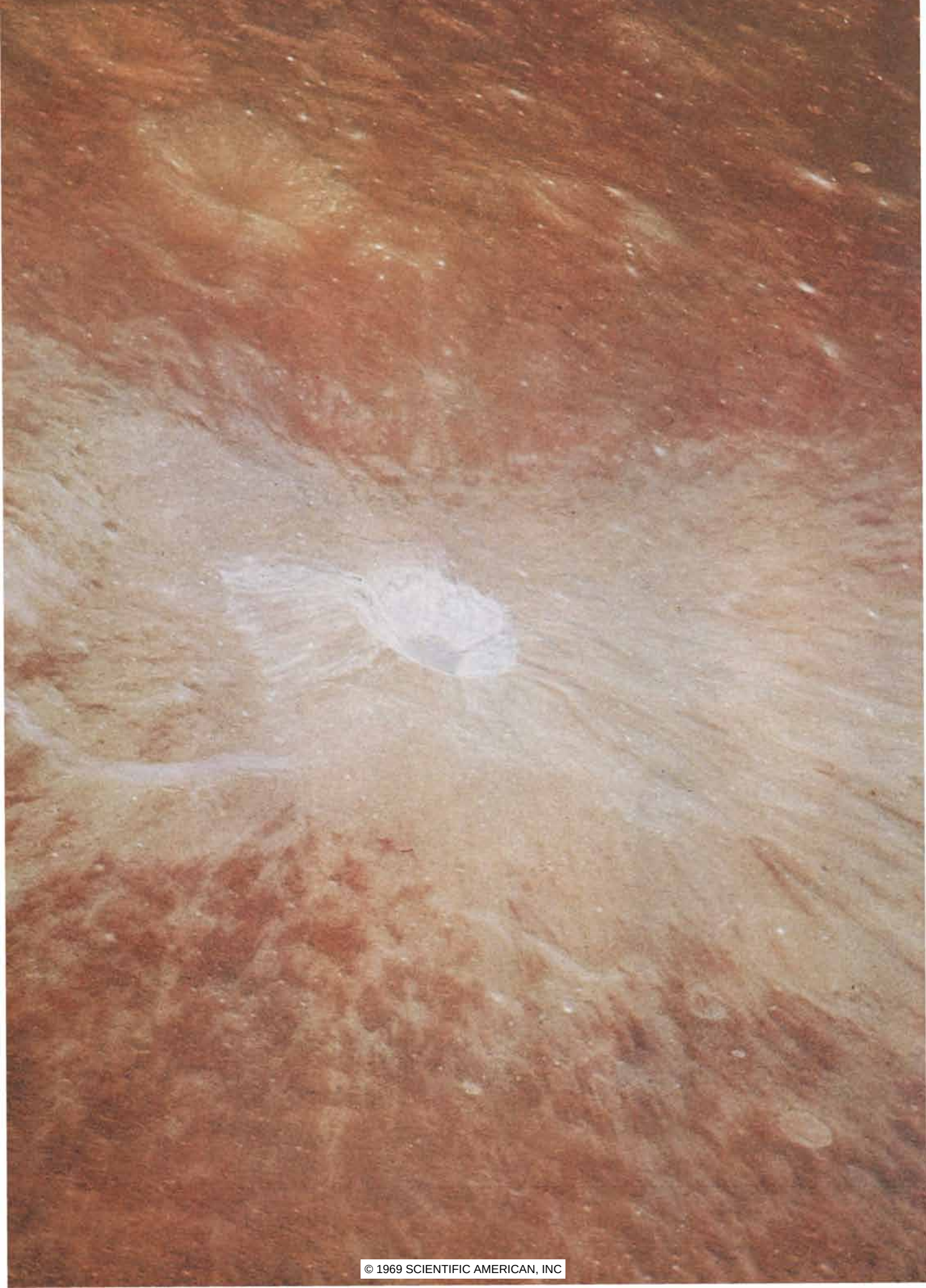


The Exploration of the Moon

The successful mission of Apollo 11 *opens an epoch of manned lunar exploration. What questions should this exploration seek to answer, and what areas of the moon should be visited to best confront them?*

by Wilmot Hess, Robert Kovach, Paul W. Gast and Gene Simmons

The success of the *Apollo 11* mission in putting men on the moon and bringing them back safely with samples of lunar material marks the beginning of what promises to be a period of fruitful exploration of the moon by men and machines. The objective will be to answer a large number of questions about the origin and evolution of the moon, its geology, its chemical and physical structure and what light its history can shed on the history of other bodies in the solar system. Our purpose in this article is to discuss the major questions the coming manned expeditions to the moon will be taking up and to describe the techniques likely to be employed on such missions.

In an astronomical sense the moon is usually considered to be a satellite of the earth. From the viewpoint of planetary processes, however, the moon can be regarded as the smallest of the "terrestrial" planets (the others being the earth, Mars, Venus and Mercury). Because its distance from the sun is about equal to that of the earth, the moon is subject to external influences similar to those affecting the earth. The moon's smaller size, however, implies a history quite different from the earth's.

Most planet-wide processes result from internal sources of energy and the means of its dissipation. The amount of internal energy and the means of dissipation are dependent on the size of the planet. On the earth the dissipation of energy has been accompanied by the transport of volcanic fluids from the interior of the earth to the surface, by the long-term development of a light crust and a dense core and by large-scale movements of the earth's crust, mantle and core. These processes, together with erosion and the chemical interaction of materials on the surface with the atmosphere and the hydrosphere, continually destroy the earth's surface features. For example, even the largest volcanoes are leveled by erosion within a few million years after volcanic activity ceases. It is extremely unlikely that any of the earth's original surface features still exist unchanged. No examples are known, and almost certainly none will be found.

It was once thought that many of the surface features of the moon date back to the moon's formation. The detailed views of the lunar surface provided by the photographs from the Lunar Orbiter space vehicles have somewhat diminished this possibility, because they indicate that erosion and other processes of change do take place on the moon. Preliminary analysis of the samples returned by *Apollo 11* nonetheless indicates that the material is very old, perhaps three billion years old. The highlands may be even older. The possibility that some of the material lying on the lunar surface is chemically unchanged since the formation of the planet remains high.

FRESH CRATER in the center of the photograph on the opposite page was photographed from the *Apollo 10* spacecraft during lunar orbit; the craft was about 70 miles above Mare Spumans, which is close to the lunar equator and almost at the right edge of the moon as it is seen from the earth. The unnamed crater is about one kilometer in diameter. It is identifiable as a recent crater by the fact that the light-colored material ejected from it covers a number of adjacent surface features. Plans for future Apollo missions include exploration of such a crater.

The Major Questions

Fundamental scientific questions about the moon are often stated in terms of terrestrial characteristics, which are of course more familiar. In inquiring about the gross chemical and physical structure of the moon, for instance, one wonders if the moon is chemically and mineralogically differentiated as the earth is. If processes such as volcanism have occurred on the moon, what has been their history over long periods of time? Did the moon ever have an atmosphere? Have protobiological materials ever existed or evolved on the moon?

Answers to such questions call for the recovery and analysis of samples of lunar materials from a variety of regions on the moon. Most of the analysis will have to be done on the earth. Determining the age of a sample of lunar material or making a chemical and mineralogical analysis of it requires instruments that cannot be deployed on the lunar surface within the next few years, particularly with little or no prior knowledge of the character of the materials to be analyzed.

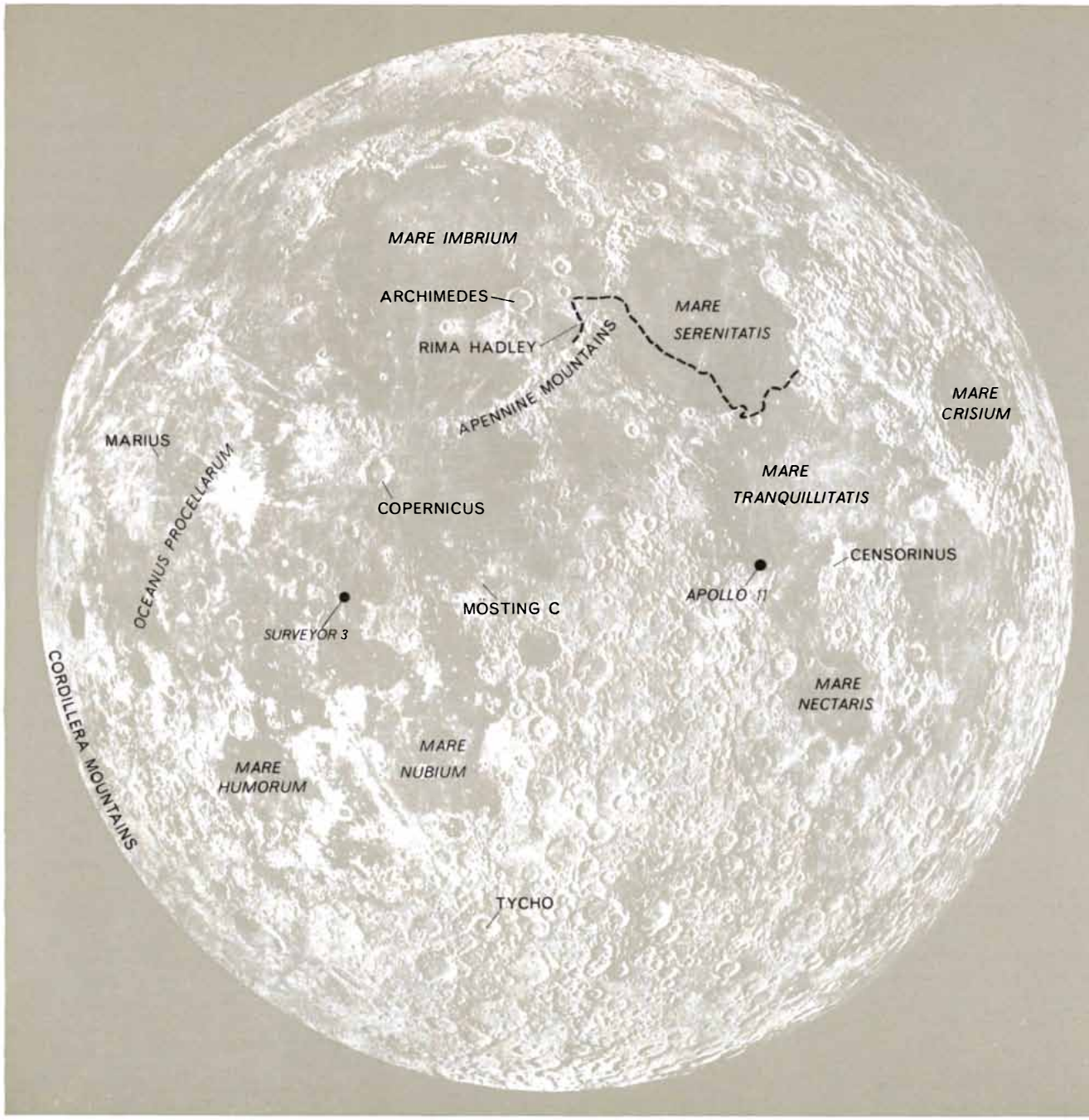
The study of returned lunar materials will in fact provide one of the most intriguing challenges ever faced by natural scientists. How much of the moon's history and how many of the lunar surface processes can be understood from a few isolated samples of lunar material, aided by the fairly detailed knowledge of the surface morphology obtained from photographs? The possibilities are considerable, because the lunar surface is not subject to many of the chemical processes that occur on the earth's surface, such as the changes accompanying erosion and sedimentation. Furthermore, the distribution of material over the surface of the moon by the impact of meteorites suggests that a substantial amount of material in any given place may have come from great distances without significant changes in chemical composition.

Efforts to trace the evolution of the

moon, to understand its gross internal structure and to explain the characteristics of its major morphological features will require knowledge of the kind and amount of internal energy released by moonquakes, heat flow at the surface and volcanism. The occurrence of moonquakes would reveal something of the distribution of stress with depth. The seismic waves arising from moonquakes would provide a powerful tool for deducing the distribution of basic physical properties with depth. Measurement of heat flow at the surface, combined with estimates of the distribution of radioactive elements in the lunar rocks, would make possible a determination of whether or not internal energy is in fact the cause of volcanism on the moon. Data for attacking these problems will be needed from a number of widely distributed points on the moon.

The Problem of the Mascons

The space vehicles employed in the Lunar Orbiter missions not only made excellent photographs of the lunar surface but also yielded a startling discovery having to do with the gravitational field of the moon. If the moon were a symmetrical spheroid, internally as well as externally, a satellite would move around it in a well-defined elliptical orbit at a smoothly varying speed. In actuality the moon, like the earth, is not quite a symmetrical spheroid, which introduces perturbations in satellite orbits. Over and above these perturbations, however, there are others introduced by lateral variations in the moon's density. As the Lunar Orbiter vehicles were tracked in



AREAS DISCUSSED in this article are identified. Possible sites for future manned exploration include the fresh craters Censorinus and Mösting C, the major craters Copernicus and Tycho, the Marius Hills region and the Apennine Mountains. Broken line shows a possible route for a traverse by an unmanned vehicle guided from earth. *Apollo 12* explorers are scheduled to land near *Surveyor 3*.

their orbits it was noted that they gained speed whenever they passed over one of the moon's ringed maria, or dark circular "seas." Analysis of these motions by Paul M. Muller and William L. Sjogren of the Jet Propulsion Laboratory led to the finding that over the major circular maria (Imbrium, Serenitatis, Crisium, Humorum and Nectaris) there is a substantial excess of gravity [*see illustration below*].

What is the cause of these gravitational variations? The large positive anomalies associated with the maria imply concentrations of mass, now abbreviated as "mascons." An example of the concentration involved is provided by the estimate that the gravitational anomaly over Mare Imbrium is equivalent to one produced by a sphere of nickel-iron 70 kilometers in diameter centered at a depth of 50 kilometers.

The discovery of lunar mascons has given rise to much speculation and debate about their origin. It has also revived interest in exploring the lunar maria, which many investigators had dismissed as unlikely to be as rewarding scientifically as other areas of the moon. Do the mascons represent remnants of giant iron asteroids that struck the moon and subsequently were buried and fragmented, or were they formed by some other mechanism?

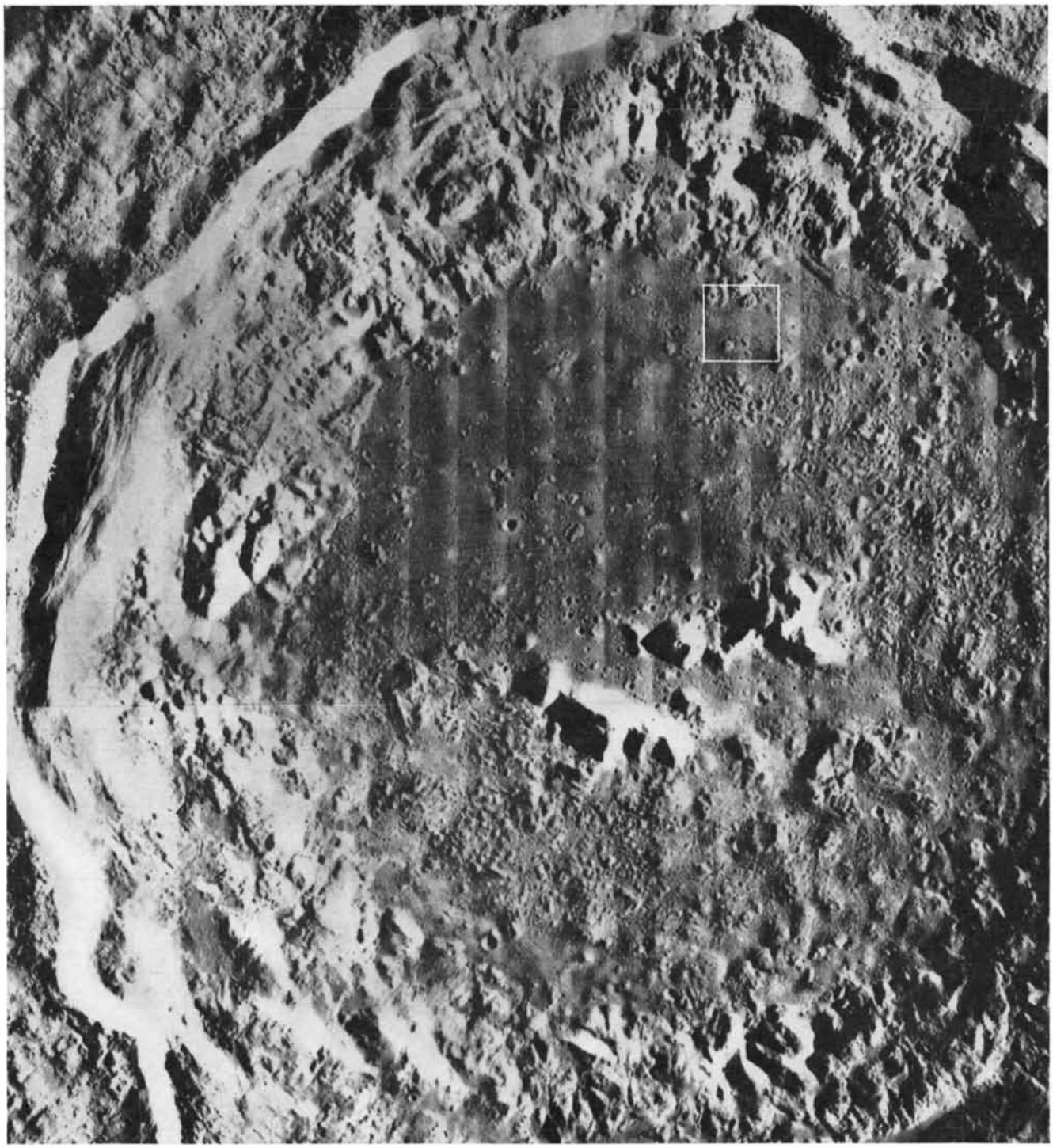
Most students of the moon favor the latter possibility. The debate centers on what the mechanism might have been. Several mechanisms have been proposed: the filling of a low-density, fragmented lunar crust with lava; a flow of lava into an impact crater; the upwelling of denser material from the lunar depths

MASS CONCENTRATIONS revealed by perturbations in the orbits of spacecraft orbiting the moon are represented by contours showing gravitational acceleration in tens of milligals. One milligal is equal to an acceleration of .001 centimeter per second per second. The mascons, as they have come to be known, are large under such circular maria as Imbrium, Serenitatis, Crisium and Nectaris.

into giant impact basins; even the deposition of sediment in the maria by flowing water that later dried up. The last hypothesis carries the intriguing implication that water not only existed on the moon at one time but also played an important role in lunar history. In any case, the analysis of samples from the moon takes on added significance as a result of the mascon phenomenon. An exciting result from the preliminary measurements of *Apollo 11* samples is that their density of 3.2 to 3.4 grams per cubic centimeter, which would be high for terrestrial rocks, may be related to the existence of the mascons.

Sites for Exploration

The present plan of the National Aeronautics and Space Administration is to make nine more manned explorations of the moon over the next three or four years. The sites for the first few will probably be determined on the basis of constraints similar to those that were in effect for the *Apollo 11* mission, namely that a landing place must be on the side of the moon facing the earth, so that constant radio communication can be maintained between the earth and the landing party; that the site be in a region free of obstacles, and that it be accessible



CRATER COPERNICUS was photographed by the low-resolution camera of the spacecraft *Lunar Orbiter V*. The prominent mountains in the floor of the crater are of particular interest for exploration. The boxed area appears in high resolution on opposite page.

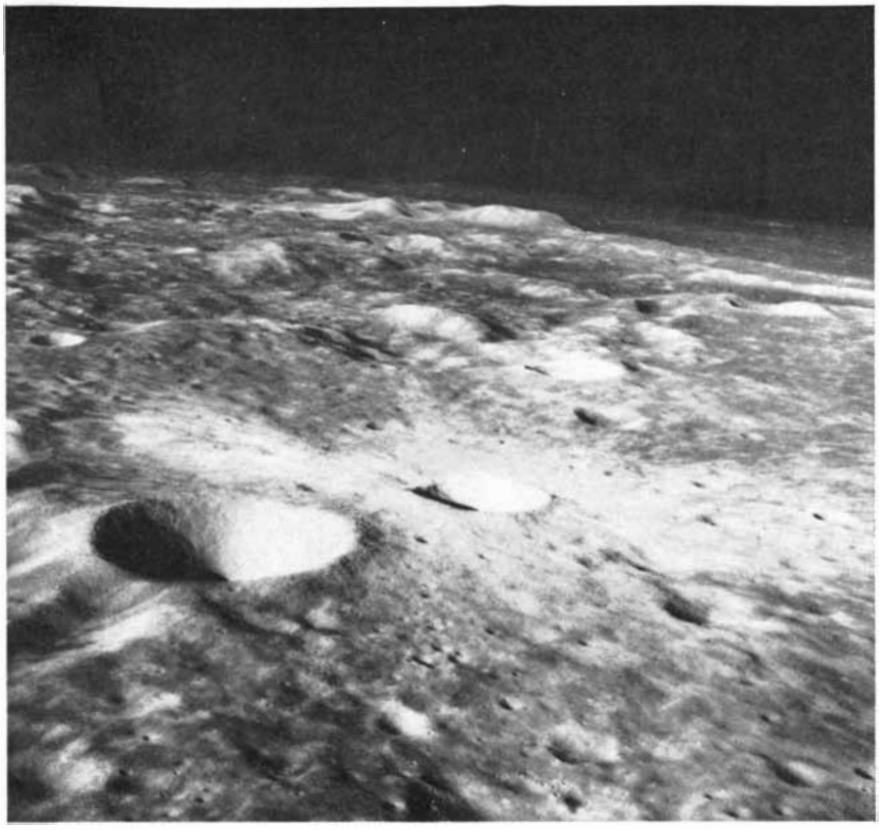
from a free-return orbit, meaning an orbit that will enable the astronauts to return to the earth with a minimum of power if the main engine in the command module should fail. These constraints restrict the next few landings to mare sites near the lunar equator.

Later it should be possible to venture farther afield and to land at or near other sites of particular scientific interest. A number of places are under discussion as possibilities for these landings. Instead of describing them all, we shall focus on four candidate sites and a long-traverse area that we believe offer significant clues for deciphering lunar history. The five areas are identified in the illustration on page 56. No particular significance should be attached to the order in which we discuss the sites.

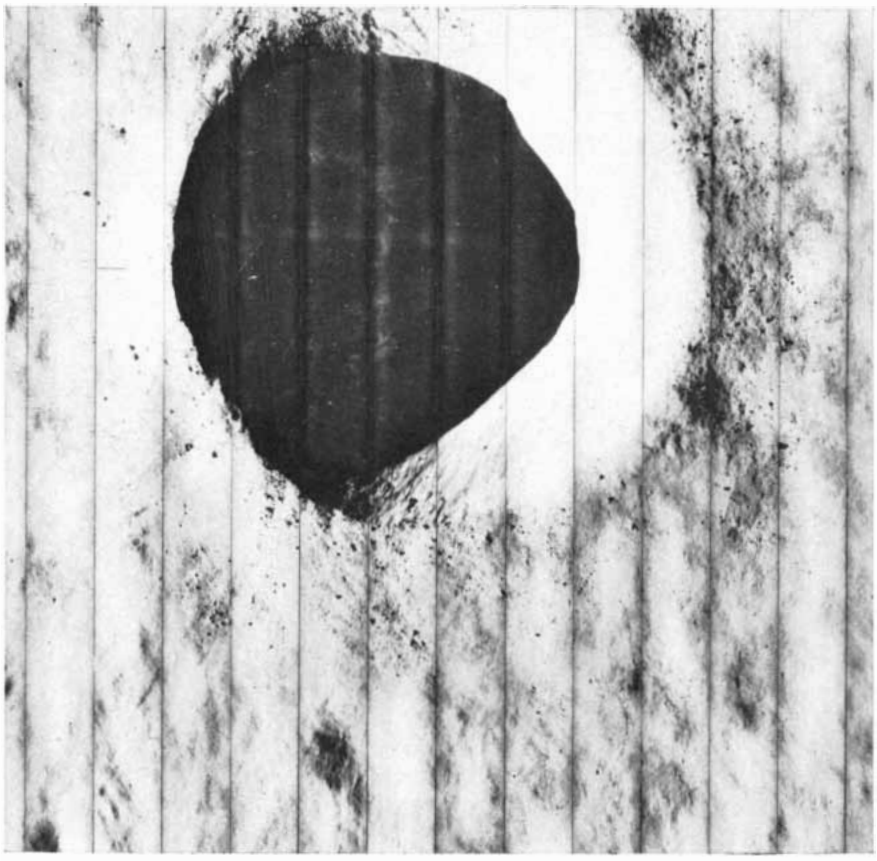
The first site is the small, extremely fresh crater Censorinus. A landing here could be expected to achieve three objectives: to establish the age of what is clearly a very young feature on the lunar surface, to investigate and characterize an unquestioned impact feature and to obtain samples of material from a region in the highlands. An alternative site, which would offer similar possibilities, is the crater Mösting C.

The second site represents the much more ambitious goal of exploring one of

HIGH-RESOLUTION *ORBITER* VIEW of the area of the floor of Copernicus that is outlined in the photograph on the opposite page shows hills and apparent fractures. Large blocks of material are visible in several places, particularly on the slopes of the hills.



CRATER CENSORINUS, the fresh crater near the center of this *Apollo 10* photograph, is of notable interest for exploration. It is one of the freshest craters on the moon's near side and appears as a bright spot in infrared photographs made during eclipses of the moon.



CLOSER VIEW of Censorinus was obtained by the high-resolution camera of *Lunar Orbiter V.* Large blocks that are as much as 100 meters in diameter appear on the crater's rim.

the major craters. Such a crater is Copernicus, which is about 70 kilometers in diameter and has prominent central peaks within it. The ejecta from this relatively young crater cover more than a tenth of the front face of the moon. The relief within the crater is more than 15,000 feet, making it comparable to the most mountainous areas on the earth. An alternative site, with quite similar characteristics, is the crater Tycho. These large craters are of interest not only because they represent major events in the history of the moon but also because, by analogy with much smaller terrestrial craters, they should expose material from a range of depths up to 10 kilometers, and perhaps even more. It has been suggested that the central peaks in these craters may consist of material now at the surface that has come from depths of 10 to 15 kilometers or more. Thus even though the material in a crater may be jumbled, broken and deformed by shock processes, it should provide a diverse sample of the outer few kilometers of the moon and a basis for interpreting its history.

Third, we point to the extremely interesting Marius Hills region. It is one of several areas where constructional features such as domes and built-up cones are more numerous than craters of a comparable size. The region is also associated with one of the longest lunar ridge systems, which crosses a large expanse of Oceanus Procellarum on the western half of the moon. The tectonic setting of the region is similar to that of terrestrial volcanic fields such as Iceland and the Azores. The setting and structure of the Marius Hills region suggest that it is an area of volcanic activity where igneous material has been added to the surface through vents.

The origin and age of the seemingly volcanic features in the Marius Hills region are of considerable importance in understanding the evolution of the lunar surface. Terrestrial volcanic features are built up in very short times compared with the entire history of the earth. Even an extensive region such as the volcanic chain constituting the Hawaiian Islands represents a period of less than 70 million years. The absolute age and the length of time involved in building up the Marius Hills domes will be of great interest in the characterization of lunar volcanism.

The Marius Hills region is far too extensive to be covered in a single manned expedition to the moon. Fortunately a number of characteristic features of smaller scale can be visited in several areas that are no more than 70 kilome-

SCIENCE/SCOPE

Nearly all major U.S. space flight missions have relied on Hughes traveling-wave tubes to beam voice and picture signals back to earth -- most recently Apollo 11 and Mariners 6 and 7. The powerful but compact Hughes TWT, amplifier, and power supply are also aboard the Early Bird, Intelsat II, ATS-1, ATS-3, and Tacsat-1 satellites, which were part of the network that gave worldwide distribution to Apollo 11 TV coverage. Early Bird had been retired recently after nearly four years of service, but was reactivated for the Apollo 11 mission.

The nuclear-powered USS Long Beach, already the world's most advanced missile cruiser, will soon be given a battle-control capability unmatched in naval history. Her Hughes-built Scanfar radars and radar computers, which can detect and automatically track hundreds of targets simultaneously, are scheduled for an electronic face-lifting that will improve her surveillance of a battle zone covering thousands of square miles of land and sea.

The infrared radiometers aboard Mariners 6 and 7 provided high-accuracy surface temperature measurements which were correlated to the TV pictures of the Martian surface. The Mariner 7 radiometer also measured polar cap temperatures consistent with the presence of dry ice. The 7½-pound instruments were made by Hughes' Santa Barbara Research Center, which is now at work on two radiometers for the Mars Mariner 1971 orbiter mission.

In a recent Project BOMEX weather experiment, a Hughes-built 30-foot antenna and portable terminal were installed on Barbados Island to receive the 35 color pictures transmitted daily by the ATS-3 satellite over the Atlantic (it was the same equipment Hughes set up in San Jose, Calif. last year to relay live TV of the Olympic games from Mexico to Japan). BOMEX is directed by ESSA, which is coordinating the efforts of 10 government agencies, 19 educational institutions, and seven contributing corporations including Hughes.

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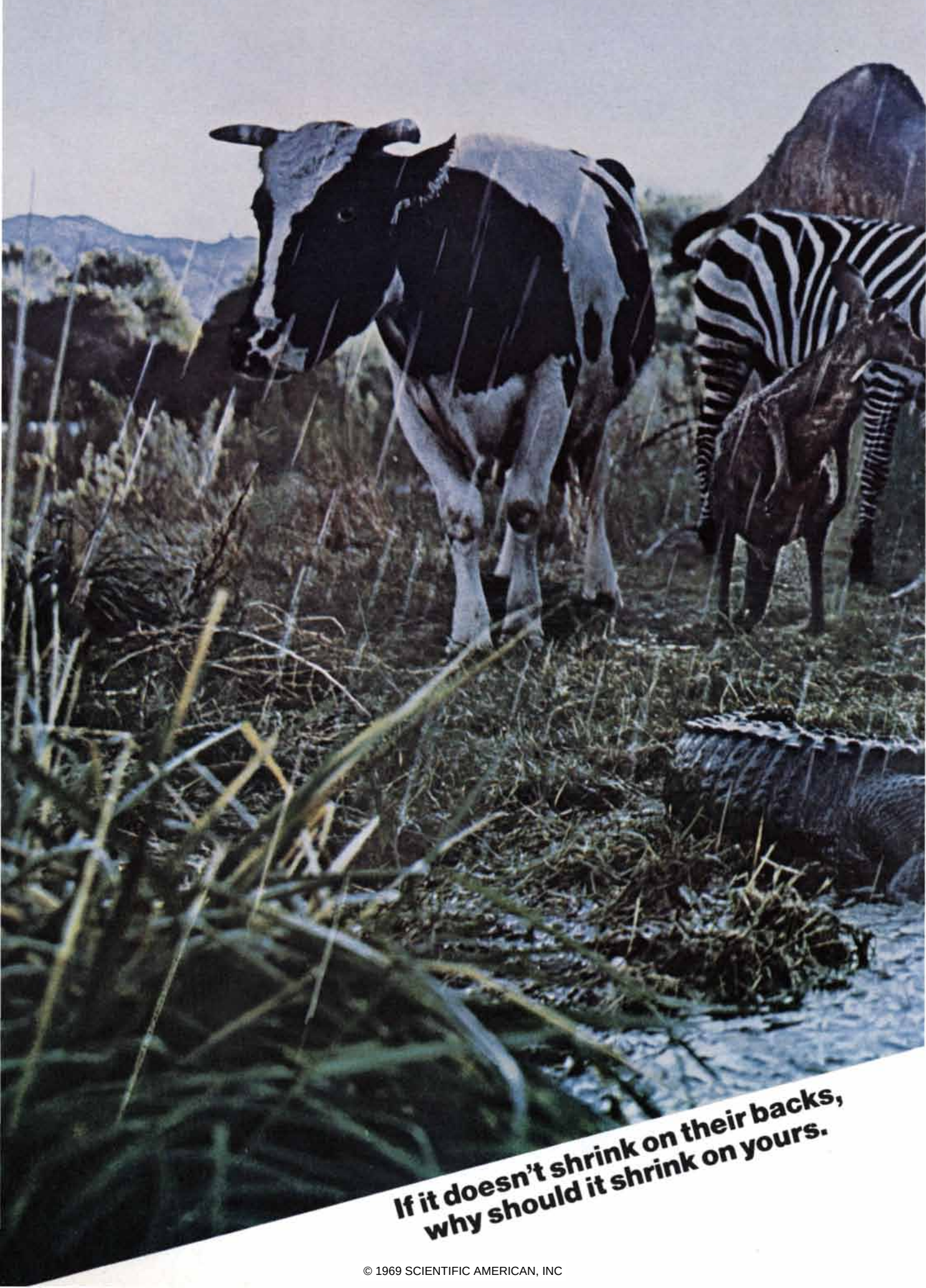
A night-vision system for helicopters, developed for the U.S. Army by Hughes, presents a cockpit image almost as bright as day -- even when the target is illuminated only by starlight. New system combines the latest developments in fiber optics, low-light-level TV, image-intensifier tubes, and covert illuminators. Called INFANT (for Iroquois Night Fighter and Night Tracker), it has been installed in a UH-1M Iroquois helicopter and successfully demonstrated during night operations in the California desert.



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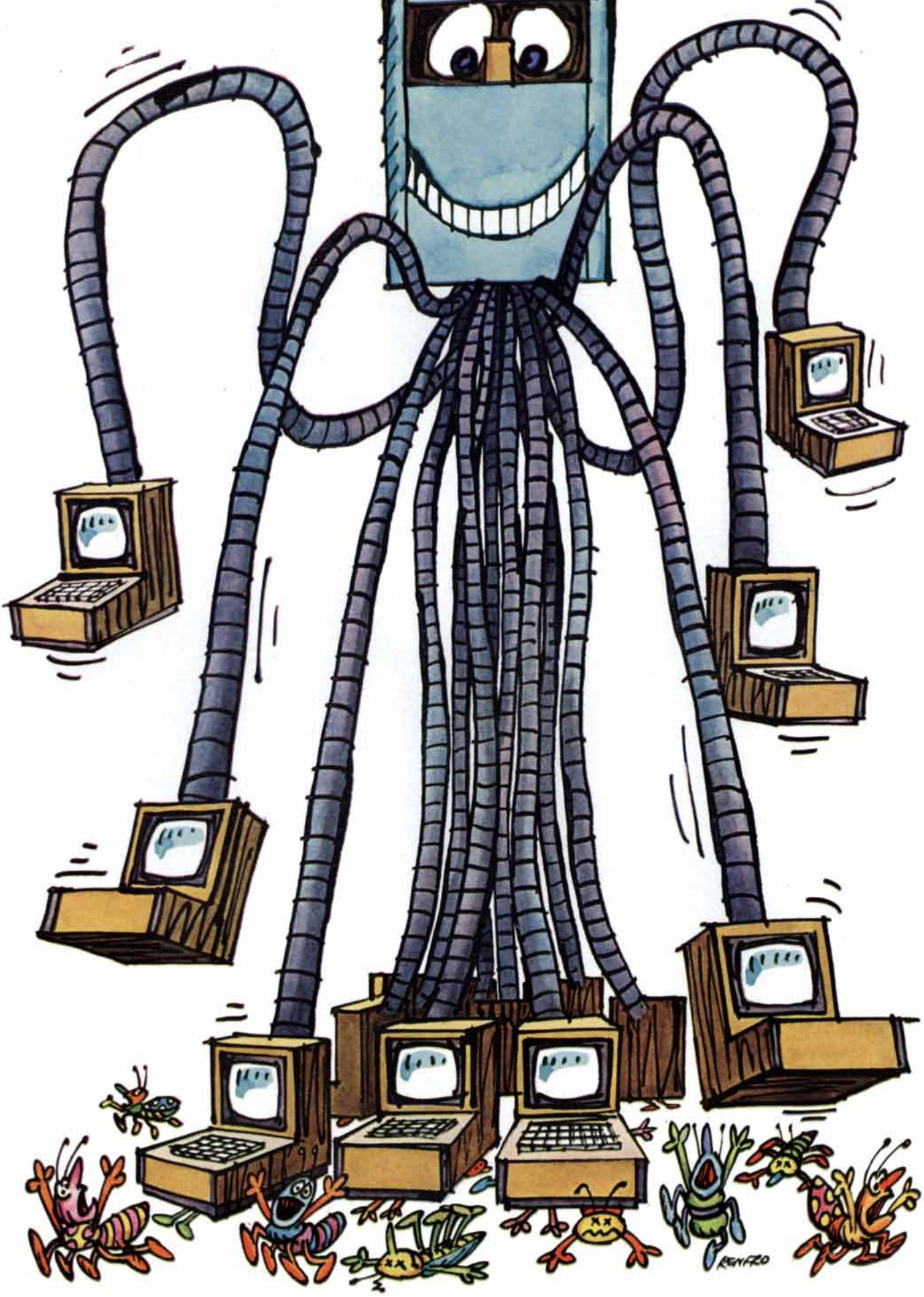

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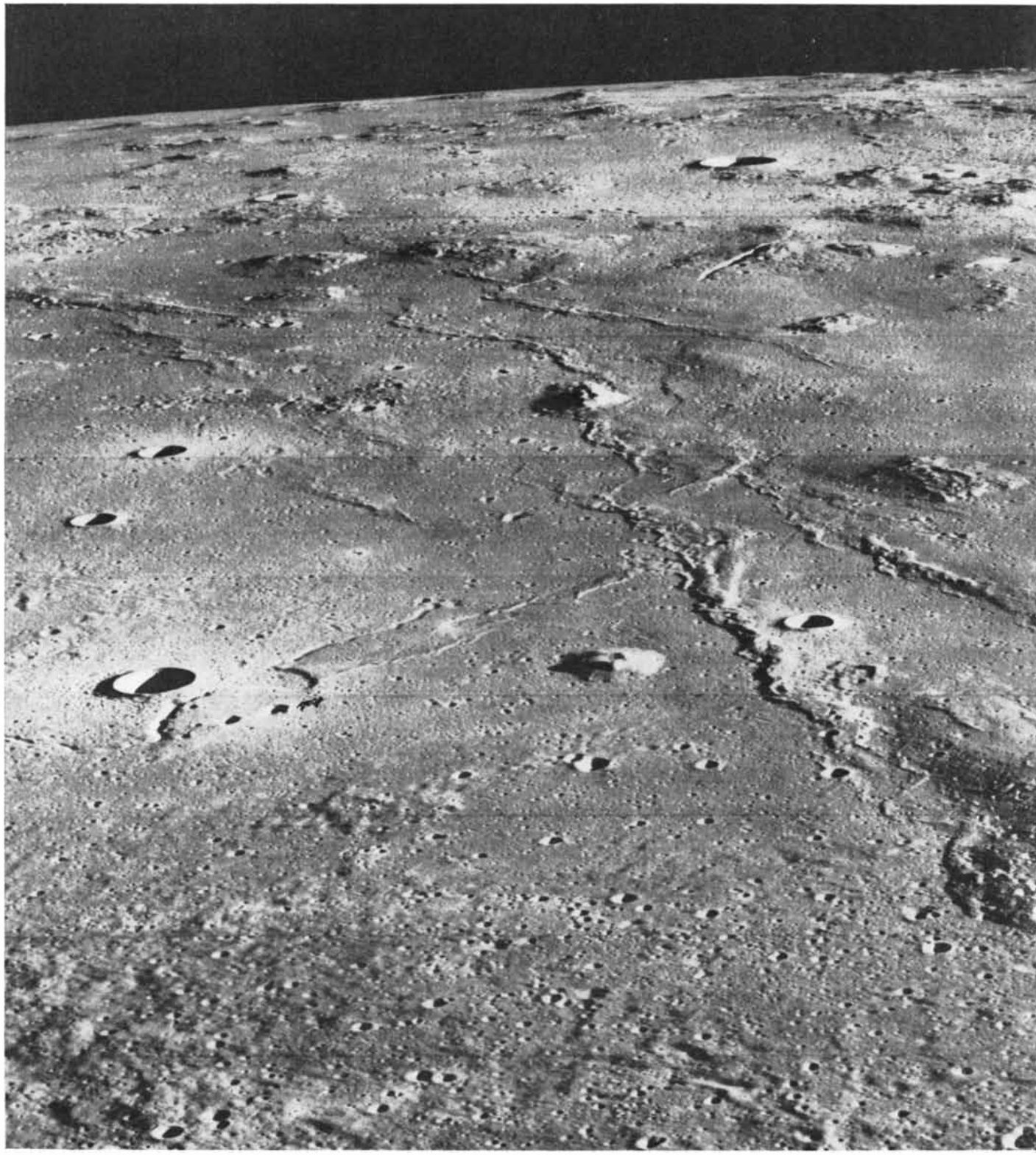
ters in diameter. A mission to such an area would be able to sample and study a number of small domes 50 to 100 meters in elevation with convex slopes; steep-sided domes with rough, intricate surfaces; steeply convex or bulbous domes that are smooth and generally symmetrical; steep-sided cones with linear depressions at the summit; narrow, steep-sided ridges, and a variety of impact features.

The fourth candidate site is the region of the Apennine Mountains, which roughly form the southeastern boundary of Mare Imbrium and also the northwestern leg of a triangular highland area bounded by Mare Imbrium, the southwestern boundary of Mare Serenitatis and the northern part of Sinus Aestuum. The Apennines are among the most impressive of the lunar mountain ranges.

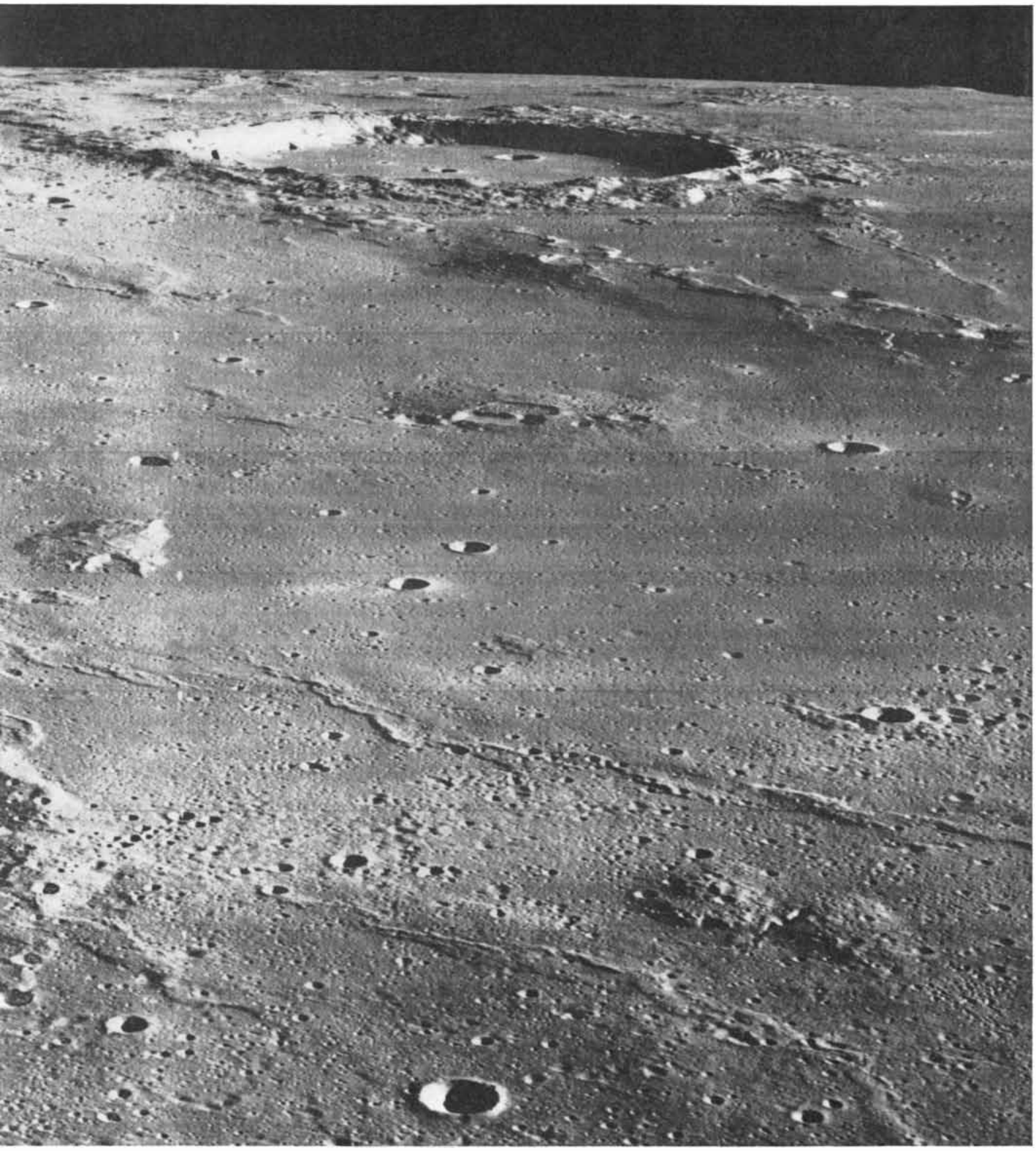


MARIUS HILLS REGION takes its name from the crater Marius, which is at upper right in this oblique photograph by *Lunar Orbiter II*. The region is of interest because of its many domelike structures, which are more conspicuous here than craters. The

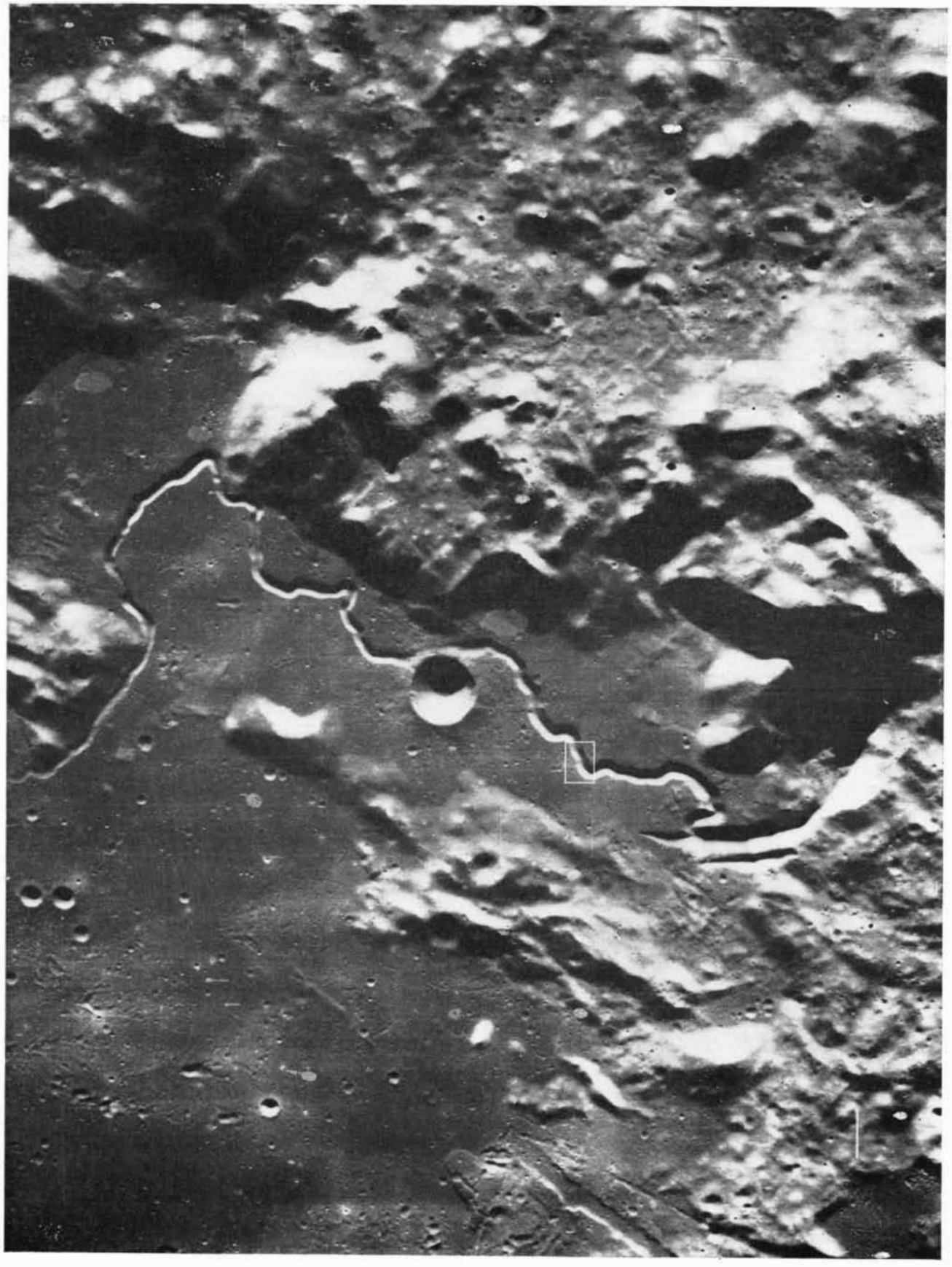
The Apennine front rises 4,800 meters above the adjacent mare level to the west.

What can be learned about the moon by visiting this area? The Apennine front is a major physical feature of the moon, exposing an extensive vertical section several thousand meters thick for sampling and examination. Here is an opportunity to assess what may be a long period of lunar history. Are the rocks uniform or physically and chemically heterogeneous? How old are they? Are they stratified? Answers to such questions could have a profound effect on our understanding of lunar history.

Two landing sites have been proposed near the Apennine front that are within five kilometers of important lunar features. One such feature is the rille, or canyon-like configuration, known as



domes are believed to be of volcanic origin. If they are, material on surface near them may have issued from great depths and so could reveal information on moon's internal composition and temperature. Region is near equator at far left of moon as seen from earth.



HADLEY'S RILLE is a conspicuous feature of the Apennine Mountain region. The rille, also known as Rima Hadley, is the river-like structure visible across the center of the photograph. Whether it is a collapsed lava tube or a channel resulting from the surface flow of a liquid might be determined by a manned exploration. Outlined area is shown at higher resolution on the opposite page.

Rima Hadley [*see illustration on opposite page*]. Is it a surface-flow channel or a collapsed lava tube? If it was formed by water, as has been speculated, where did the water come from and what prevented its immediate evaporation?

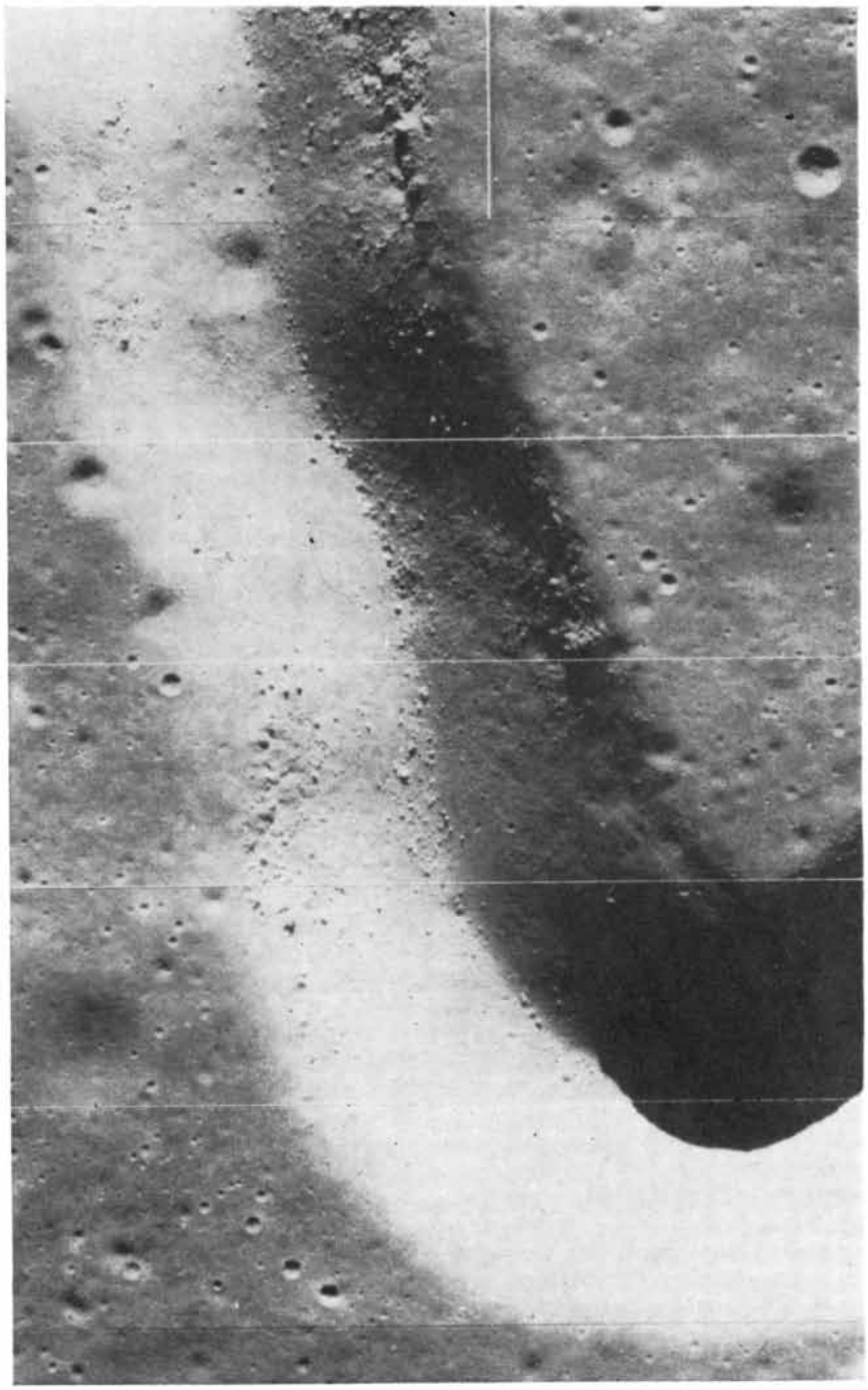
The Significance of Rima Hadley

Close examination of the Lunar Orbiter photographs of this rille reveals that fresh exposures of rock are visible along its walls and that blocks have fallen down the walls to the floor of the rille [*see illustration at right*]. Rima Hadley cuts into the floor of a mare and thereby yields a depth and perhaps a cross section of the history of a major lunar feature. Hence it might provide answers to such questions as whether the maria are bedded deposits of lava or ash flows, sedimentary deposits that contain a sequential history of formation or simply an agglomeration of cold particulate matter accreted from space.

The location of the proposed landing site at the boundary between a highland and a mare provides the opportunity for another promising investigation. Deployment of a multiple-axis seismometer and recording of seismic waves from different directions should reveal something about any deep structural differences between the maria and the highlands. Thus one might answer the question of whether or not the maria and highlands are analogous to the oceans and continents on the earth, which show major structural differences.

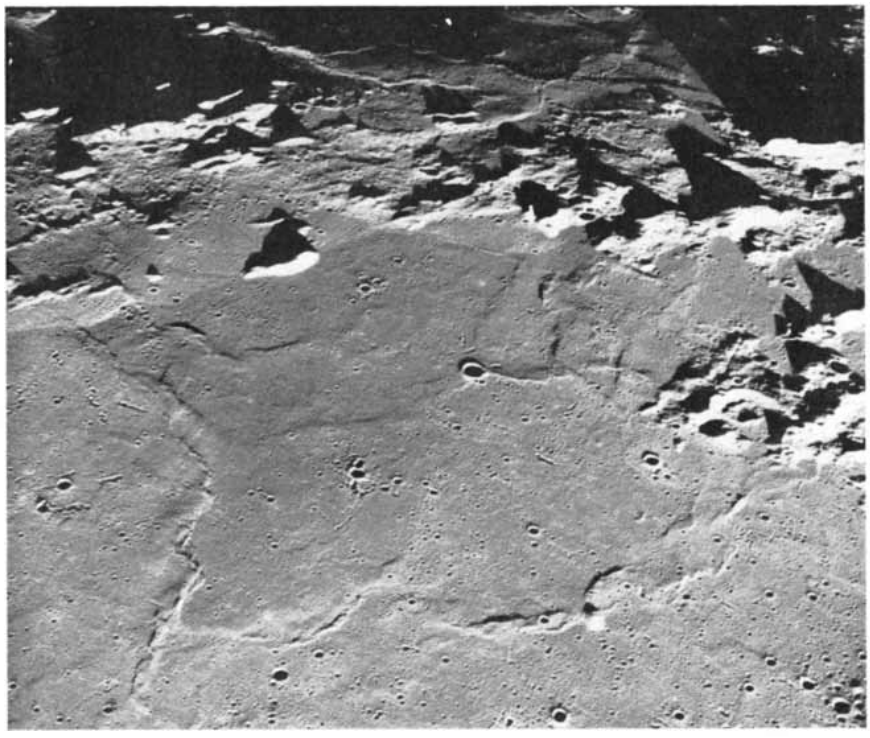
The Long Traverse

After the early fixed-station landings at a wide variety of lunar sites some form of long-range, mobile surface exploration will be necessary to overcome the limitations of men on foot. The answer lies in vehicular traverses, which would make it possible to study cross-country variations on the moon and so form the bridge between the intensive observations that can be made in the vicinity of a landing site and the extensive averaging observations that can be made from orbit. The technique that is attracting particular interest at present is called the dual-mode lunar surface roving vehicle system. The term dual mode refers to the fact that the vehicle can be used by the astronauts while they are working on the lunar surface and can be operated remotely from the earth after they depart. The present plan entails two separate lunar landings 500 kilometers apart at sites chosen to maximize the amount of information returned from the unmanned, automatic traverse.



HIGH-RESOLUTION VIEW of the portion of Rima Hadley outlined in the photograph on the opposite page was obtained by *Lunar Orbiter V*. Evidence of a ledge of bedrock appears on the right-hand wall at top center. Large rocks are abundant on the slopes of the rille. The average distance from rim to rim is 1.5 kilometers; depth is between 300 and 500 meters.

Such an operation would proceed as follows. Near the end of surface activities in the first landing the men would start their unmanned vehicle on an automatic traverse. The vehicle, guided from the earth, would move across the moon toward a distant point that is within the second landing area. There the men participating in the second landing would meet the vehicle several months after it had started its journey. During its traverse the vehicle would collect samples of rock, transmit television pictures and conduct geophysical experiments yielding data that would be transmitted to the earth by telemetry. After the rocks



MARE AND MOUNTAINS are contrasted in this photograph made near the western edge of the Sea of Tranquility from *Apollo 11*. The view is westward. It emphasizes how flat the maria are in comparison with the terrain around them. The wrinkled ridges, which are common features of maria, may be places where volcanic rocks have come to the lunar surface.

had been retrieved by the astronauts at the second site the vehicle could be used by them in the exploration of that site. If the vehicle was still in satisfactory condition, they could start it on another long traverse.

A typical traverse might go from Rima Hadley into Mare Imbrium and thence into Mare Serenitatis. Along the way it would provide continuous profiles of the variations in gravity, magnetic and electric fields and depths of the surface layer. This particular traverse crosses one of the largest of the mascon areas and would cover enough ground to explore the phenomenon adequately with geophysical techniques.

The continuous monitoring of gravity along the traverse would provide information on the regional isostatic balance on the moon, that is, whether the higher topographic features are compensated by a deficiency of mass below them or whether they represent loads on the surface. An answer to this question would tell a great deal about the mechanism of formation of such features. Gravity information will also yield clues about the maximum depth of variations in density. If the moon has a crust analogous to the earth's, how does it vary between the lunar highlands near Rima Hadley and the center of the Imbrium basin?

The value of gravity measurements is increased if they can be combined with seismic information. Seismic measurements could be expected to resolve details of any layering in the lunar substrata. Along the traverse we have been describing a properly executed seismic experiment would quickly reveal the presence of giant iron asteroids buried in the mascons.

Improved Capabilities

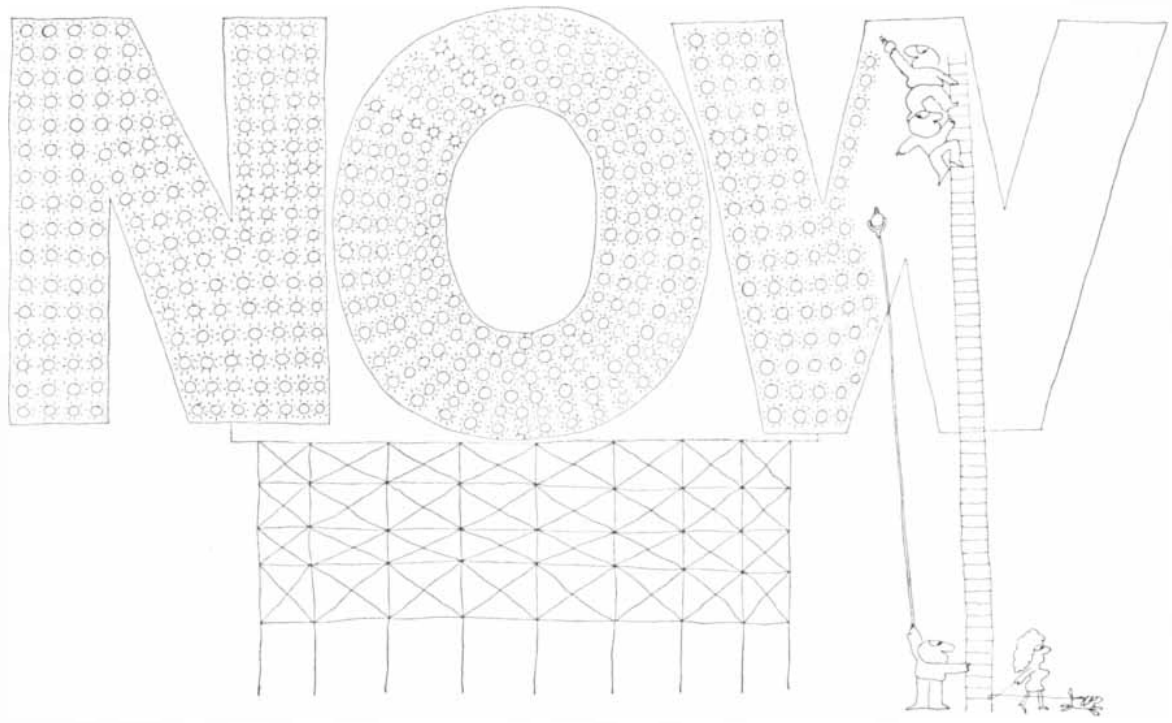
Implicit in the accomplishment of the missions we have discussed is a considerable improvement of the already substantial capabilities shown in the *Apollo 11* mission. We shall enumerate a number of improvements that we think can be expected by 1972, although we should point out that the estimates are somewhat uncertain. The present capability is for a mission lasting 10.8 days, with a total of 22 hours spent on the moon; by 1972 a 16-day mission with 78 hours on the moon should be possible. The payload of scientific instruments delivered to the surface should increase from 300 to 600 pounds and the amount of material of scientific interest returned to the earth from 150 to 300 pounds. Landings, which are now limited to the equatorial zone, may be possible on most of the front face of the moon, and it may also be possible to land within .5 kilometer of a target area instead of within 10 kilometers as now. For men outside the lunar module the walking radius on the moon should increase from 100 meters to four kilometers, and the total distance covered during a single extravehicular activity from 500 meters to several kilometers. The capacity of the life-support pack worn by the astronauts as they move about the lunar surface may be increased by as much as 50 percent from the present 4,800 B.T.U.'s. It may also be that the command module will be able, while it is in orbit around the moon, to launch a subsatellite that could make additional measurements.

These new capabilities seem within reach when considered individually. It will not be possible to have them all, because a few are mutually exclusive. For example, if it were decided to land a 600-pound load of scientific instruments on the moon, it probably would not be possible to equip the astronauts to traverse as much as 10 kilometers of the lunar surface.

It also seems probable that a constant-volume suit will be available for lunar astronauts soon. With the present variable-volume suit the astronaut has to do a considerable amount of work against the suit. He also cannot bend his waist or his ankles. The constant-volume suit will require about 30 percent less work for equivalent tasks because almost no work will have to be done against the suit. It will also be flexible at the waist and the ankles. With this suit the astronaut should have considerably more mobility on the lunar surface.

Even so, several of the sites we have discussed cannot be explored adequately unless the astronauts have more mobility than walking provides. Indeed, the radius of mobility ought to be about 30 kilometers from the landing site. Obviously a vehicle will be needed. Two approaches are possible: the vehicle could crawl along the lunar surface at a few miles per hour or it could fly over the surface at low altitude. The ground vehicle has the advantage of enabling the occupants to stop and look at interesting objects, whereas a rocket-powered flying platform makes it possible to move rapidly from one point of major interest to another. A flying vehicle could also move vertically, as will be desirable at certain lunar sites. Although both flying and crawling vehicles have distinct advantages, both are expensive, and it may well be that only one capability will be developed.

Inasmuch as the most that can be expected of a landing party is the exploration of 10 to 100 square kilometers in the



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vicinity of the landing site, the nine additional landings now planned will cover only about one part in 10,000 of the front face of the moon. In order to obtain a more comprehensive picture of the surface, including the far side, and to look for classes of features missed at the landing sites, NASA plans to use instruments mounted in the service module for remote sensing from orbit. The sensors will be put into service starting at about the sixth landing.

Orbital Sensing Instruments

Eight types of instrument are under consideration for the remote-sensing activity. Spectrometers measuring gamma rays, X rays and alpha particles emerging from the lunar surface would be able to detect several elements. The gamma ray instrument could ascertain the amounts of iron, potassium, thorium and uranium in the top foot of the lunar surface. The X-ray instrument would receive radiation excited by the sun in a very thin surface layer and give information on the concentration of major elements such as silicon, magnesium and aluminum. The alpha instrument would reveal if there were any extensive leakage of radon gas from the lunar interior, such as often accompanies volcanic or hot-spring activity on the earth. An infrared radiometer would measure infrared emission from the surface and thus would be able to find hot spots and volcanic activity. A gas mass spectrometer would measure the number and type of atoms around the service module, thereby determining the density and composition of the vanishingly small amounts of gas at lunar orbital altitudes. An electromagnetic sounder would bounce pulses of radio waves (10 kilohertz to 100 megahertz) off the moon and measure how much came back, thereby finding out about subsurface layering and determining whether there is chemical differentiation or even possibly a layer of ice. A metric camera would photograph most of the moon with good geometric control in order to determine how out-of-round the moon is and whether the centers of maria are lower than the edges. A laser altimeter would bounce a light beam off the lunar surface to measure altitude accurately; such measurements, taken together with orbital data and information from the metric camera, would help to determine the moon's shape.

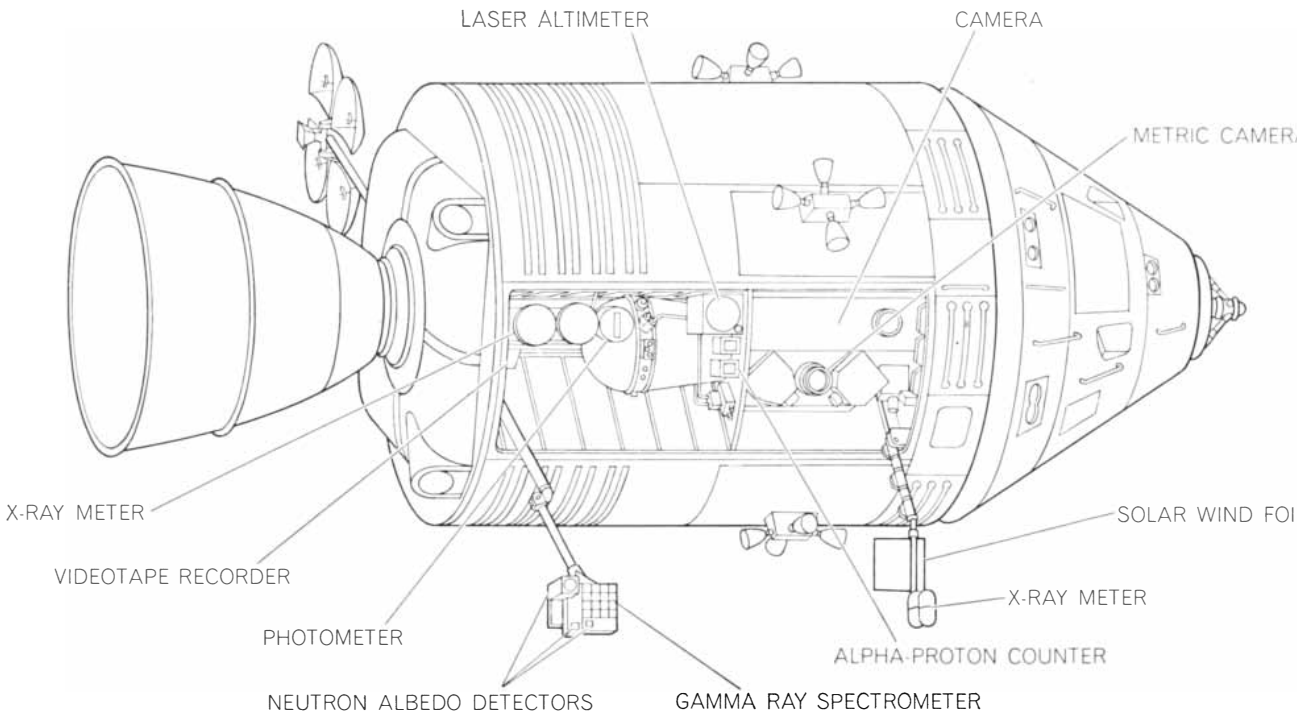
This kind of broad coverage would mesh well with the detailed coverage astronauts on the surface would make of small areas. Each landing would provide a standard for the orbital experiments by measuring in detail what the instruments should see from orbit. The orbiting instruments then would yield a far broader coverage of surface characteristics than could be obtained from manned landings alone.

Attainment of the goals we have described will still leave several exciting frontiers for lunar exploration. They include visits to Mare Orientale, the polar region and the far side of the moon. Such visits will require the development of a new technology.

Long-Term Goals

Mare Orientale, the huge "bull's-eye" feature discovered in Lunar Orbiter photographs, is on the far western edge of the moon as viewed from the earth. It is a splendidly preserved, concentrically layered feature probably formed by the impact of a giant meteorite. The feature offers an unparalleled challenge for exploration, but it also presents large operational difficulties for a landing. The Cordillera Mountains, which ring the Orientale basin to form a circular outer scarp some 960 kilometers in diameter, are among the most massive on the moon, rising some 18,000 feet above the adjacent terrain. Perhaps this site, of all the possible ones on the moon, offers the best opportunity for studying the evolution and history of the moon.

A polar landing is a particularly fascinating prospect. Areas near the poles are in permanent shade, so that one might hope to find frozen ammonia, carbon dioxide, water and similar volatiles that otherwise would have escaped from the moon long ago.



REMOTE SENSING by instruments carried in the service module is planned as a supplement to manned exploration. The nature of the experiments it would perform to measure the lunar surface and assess the structure of the moon is indicated by the instruments.

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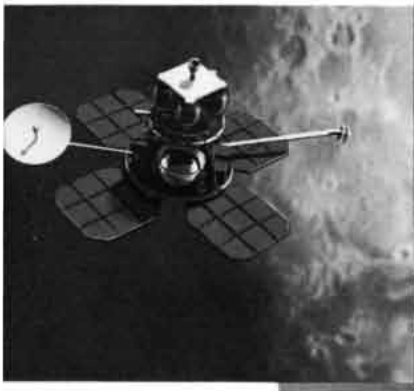

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NORMAL RHESUS MONKEY assumes an alert, crouching stance soon after birth. Curious and playful, it can feed itself easily by sucking on a bottle. At about three months the infant monkey will be more advanced than a human child three or four years old.

ABNORMAL RHESUS MONKEY was experimentally subjected to asphyxia at birth. Like a child suffering from cerebral palsy, this monkey is unable to use its arms and legs normally. It sprawls, and it will not move unless prodded. It is also unable to feed itself.

Brain Damage by Asphyxia at Birth

In both monkey and human infants handicaps that arise from such asphyxia seem to disappear with time. Experiments with monkeys, however, demonstrate that asphyxia permanently damages the brain

by William F. Windle

Birth is a normal physiological event. Most animals that bear live young pay no more heed to it than they do to their everyday activities. The human animal is exceptional. He has come to look on the time of birth as one of the most critical in the life of both mother and child, and rightly so. There are many things that can go wrong with the delivery of the human infant. Not the least of the hazards is asphyxia that can lead to brain damage and possibly cerebral palsy and mental retardation. It is this hazard that I shall discuss here.

Asphyxia is a condition resulting from a disturbance of the respiratory mechanism. It has been defined as a state of suspended animation due to a lack of oxygen in the blood. In the fetus at birth it involves more than a lack of oxygen (hypoxemia). The blood of an asphyxiated newborn infant may not only contain virtually no oxygen but also contain excessive amounts of carbon dioxide and lactic acid, which lower its *p*H (that is, make it acid). The infant's heartbeat will have slowed, its blood pressure may be alarmingly reduced and it cannot begin to breathe. This combination of events is termed asphyxia neonatorum. When such asphyxia occurs, immediate resuscitation measures are of course imperative. Several stages of birth asphyxia are recognized. The hypoxemia is not always prolonged to the point where spontaneous efforts to breathe stop (terminal apnea). When asphyxiation stops short of apnea, the infant will not need resuscitation and its body functions may be only temporarily depressed.

Asphyxia neonatorum is an unnatural event that in human infants may come about because of unavoidable conditions. Among them is the fact that the human infant has a large head. Evolution has given man a highly developed brain and a skull that attains such a size at the end of gestation that its delivery is an unusual biological problem. Today many women have come to fear childbirth and to demand relief from their physician. Sometimes the well-being of the fetus is unwittingly placed in jeopardy in ensuring the mother's comfort and peace of mind. Not all factors that complicate the delivery of the human infant are clearly perceived; some, however, are recognizable and can be avoided.

The role of asphyxia neonatorum in brain damage has been debated for more than a century. As early as 1861 an English physician, W. J. Little, suggested a relationship between asphyxia during birth and neurological and mental disorders of infancy. His view was accepted by few and had little impact on medical practice, although from time to time it was advocated by others. This long debate illustrates what little influence retrospective clinical observations have had on medical opinion. In 1957 C. J. Bailey, speaking at a Puerto Rico conference titled "Neurological and Psychological Deficits of Asphyxia Neonatorum," pointed out that retrospective clinical studies can never logically answer the question of whether asphyxia at birth causes brain damage resulting in symptoms of cerebral palsy and mental retardation or whether other factors causing cerebral palsy and mental retardation also induce asphyxia. Any child with cerebral palsy or mental retardation who also presents a history of asphyxia at birth can be used as an example to support either proposition. The answer can be found only by experiment.

Over the past 15 years much experimental work has been done on asphyxia neonatorum. Obviously such investigations cannot be pursued with the human fetus; controlled experiments with animals have been designed. These experiments, in conjunction with clinical observations, have made us better able to evaluate the role of asphyxia neonatorum in brain damage and propose measures of prevention.

Earlier experiments had been conducted on asphyxia at birth in guinea pigs. Brain damage and impairment of learning ability were found, but the asphyxia required was severe and the relevance of experiments with rodents to findings in human infants was questioned. Therefore when adequate facilities and support became available workers in the field turned their attention to nonhuman primates. The experiments I shall review here were conducted in two National Institutes of Health laboratories (one in Bethesda, Md., and the other in San Juan, Puerto Rico) and more recently at the New York University Medical Center.

We chose the rhesus monkey (*Macaca mulatta*) for studying fetal physiology and its experimental alteration. We used more than 500 fetal and newborn monkeys, about a fifth of which were asphyxiated during birth. Before I turn to the experiments it will be helpful to compare the monkey's birth with the birth of the human infant. There are marked differences that bear on the relevance of comparisons between the two, but there are also many similarities.

Spontaneous neurological deficits are practically unknown among rhesus monkeys born in their natural habitat or in colonies housed in laboratories. In this respect the monkeys differ from human beings. There are a good many defective human offspring and, more important, the techniques of modern medicine can keep them alive. If defective monkeys are conceived, they die at birth and

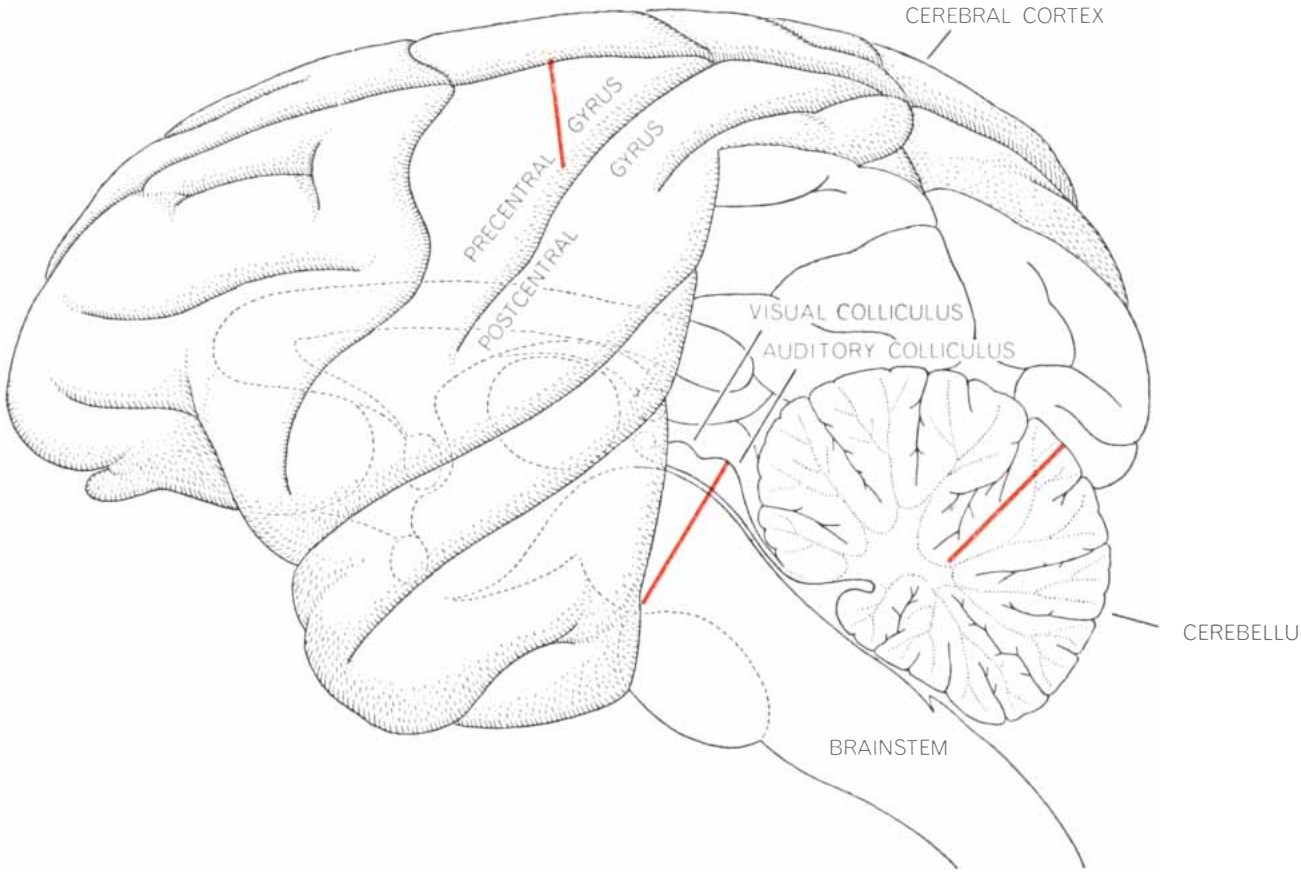
disappear from the monkey population.

Most monkey births occur at night, as is the case with human beings. Labor is short: an hour or less. The female squats and drops the infant on the ground. During delivery most of the blood in the placenta passes to the infant and, as the uterus continues to contract after birth, the placenta is expelled. Thereupon the female severs the umbilical cord with her teeth and, like most other mammals, eats much of the placenta. Human infants are born in much the same way in many parts of the world. The woman delivers, often unassisted, in the squatting position, and the infant, being below her, recovers most of the blood from the vessels of the placenta and the umbilical cord. I would not recommend that women revert to primitive ways, certainly not to chewing the umbilical cord to sever it (a practice that is still encountered in some places). Nevertheless, in any delivery it is important to keep the umbilical cord intact until the placenta has been delivered. To clamp the cord immediately is equivalent to subjecting the infant to a massive hemorrhage, because almost a fourth of the fetal blood is in the placental circuit at birth. Depriving the infant of that much blood can be a factor in exacerbating an incipient hypoxemia and can thus contribute to the danger of asphyxial brain damage.

In advanced countries, of course, the supine position of delivery is used to enable the attending physician or midwife to observe the birth conveniently and to assist if necessary. The squatting position, in addition to allowing the infant to receive the placental blood from above, has other advantages over the supine position. It avoids compression of the blood vessels supplying the placenta, which occurs in the supine patient when the gravid uterus tilts back against the pelvis. Delivery while the woman is lying on her side, however, can also avoid such compression and prevent the infant's oxygen supply from being sharply reduced. Doubtless this position would be more acceptable to American women than the squatting one.

Monkeys offer a number of benefits in experiments on asphyxia at birth. Many of the variables that cannot be avoided in human births can be controlled. Anesthetic drugs that might affect the infant's ability to begin breathing need not be administered. The production of asphyxia can be timed with some accuracy and terminated at precisely the desired moment. Most important, after observations of the behavior of a monkey that has been asphyxiated and resuscitated have been completed, the brain of the monkey can be prepared for histological examination, thus providing the kind of neuropathological material that can rarely be obtained from human subjects.

We began our experiments by inducing asphyxia in infant monkeys near the end of gestation (which lasts about six months). The fetus and its surrounding membranes were removed by Cesarean section after the mother had been given a local anesthetic. Stimulated by the asphyxia imposed by its removal from the mother, the fetus attempted to breathe while it was still enveloped in the surrounding membranes. These respiratory movements continued for eight or nine minutes. When they had stopped, the membranes were opened, a tube was inserted into the monkey's trachea and at a predetermined time artificial respiration with oxygen was started. This was continued until the infant monkey began



INJURIES of the monkey brain are produced by asphyxiation for varying periods. Lines (*color*) indicate regions that are often severely damaged by asphyxiation during birth. Asphyxia lasting more than 12 minutes creates lesions in the auditory colliculus and in deeper brain structures but does not affect the visual colliculus. It also causes degeneration of cells in the cerebellum and sometimes in the precentral gyrus of the cerebral cortex, a part of the brain concerned with such functions as memory and learning.

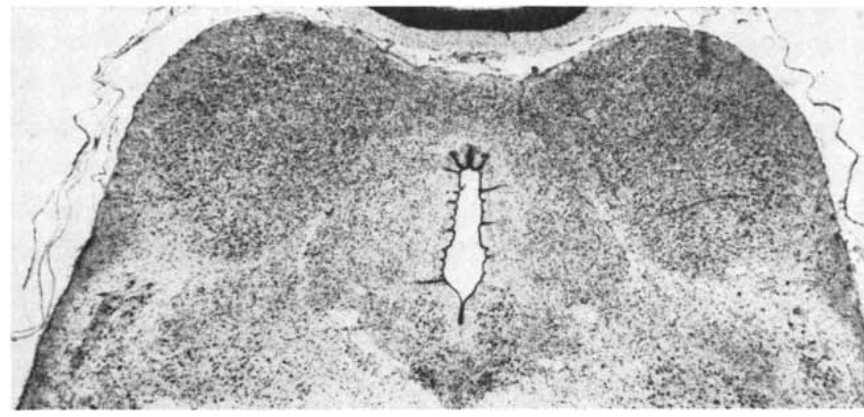
to breathe. In some experiments asphyxiation was halted before the monkey's efforts to breathe had stopped, so that no resuscitation was required. Other monkeys were delivered by Cesarean section but were not asphyxiated; these animals and some that were born spontaneously served as controls.

The period of asphyxiation ranged from four minutes to more than 21 minutes. Some of the more severely asphyxiated monkeys died soon after birth. Others were killed for neuropathological studies after as little as a few days and as much as several years. A few are still living more than 10 years after asphyxiation.

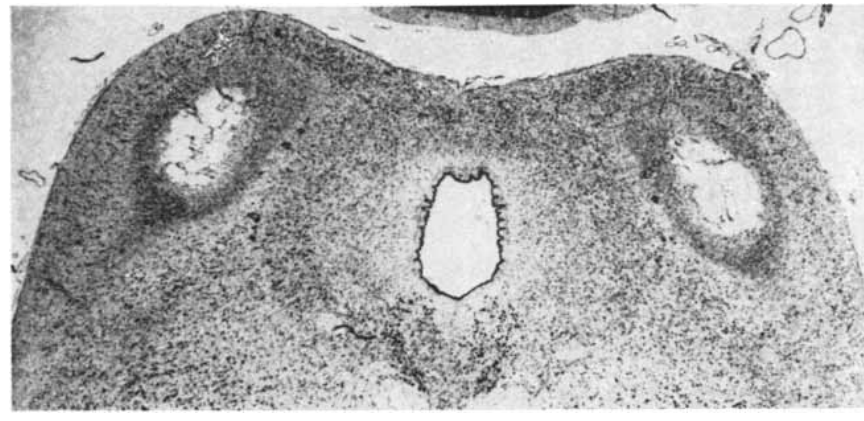
Both the experimental monkeys and the controls were raised by technicians, when necessary in an oxygen-enriched atmosphere. Periodically the animals were examined and given tests to evaluate their neurological status. The experimental procedures and the monkeys' behavior and reactions were recorded with motion pictures, which proved invaluable for later review. For the neuropathological studies each brain was sliced into as many as 5,000 sections for microscopic examination. Sections were also made at representative levels of the spinal cord.

One of our first aims was to find out how short a period of asphyxia will leave a mark and how long a period is compatible with survival. In two monkeys that had been asphyxiated for only six minutes at birth and had not needed resuscitation we detected what we termed "minimal" structural brain damage, but there was no appreciable deficit in function. At the other extreme was a monkey that had been asphyxiated for more than 21 minutes at birth and had been in coma until it was killed after three days. Nearly all parts of its brain showed severe damage. Most of our observations were made on the brains of animals that had been asphyxiated for eight minutes or more. (More than eight minutes must elapse during asphyxiation before resuscitation becomes necessary.) We found no lesions in the brains of the control monkeys.

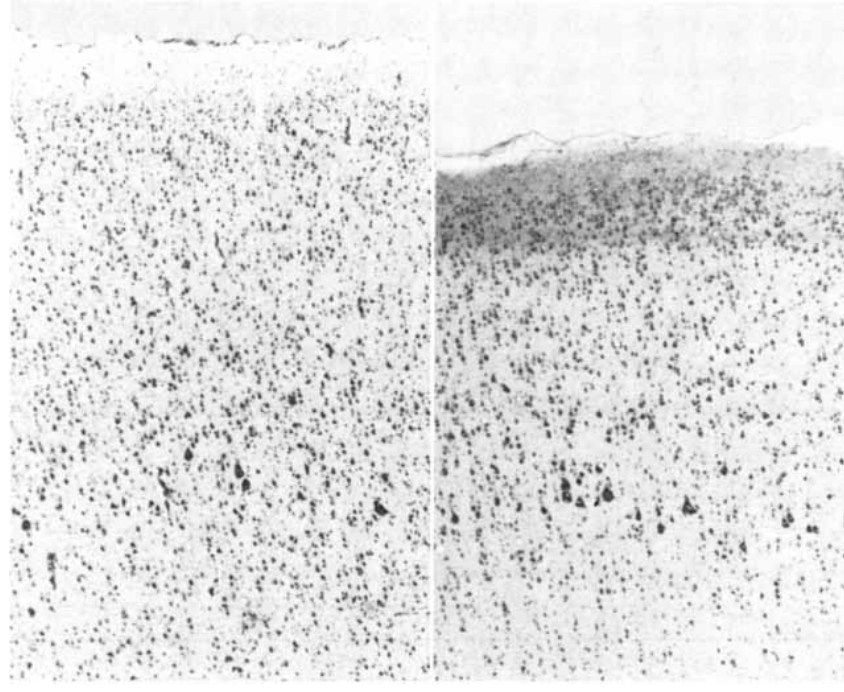
In monkeys that had been asphyxiated for eight to 12 minutes there was loss of nerve cells in the thalamus and the inferior colliculus of the midbrain (both are centers that receive nerve impulses concerned with general body sensations and hearing and relay them to the appropriate higher centers) and in some other groups of cells in the brain stem. Symmetrical lesions were produced on both sides of the brain. They were sharp-



NORMAL COLLICULUS consists of densely packed nerve cells that relay nerve impulses related to hearing originating in the structures of the ear to the higher brain centers.



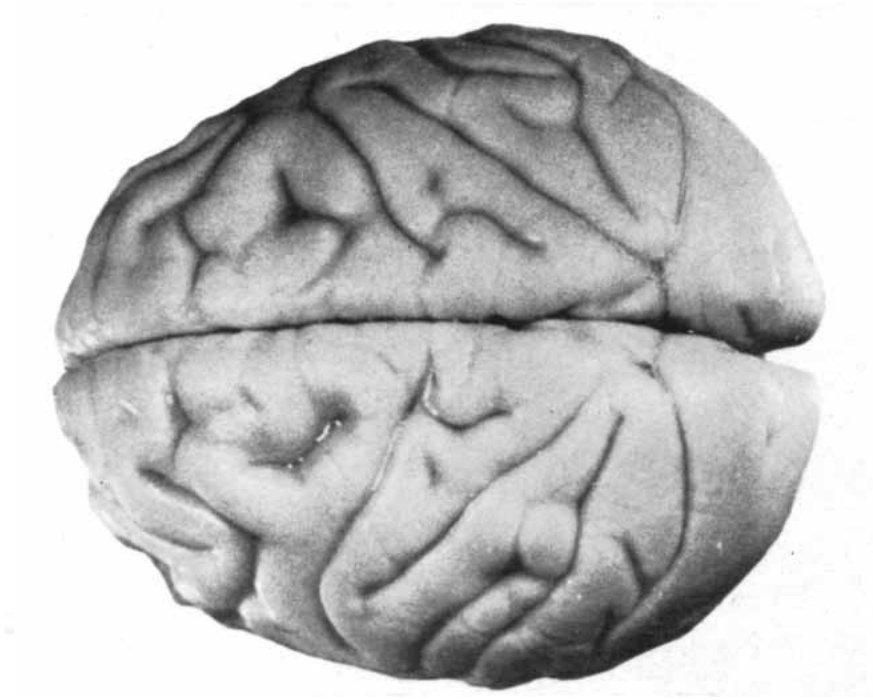
DAMAGED COLLICULUS from a monkey that was asphyxiated during birth nearly five years previously is pitted by cavities (*left and right*) left by cells that disintegrated.



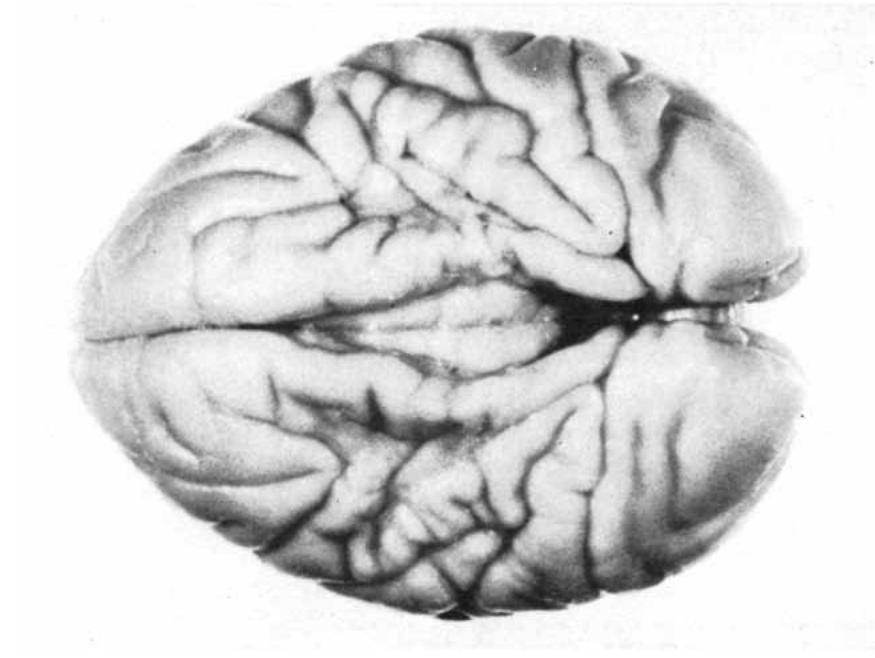
PRECENTRAL GYRUS normally consists of a thick structure of cells (*left*) organized into layers. Asphyxia at birth causes the precentral gyrus to atrophy (*right*), because cells in this structure are linked to those in the thalamus by fibers. When asphyxia destroys the cells of the thalamus, both the linking fibers and cells of gyrus degenerate and disappear.

ly circumscribed by unaffected tissue and showed no hemorrhages. Most other parts of the brain, including the motor components of the spinal cord, the cerebellum and the cerebral cortex, were also unaffected.

Monkeys asphyxiated at birth whose brains were affected in this pattern displayed abnormal neurological signs after resuscitation. They had trouble righting themselves and for a time could not move about easily. Their limb movements were uncoordinated. All of them had trouble feeding because they could not suck. These abnormalities eventually disappeared, often within a few days and at most within a few weeks. The electroencephalogram of the monkeys, when it was affected at all by such asphyxia, quickly became normal.



NORMAL BRAIN of a rhesus monkey that was not asphyxiated has a fully developed cerebral cortex. The convolutions of the cortex have a characteristically rounded form.



ABNORMAL BRAIN of a three-month-old monkey that had been asphyxiated and revived, but suffered respiratory distress, is shriveled because lack of oxygen killed tissue.

These monkeys may be comparable to human infants who encounter some degree of asphyxia at birth, have low Apgar scores (an index of the newborn infant's general condition) but recover without apparent neurological deficit. It is generally believed that such infants are normal. If one could inspect their brains as we examined the brains of our monkeys, one would probably find the same kind of lesions. It is no longer acceptable to assume that the human fetus or newborn infant is so resistant to oxygen deficiency that it will escape harm from a short exposure to asphyxia neonatorum. If the infant's brain can be compared to the monkey's, asphyxia of such duration that resuscitation was required will certainly have damaged it. The damage, although it is minimal, will be permanent even when it is clinically noticeable for only a short time or when it produces no symptoms at all. What effect such minimal brain damage will have as the child matures is not known.

Asphyxia lasting more than 12 minutes during the monkey's birth damaged brain structures more extensively and caused more pronounced functional deficits. The basic lesions of the thalamus, the inferior colliculus and the brain stem were more severe. They consisted of regions where nerve cells had degenerated and in time had been replaced by scars surrounded by normal tissue. Furthermore, there were new centers of destruction in the basal ganglia, the cerebellum and the spinal cord. The cerebral cortex and the primary motor nuclei remained less damaged than other regions. (This was true even in the brain of the monkey that had sustained more than 21 minutes of asphyxia.) The white matter in the brain and the spinal cord was not affected directly, although tracts of nerve fibers associated with cells that had been destroyed by asphyxia had themselves degenerated.

All the monkeys that had been asphyxiated during birth for more than 12 minutes and had to be resuscitated exhibited functional deficits that persisted for some time. Many required intensive nursing care. The most seriously injured animals presented symptoms resembling those encountered in human beings with cerebral palsy.

The amount of brain damage and the extent of functional loss were sometimes increased by complicating factors associated with asphyxia neonatorum or arising afterward. Some of these factors are premature birth, postnatal respiratory distress accompanied by so-called hyaline membrane disease, cerebral

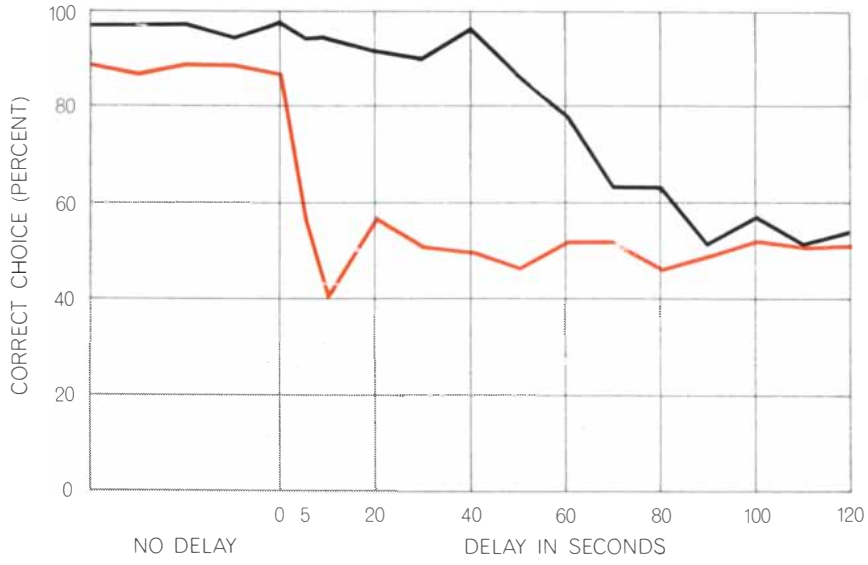
hemorrhages, swelling of the brain and the neuropathological condition known as kernicterus.

Inadequacy of lung function is often encountered in prematurely born infants. The establishment and maintenance of breathing depends on the immediate expansion and activation of the alveoli, or air sacs. The lungs attain a state of development that can support breathing well in advance of a normal full-term birth. There is a point in time, however, before which full efficiency of the pulmonary mechanism has not been attained, and if birth occurs prematurely, the lungs cannot adequately oxygenate the blood. The infant turns blue and enters a state of respiratory distress.

Postnatal respiratory distress in the monkey resembles such distress in human infants. It is manifested by rapid gasping and by inward movement of the edges of the rib cage, often accompanied by audible grunts. The monkey is pale and, even when it is kept in an atmosphere enriched with oxygen, its respiration occasionally fails and it turns blue. Respiratory distress arose spontaneously in only four out of 90 of our nonasphyxiated infant monkeys, and three of these were so premature that their lungs were incapable of normal function. In contrast, the incidence of respiratory distress was high (50 percent) among 68 monkeys that had suffered asphyxia neonatorum or other kinds of experimentally induced crisis.

Some of the monkeys exhibiting respiratory distress and requiring intensive nursing care in incubators supplied with oxygen showed evidence of added neurological deficits. When their brains were examined later, certain regions of the cerebral cortex were found to have undergone marked degeneration. Thus it appears that postnatal respiratory distress can increase the brain damage of asphyxia neonatorum, and although it is not the primary cause of damage in such disorders as cerebral palsy and mental retardation, it is surely an important contributing factor.

When the lungs of some of the monkeys that had failed to survive were examined, membranes were found in the alveoli similar to those seen in some human infants who are said to have died of hyaline membrane disease. Such membranes interfere with the normal exchange of carbon dioxide and oxygen in the alveoli. They were not encountered in the lungs of monkeys that had not been asphyxiated. The formation of hyaline membranes appears to be a manifestation of abnormal pulmonary function. This condition is therefore not really a disease but an effect of the asphyxia. It can be prevented but not cured.



TEST PERFORMANCE shows that monkeys with atrophied brain tissue have a diminished ability to remember. In this test experimental and control monkeys watched through a plastic window as a food pellet was placed in one of two covered containers. The window was then opened so that the monkey could take the food. If the opening of the window was delayed for five seconds or more, the monkeys that had suffered asphyxia 10 years earlier (*colored curve*) reached for the food receptacle only about 50 percent of the time, a record that was no better than what would have been expected on the basis of random choice.

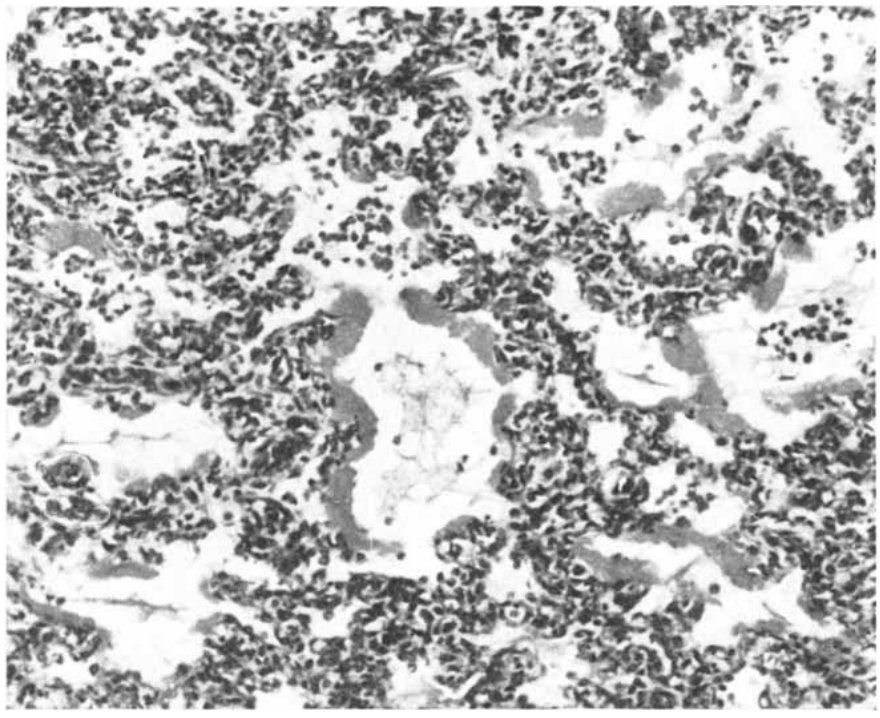
As for the complicating factor of cerebral hemorrhage, it is widely believed asphyxia neonatorum produces little hemorrhages in the brain, because they are sometimes found after death in human infants who had suffered asphyxia at birth. The belief that hemorrhages in the brain are the result of asphyxiation is so firmly held in some places (notably France) that if an infant is found dead in its crib with its face up, and if postmortem examination by the medical examiner discloses hemorrhages, the death is likely to be considered homicide by suffocation. Experimental findings in monkeys place brain hemorrhages of the newborn in a different light.

The asphyxiation of monkeys produced no hemorrhages, large or small. The duration of asphyxia made no difference; hemorrhages were absent from the brain of the one monkey that had been resuscitated after more than 21 minutes of asphyxia. Even monkeys asphyxiated so long that they could not be resuscitated showed no cerebral hemorrhages. On the other hand, little hemorrhages were sometimes found in the brains of asphyxiated monkeys that had been resuscitated but then for one reason or another, days or even weeks later, had difficulties in breathing that led gradually to their death. Hemorrhages of this kind must be caused by factors other than the lack of oxygen.

Premature birth is said to enhance the likelihood of cerebral hemorrhage. Traumatic delivery may also be an important cause of such hemorrhage. We observed brain hemorrhages in a monkey whose head had had to be extracted manually during a breech birth (a feet-first delivery). Human infants may be more susceptible to traumatic birth injury and brain hemorrhage than monkeys because of their larger heads. The use of drugs to strengthen uterine contractions and hasten delivery can cause bleeding from the vessels of the brain. Oxytocin administered to a gravid monkey to induce labor was responsible for hemorrhages in such deep-seated fetal brain structures as the globus pallidus.

Some neuropathologists believe swelling, or edema, of the brain is a primary cause of brain lesions. Other investigators have reported that edema of the fetal brain was induced by experimental interference with the passage of oxygen across the placenta in monkeys. Our experimental asphyxiation of monkeys during birth, however, did not result in any swelling that could be identified at any time after their resuscitation. It seems probable that edema of the brain at birth is not an important cause of brain damage.

Kernicterus is characterized by groups of nerve cells with a canary yellow color. This condition is related to high levels in the blood of the bile pigment bilirubin. A high bilirubin level (hyperbilirubinemia) is manifested by jaundice and



HYALINE MEMBRANE appears as a dark lining inside the lung sacs in this micrograph. It is widely believed the hyaline membrane causes asphyxia at birth. The author proposes that, rather than being a cause of asphyxia, the membrane is the result of asphyxia.

occurs in infants with such disorders as Rh incompatibility. Sometimes extraordinary efforts are made to ameliorate hyperbilirubinemia in human infants in the belief that the excessive amount of bilirubin can produce brain damage. We found no experimental evidence that hyperbilirubinemia per se causes the lesions that have been associated with kernicterus.

When the level of bilirubin was experimentally elevated in the blood of newborn monkeys, a marked jaundice developed, but no kernicterus. An episode of asphyxia during birth superimposed on hyperbilirubinemia did, however, bring about a full-blown kernicterus. It is true that hyperbilirubinemia is associated with the reduced ability of tissues to utilize oxygen, and that it can thus compound the metabolic disturbances caused by asphyxia or other conditions. These observations suggest that when hyperbilirubinemia is present, the emphasis should be placed less on relieving the jaundice than on avoiding or preventing asphyxia. Maneuvers aimed at eliminating or reducing excess bilirubin in blood of the fetus may only exacerbate other conditions that may give rise to asphyxia. Such maneuvers may produce the same brain damage or even worse damage but without the telltale yellow color of kernicterus.

Most of our experiments on asphyxia neonatorum in monkeys were designed with the hope of avoiding these various complicating conditions. One of our major concerns was to determine what effects asphyxia neonatorum might have on the individual as he matured. It is known that children with some forms of brain damage arising from difficulties at birth show improvement over a period of time. Credit is often given to intensive therapy, but many instances of spontaneous improvement are known.

The briefly asphyxiated infant monkeys with minimal brain damage lost their signs of neurological deficit. Even those whose brains had been severely damaged by more prolonged asphyxiation, including several that had experienced other difficulties after birth, exhibited substantial improvement in their physical condition in due course. The extent of this "recovery" was surprising because no replacement of the nerve cells destroyed by asphyxia neonatorum could be expected. Only after we had made thorough histological studies of the brains of the animals that had been allowed to reach adolescence or adulthood did the significance of the apparent recovery become clear.

Seventeen monkeys were selected for a study of changes in neurological status over a period of time. All of them had shown marked neurological deficits on the first day after resuscitation. Seven of them had turned blue after birth, and two had been in coma. None could suck, and six showed impaired swallowing. All 17 monkeys tended to be lethargic. They could not right themselves but lay on their side and made uncoordinated flailing movements of their arms and legs when they were disturbed. Normal newborn monkeys can right themselves and crawl in a few hours; a few can stand, although they are unsteady when they try to walk.

During the first week or two it was necessary to keep most of these asphyxiated monkeys in incubators in order to control their body temperature and to be able to administer oxygen on occasion. Some required nursing care around the clock. They slept most of the time but made random movements when they were handled. When they awoke, their crying was weak. Three of them had minor seizures of forelimbs and five had generalized seizures of the trunk and the extremities, accompanied in two cases by salivation and vocalization.

By the end of the first or second week the condition of most of the monkeys showed some improvement. Although they could not right themselves, they maintained a sprawling attitude when they were placed in the prone position. They did not move, however, until they had been stimulated. Then their attempts to progress forward were weak, their limb movements being uncoordinated and tremulous. They could not localize sounds. They were still quite helpless.

Some of the early neurological deficits gradually disappeared or were masked as the monkeys matured. The adjustment to handicaps began to be evident during the first month. Normal monkeys a month old are active, alert and highly emotional. They run, climb and jump, and are more advanced in many ways than human children three or four years old. The month-old asphyxiated monkeys, on the other hand, were dull, slow and generally inactive. They lacked curiosity about surrounding objects and were undisturbed by strange environments. Their motor functions were not normal. Their limb movements were imperfectly coordinated, their forelimbs often acting independently of their hindquarters. Some of the infant monkeys had marked peculiarities of locomotion. They hopped forward like a rabbit, using their hind limbs as a pivot. One monkey had such marked spasticity of the forelimbs that it used its limbs as crutches in hopping. Some of the month-old monkeys still had difficulty sucking. Seizures were no longer seen and electroencephalograms showed few abnormalities.

In most cases the functional defects

gradually became less noticeable. The daily care of one animal, however, was so burdensome that it was killed at 10 months. The rest were permitted to live until adolescence or maturity; five of them are still alive nine to 11 years after asphyxiation at birth. This is about a third of their normal life-span.

The adjustment of the monkeys to the neurological deficits of infancy reached a plateau after three or four years. The residual deficits of the surviving animals are now inadequate manual dexterity and a reduced level of spontaneous activity. The monkeys find it difficult to pick up small morsels of food and prefer to feed themselves as dogs do. They can run, climb and jump when forced, but usually they do not choose to do so. They simply do not engage in all the activities of normal rhesus monkeys. Nevertheless, casual inspection of them in their cages reveals little or nothing of an abnormal nature. This was the case in all of the monkeys that had survived for a long period, including the 12 that were killed for brain studies.

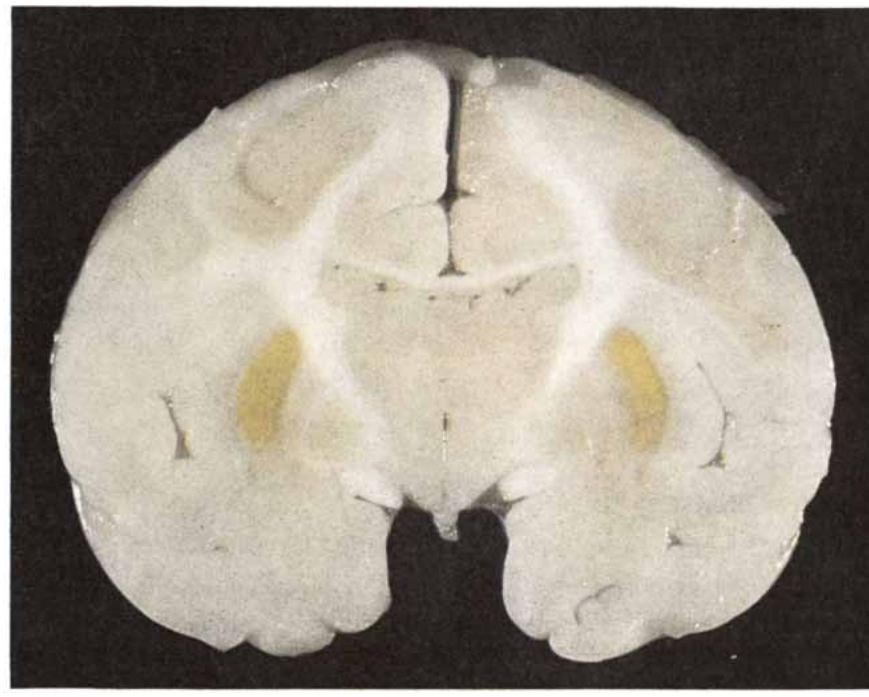
Sections of these brains showed the same pattern of lesions found in the brains of the monkeys killed a few days to a few months after resuscitation. The original lesions of asphyxia appeared as shrunken scars or even cavities. There was no evidence of structural "repair" of the brain tissue. Indeed, there was more loss than we had encountered in the brains of asphyxiated monkeys killed soon after birth. A widespread depletion of nerve-cell populations in regions that had not been affected by the initial asphyxiation had developed. This was particularly noticeable in certain regions of the cerebral cortex, but it was also encountered in parts of the thalamus, the basal ganglia and the brain stem, and in the dorsal regions of the spinal cord. The cell loss was not accompanied by scar formation, as it had been after the primary asphyxia lesions. Nerve cells of these initially intact regions simply were not there. It is probable that their disappearance from the cerebral cortex had come about because nerve cells in the thalamus had been destroyed by the asphyxia at birth and their nerve fibers, which radiate from the thalamus to the cortex, had degenerated. The nerve cells of the cortex on which these fibers had terminated atrophied and disappeared.

The monkeys that showed this secondary brain damage had been severely affected by the primary losses incurred with asphyxia neonatorum, and early in life they had exhibited symptoms comparable to human neurological disorders, including cerebral palsy. The symptoms gradually lessened, and in time most of them disappeared. (This is strikingly evident in our motion-picture records.) In view of the extensive nerve-cell loss that had been sustained by the brain it is remarkable that so few physical handicaps persisted. The main structural defects involved centers that process signals from the environment and others that control the association and integration of information. The motor elements withstood the effects of asphyxia neonatorum to a greater degree. This leads one to wonder if such functions as memory and learning were affected by the physical damage so apparent in the microscope slides.

In undertaking to answer this question Jeri A. Sechzer tested four of the surviving experimental monkeys against four similarly reared normal monkeys for their ability to execute a standard delayed-response test. The testing was done in their home cage, to the front of which a special device had been attached. Through a plastic window the monkeys could watch the experimenter place a banana-flavored food pellet in one of two closed wells. After a delay of between five and 120 seconds the window was raised and the monkey was expected to open the correct well to get the reward of food. The study clearly demonstrated a memory deficit in the monkeys eight to 10 years after asphyxia [*see illustration on page 81*].

How can these findings in monkeys be related to human infants who survive asphyxia neonatorum and initially have alarming neurological deficits? Significant data on the question are now available from the Collaborative Perinatal Research Program supported by the National Institutes of Health. Approximately 1.5 percent of all the infants who had been born on the obstetrical services of the 14 participating U.S. medical institutions were found to have neurological abnormalities at the end of their first year. If the neurological examinations had been conducted before the infants were a year old, the number with detectable deficits would undoubtedly have been much greater; for example, 21 percent of the infants in the study had low Apgar scores at birth.

The findings were not considered to be particularly alarming because most of these children seemed to be normal by the time they were four years old. It may be wishful thinking, however, to conclude that all is well with such a child because he does not have a physical handicap. It is commonly recognized that improvement can be expected after a distressful birth. A child with a slight brain defect often appears no different from a normal child. His intelligence quotient may lie in the range considered



CELLS STAINED YELLOW, a condition called kernicterus, appear in this micrograph of tissue from monkey brain. It was thought that such staining, produced by excessive amounts of the bile pigment bilirubin in the blood, damaged brain cells. It appears, however, that only those cells that are already damaged by asphyxia at birth become stained with pigment.

"LASER LIGHT"

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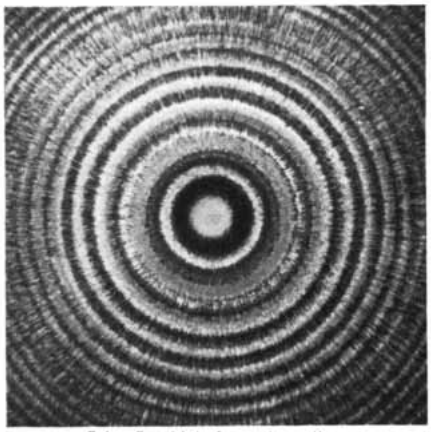

Fabry-Perot interferometer pattern
in krypton-ion laser beam

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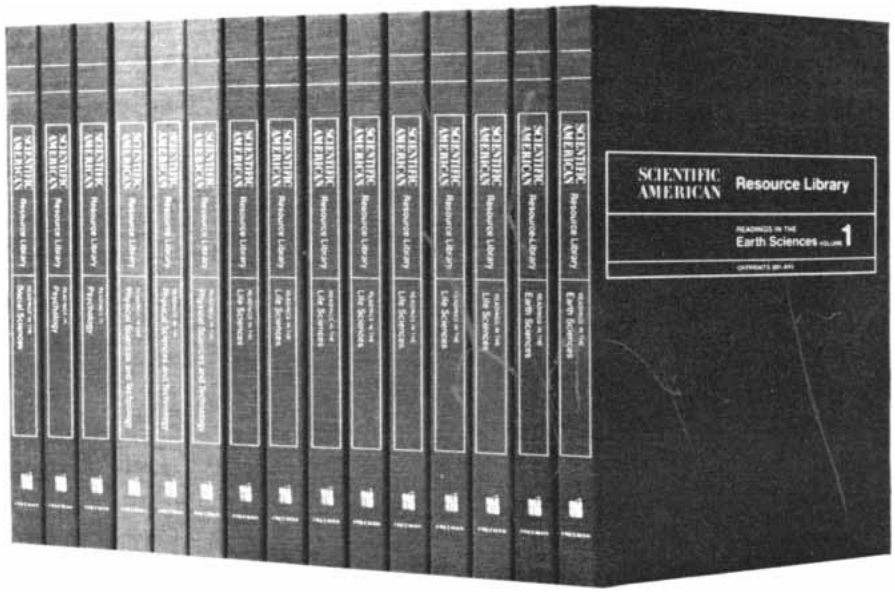
normal, but one never knows how much higher it would have been if his brain had escaped damage in the uterus or during birth. The brain-damaged monkeys also overcame most of their neurological deficits at roughly comparable stages of development. The difference is that we know that the brain of a "recovered" monkey is structurally damaged, whereas we only assume on clinical grounds that the brain of a "recovered" human infant is normal. There can now be little doubt that the brain of such an infant also harbors lesions. The few postmortem studies of the brains of human infants who suffered asphyxia at birth have revealed damage similar to that sustained by the asphyxiated monkeys.

The monkey experiments described in this article have taught us that birth asphyxia lasting long enough to make resuscitation necessary always damages the brain. This could be proved, however, only by histological examination. A great many human infants have to be resuscitated at birth. We assume that their brains too have been damaged. There is reason to believe that the number of human beings in the U.S. with minimal brain damage due to asphyxia at birth is much larger than has been thought. Need this continue to be so? Perhaps it is time to reexamine current practices of childbirth with a view to avoiding conditions that give rise to asphyxia and brain damage.

AZTEC FIGURINE of Ixcuina, the goddess of childbirth, illustrates the squatting position of delivery that is observed in some primitive societies today. It may be that this position is less likely to cause asphyxia of the infant than the supine position of delivery.



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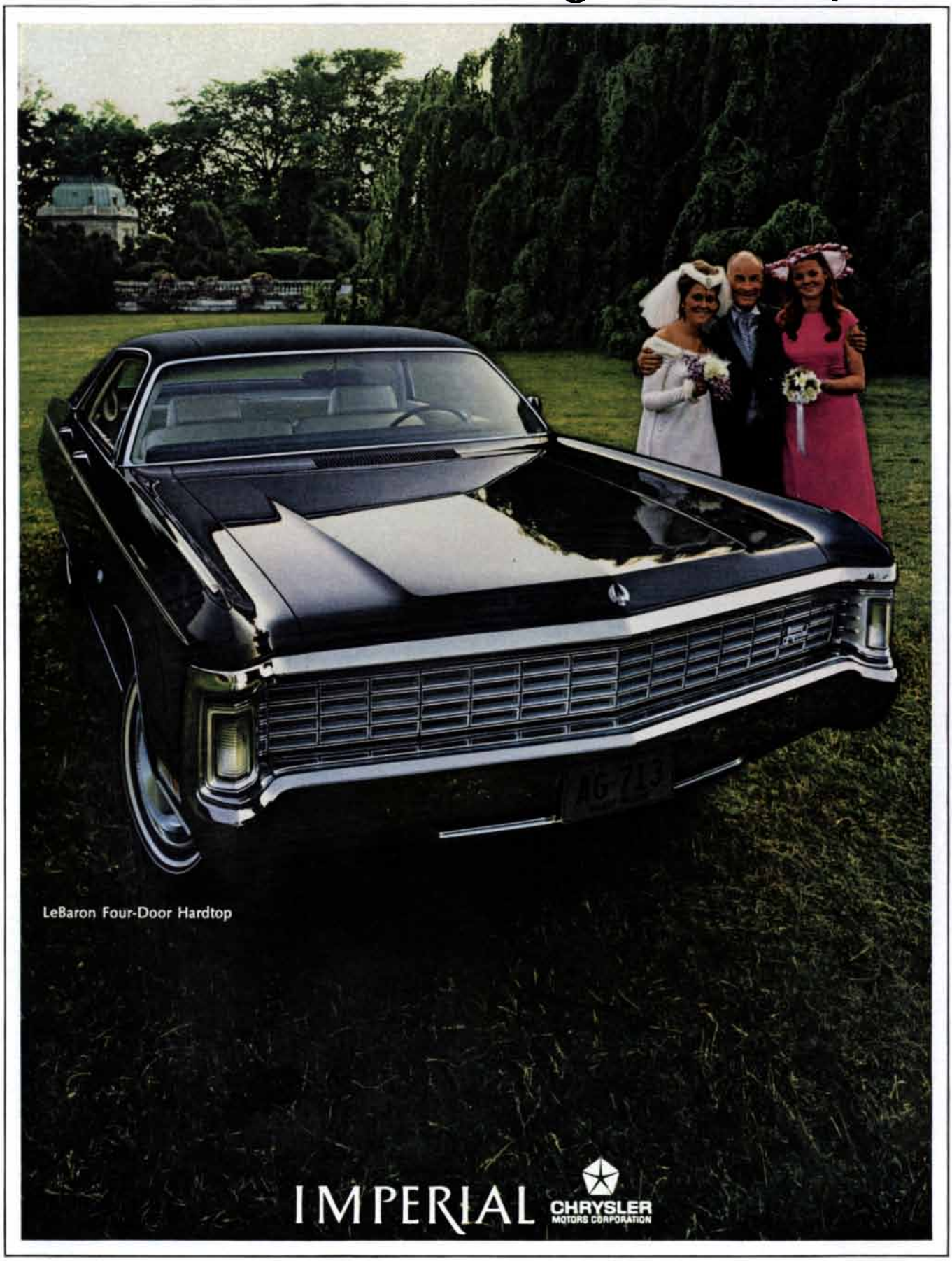

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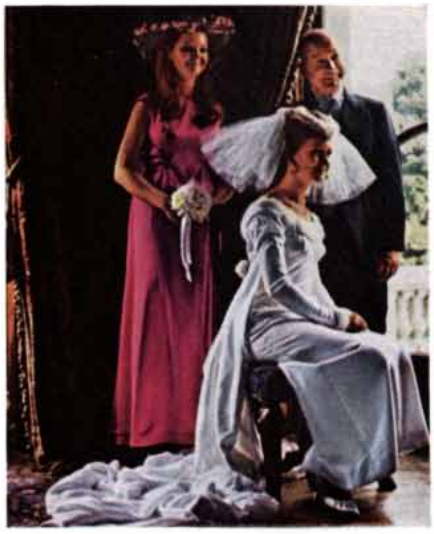

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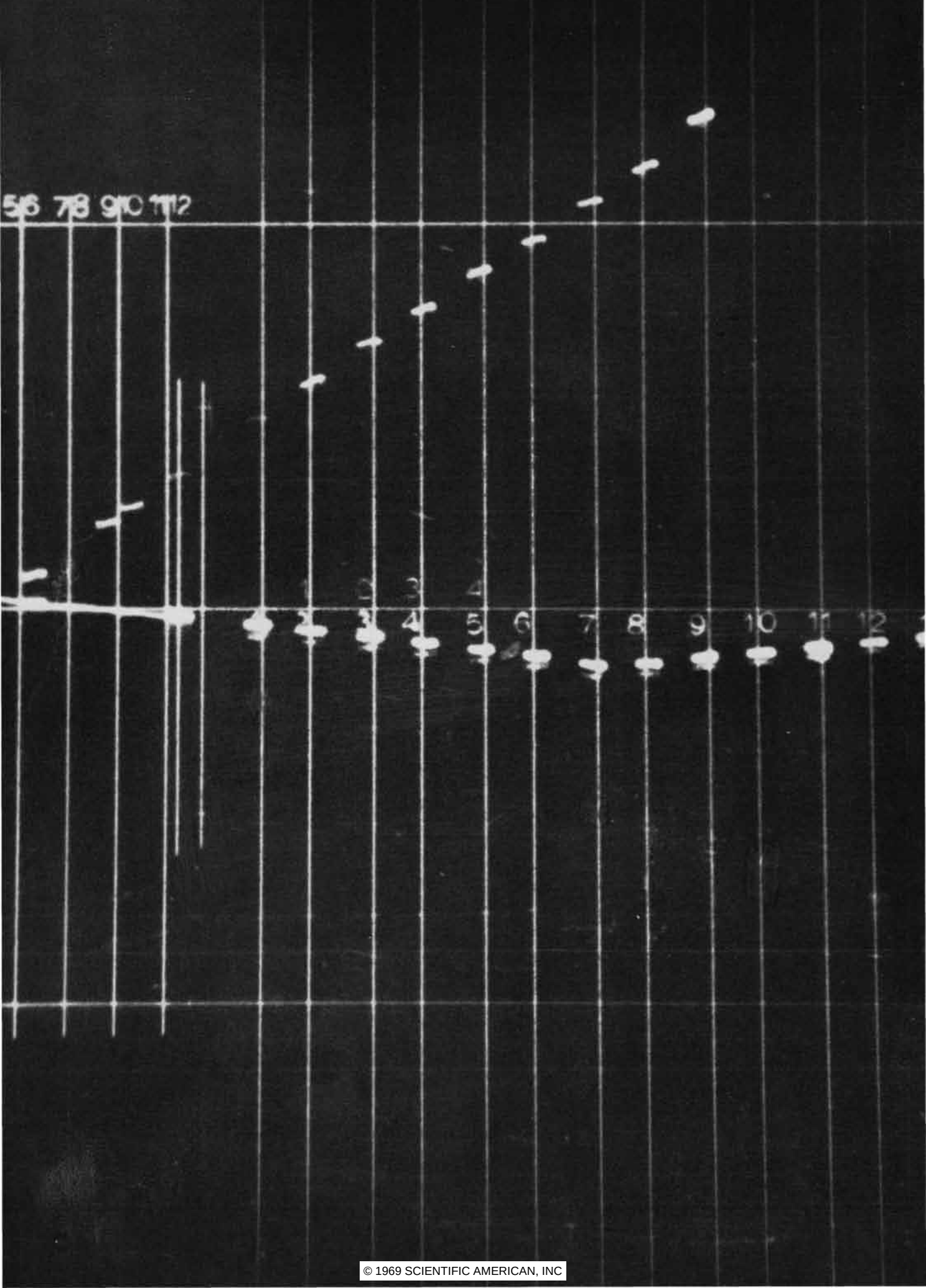


Experiments in Time Reversal

With the presumed symmetry of charge and parity disproved, rigorous tests have been made of nature's indifference to which way time flows. No proof to the contrary has yet appeared but the hunt for it goes on

by Oliver E. Overseth

The arrow of time, to use that marvelous phrase of Sir Arthur Eddington's, points in an obvious direction. It is aimed toward the future, over which we can hope to exert some control, and away from the irretrievable past. All of us vividly recognize which way time flows; we take considerable comfort, for example, in our confidence that the carefully arranged marriage of gin and vermouth is not going to be suddenly annulled in our glass, leaving us with two layers of warm liquid and a lump of ice. It is a curious fact, however, that the laws that provide the basis for our understanding of fundamental physical processes (and presumably biological processes as well) do not favor one direction of time's arrow over another. They would represent the world just as well if time were flowing backward instead of forward and martinis were coming apart rather than being created.

This symmetry of the basic laws of nature with respect to the direction of the flow of time has long been a principle of physics. Eddington himself touched on time at considerable length (in his Gifford Lectures of 1927). After discussing the physical and philosophical foundations of the then new theories of relativity, gravitation and quantum mechanics, he concluded: "The laws of nature are indifferent as to a direction of time. There is no more distinction between past and future than between right and left."

Today we have come to realize that the laws of nature are *not* indifferent to right and left, and we now suspect that they also make a distinction between past and future. As a result of recent findings in elementary-particle physics the principle of the symmetry of the flow of time has been seriously challenged. An intense search is now under way to see if violations of the principle can be detected experimentally. Workers in the fields of atomic, nuclear and high-energy physics have undertaken a multipronged attack on the problem. No violation has yet been confirmed, but there is good reason to believe an asymmetry exists. It may be very small and difficult to detect, or perhaps we have not yet looked in the right places.

In this article I should like to show how physicists conduct the search for violations of what is known as time-reversal invariance and to summarize the results of some of the most significant tests. I shall also describe a typical experiment, not surprisingly one in which I participated. Before proceeding it will be useful to consider why the question of the violation of time-reversal invariance arose in the first place. Let us start with the concept of time reversal and the role that it and similar symmetry principles play in physics.

As an example of how physical laws remain unchanged in spite of reversal of the direction of time, consider celestial mechanics. We can apply the law of gravitational attraction to the solar system not only to predict future eclipses of the moon but also to tell us when past eclipses occurred. To "predict" past eclipses one applies time reversal. Imagine that the direction of orbital motion and the direction of spin of all the bodies in the solar system have suddenly been reversed. Now leave them free to move under their mutual gravitational attraction. Time-reversal invariance tells us that the bodies will evolve in time backward through exactly the same orbits they have just traversed. The equations of physics do not prefer one direction of planetary motion over its opposite. The planets are moving in one direction around the sun only because they somehow got started in that direction.

Another traditional example is found in the collision of billiard balls. Let a motion picture be taken of a series of elastic collisions of several billiard balls. On showing the film the projectionist gets confused and runs the film backward. Because the elastic collisions of the balls are invariant under time reversal, either a backward or a forward viewing corresponds to situations that can be physically realized; we in the audience cannot tell in which temporal direction the film sequence was actually shot. This same time symmetry has been found to be true for all known laws of physics, the classical Newtonian ones as well as those of modern quantum mechanics. On the other hand, almost everything we experience in the everyday world is strongly asymmetrical in time. It is absurd for us to conceive of our world as suddenly running backward. The ascending jet airplane will not suddenly suck up its exhaust and land tailfirst on the runway, nor will the shaving-cream foam be whisked back into the can. The world around us is most certainly evolving in one particular direction of time.

We can understand this apparent paradox by focusing our attention on the complexity of the process being considered. In a sufficiently complex event, for example a physical reaction involving a large number of particles, we find that a definite directionality of time flow is generally observed. Conversely, when we

SPARK-CHAMBER TRACKS, bright dashes in the photograph at left, are made by a pi meson (*top*) and a proton (*bottom*) following the decay of a neutral lambda particle. Time-reversal invariance has been violated if the numbers of protons that scatter to the left and to the right are not equal.

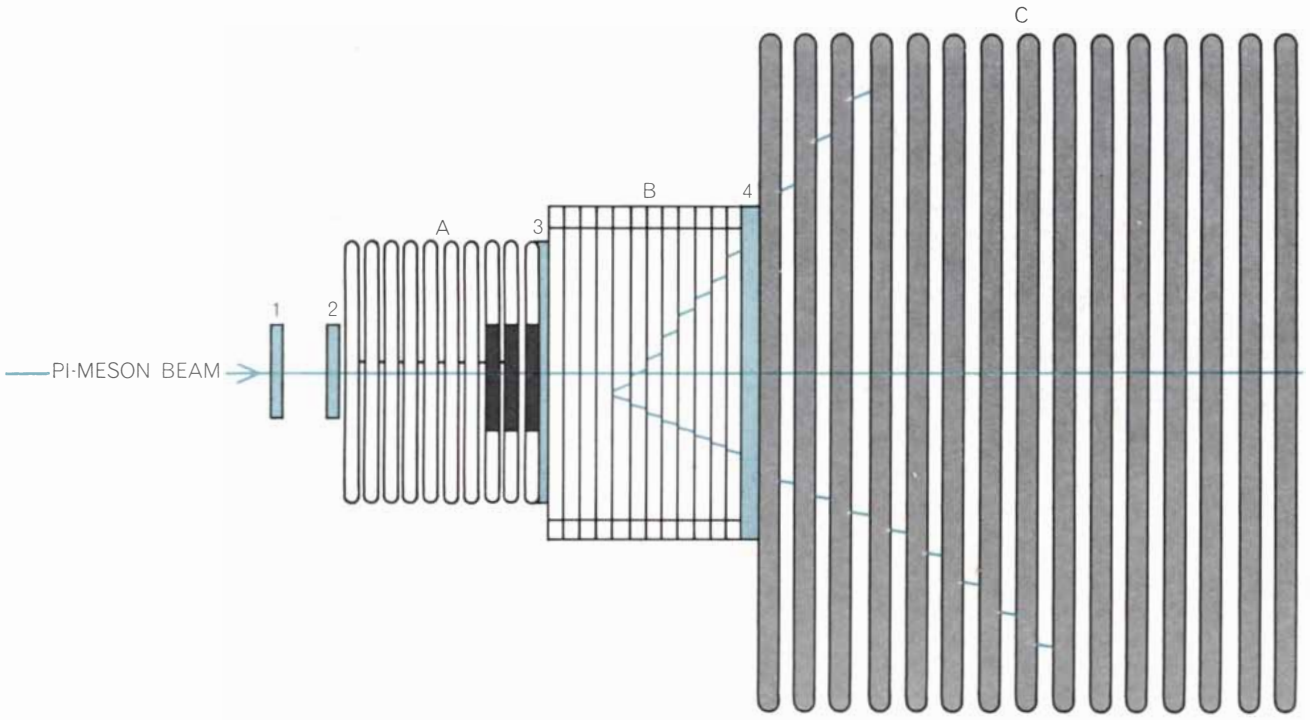
focus on elementary interactions between a few particles, this directionality is lost. The principle is the one contained in the second law of thermodynamics, which states that ordered systems tend to evolve in such a way as to increase their degree of disorder, or randomness. The evolution toward increasing randomness defines the direction of time.

Let us return to our film of billiard ball collisions. If we saw 16 balls that were being knocked around a table suddenly coalesce into a neat triangle except for a white one that proceeded away from the others to hit a cue stick at the edge of the table, we would strongly suspect an attempt at humor on the part of the projectionist. The important point, however, is that such a sequence of events violates no physical laws, only credibility. The second law of thermodynamics does not forbid you from achieving this result for a given shot at the pool table; it simply advises you not to hold your breath while you are trying to do it. Moreover, if you are in a sporting mood and want to place a bet on such an outcome, the second law can give you the odds you should demand. The time-reversed world is not impossible, just highly improbable.

The assumed indifference of elementary physical laws to the direction of time is an example of the basic symmetry property of nature. In fact, it is one of three fundamental symmetries that are of considerable importance to an understanding of the basic forces of nature. The three are denoted in contemporary physics by the letters P, C and T. When we inquire into the symmetry of nature under the operation termed parity (P), we are asking if there is any difference between our world and a mirror image of it. This is equivalent to asking if nature distinguishes left from right, since in a mirror image left and right become inverted. We can also ask if nature is symmetrical with respect to the operation called charge conjugation (C), which means reversing the sign of all electrically charged particles. This is asking whether or not we would ever know if suddenly in the middle of the night the sign of all charges were reversed. In other words, does nature distinguish the world from the antiworld? The third symmetry is the one this article is concerned with: Are the laws of nature indifferent to the direction of time (T)?

Our awareness of the importance of these symmetries is due in large part to the physicists T. D. Lee and C. N. Yang. A dozen years ago they pointed out that a paradox resulting from observations of the decay of an elementary particle, the K meson, would be resolved if parity were violated in the interaction responsible for the decay. They suggested several experiments that might detect the violation. When these were performed soon afterward, the tests proved that parity was indeed violated. The implication of these observations is that nature distinguishes left from right. It was subsequently realized, however, that a parity violation was always accompanied by a violation of charge conjugation, and that the combined symmetry (CP) appeared to be respected by nature. The conservation of CP in physical processes means that left in the world becomes right in the antiworld; hence nature does not distinguish left from right in an absolute sense since there is no way to distinguish the world from the antiworld. Nature appeared to be quite symmetrical after all.

This situation changed dramatically five years ago with a discovery by James H. Christenson, James W. Cronin,



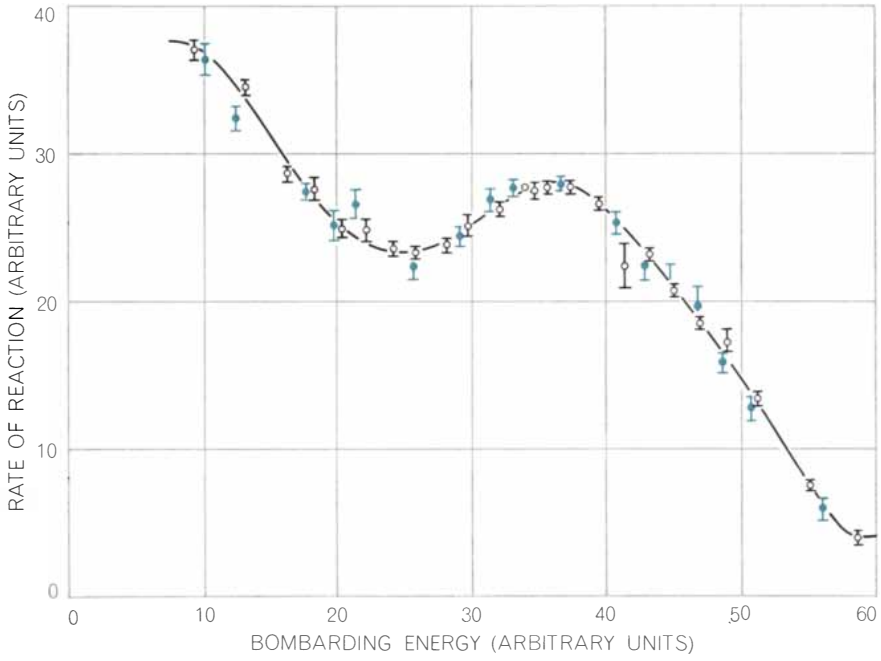
APPARATUS USED IN SEARCH for a violation of time-reversal invariance consisted of three spark chambers (A, B, C), combined with four scintillation counters. The desired event occurs when a pi meson, entering at the left, triggers the first two scintillation counters and interacts with the inserts (*dark gray*) in spark chamber A to create a lambda particle. The particle passes through the third scintillation counter and, being neutral, does not trigger it. While traveling through spark chamber B the lambda particle decays into a proton and a pi meson; these charged particles fire the fourth scintillation counter. The 1–1–0–1 sequence of firings automatically causes the spark chambers to discharge and a camera to record the track left by the proton (*lower set of dashes*) as it is scattered by the carbon plates in spark chamber C. Out of 1.2 million photographs made during the experiment 10,000 provided good proton-spin data.

Val L. Fitch and René Turlay of Princeton University. They observed a certain rare mode of decay of neutral *K* mesons that, it appears, can only be interpreted as a violation of *CP* symmetry. This finding, subsequently confirmed by other groups, implies that nature does distinguish left from right and world from antiworld in an absolute sense.

A further implication is that nature is not indifferent to the direction of the flow of time. This implication enters the picture by way of a fundamental theorem of physics. Known as the *CPT* theorem, it was first enunciated 15 years ago. It requires that the laws of physics remain unchanged under the combined operation of all three of these symmetry principles; that is to say, all the equations of physics must still be valid when we go through them and reverse the sign of all spatial coordinates, change the sign of all charges and reverse the sign of time. Once we assume that *CPT* symmetry is conserved, then the Princeton observation of *CP* violation implies that a *T* violation must occur as well. That is why the Princeton observation triggered the search for direct evidence of a breakdown of time-reversal invariance.

The implication that time reversal is violated because a *CP* violation has been observed is entirely dependent, of course, on the validity of the *CPT* theorem. Proof of the theorem is based on very general principles, and at the present stage of theoretical development in physics it would be difficult to conceive of a basic physical theory that did not satisfy the *CPT* theorem. "If *CPT* invariance were to fail," writes a distinguished theorist, "then I would say all hell will break loose." At the same time we must always bear in mind that nature apparently does not feel obliged to conform to the limitations of the physicist's imagination. The ultimate proof of the *CPT* theorem's validity must be left to experiment.

One prediction of the *CPT* theorem is that all elementary particles have antiparticles with opposite charge but with exactly the same mass and lifetime. After the Princeton observation a number of new experiments were performed with the aim of providing extremely refined tests of this *CPT* prediction. A good deal of evidence has now been accumulated [*see illustration on page 93*]. At least within the limits of refinement of the tests there is no reason to doubt the validity of the *CPT* theorem. Physics is therefore left with the inference that time-reversal invariance is violated somewhere in physical processes. It is most important to move beyond inference to direct experimental confirmation.



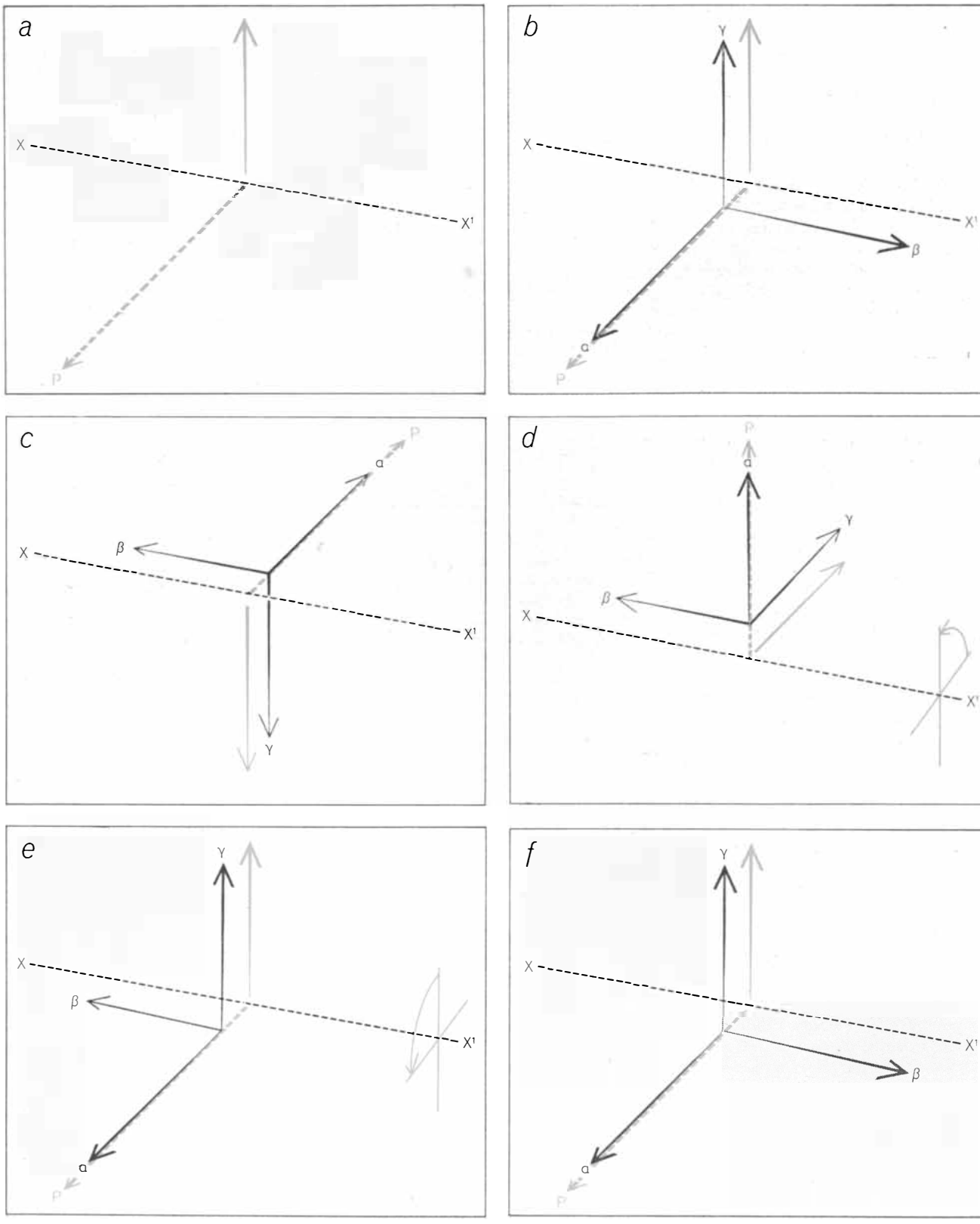
OVERLAPPING SETS of measurements are the result of a test of time-reversal invariance in a "strong" interaction. The first set (*black*) shows changes in the rate of reaction for different bombarding energies when a beam of deuterons strikes a magnesium target. The target is composed of the isotope Mg^{24}; the bombardment transforms some of its atoms into the isotope Mg^{25} and causes the emission of protons. The second set (*color*) measures the inverse reaction: the target is Mg^{25}, the bombarding particles are protons, some target atoms are transformed into Mg^{24} and deuterons are emitted. In effect time has been reversed. If time-reversal invariance is violated in this interaction, measurements of the original and inverse reactions should differ. As the graph shows, there is close agreement instead.

The desire to find symmetries in nature goes back to the earliest days of science. Since ancient times the ideal has persisted that nature is simple, symmetrical and beautiful; heavenly bodies, for example, were regarded as perfect spheres, moving in perfect circles in perfect harmony with one another. The development of science, however, has been accompanied by the slow realization that nature is not this simple, although it is no less beautiful. (Is an ellipse less attractive than a circle?) Similar desires for symmetry have also affected our concepts of space and time. To assume that nature is indifferent to left or right, plus or minus and the flow of time forward or backward may be attractive, but we must be careful. Beauty in nature, as in art, need not imply exact symmetry; the lamp in the middle of the picture window is not the ultimate in interior decoration.

A symmetry principle or conservation law is a statement of some knowledge forever denied to us by experiment. If the invariance of parity and charge conjugation were not violated, we could never hope to be able to distinguish left from right in an absolute sense. Thus the discovery of violations of assumed symmetries opens a way for us to make experimental determinations that were previously thought to be impossible. In this sense we should welcome discoveries of symmetry breakdowns, and physics currently appears to be in an era of such discoveries.

The question of whether or not there are basic physical processes that violate time-reversal invariance and thereby define the direction of time is one that can only be resolved by experiment. How do we conduct such a search and where do we look? We shall want to look on as fundamental a level as possible; a good place to start is with the interaction of elementary particles. Three fundamental forces of nature are involved here. They are the "strong" nuclear-interaction force, the electromagnetic-interaction force between charged particles and the "weak"-interaction force responsible for the decay of elementary particles. (The fourth fundamental force of nature—gravity—does not concern us here.)

One experimental way to search for



MEASUREMENT OF PROTON SPIN after the decay of a lambda particle provides a test of the invariance of time reversal, as is demonstrated in these diagrams. The first (*a*) shows the decay; the spin vector of the particle (*solid arrow*) points up. The proton that results is emitted at an angle perpendicular to the lambda spin vector. In this case it moves toward the reader (*broken arrow*). The proton's own spin vector is unknown and it is assigned three arbitrary components (*b, solid black arrows*). Next an identical event is shown, but with time reversed (*c*): the lambda spin vector now points down and the emitted proton moves away from the reader. Each arbitrary component of the proton spin vector, α, β and γ, has also been reversed. With everything backward, it is difficult to compare the original case with the time-reversed one, but by rotating the time-reversed case 180 degrees around its x–x' axis the comparison is made easier. The rotation is shown in two 90-degree steps (*d, e*) and the original diagram, *b*, is placed beside it (*f*) to facilitate comparison. The two diagrams prove to be identical, except that the proton spin-vector components labeled β point in opposite directions. If time-reversal invariance is not to be violated, the observed value of this component must never be anything but zero.

time-reversal violations that is well suited to the study of both strong and electromagnetic interactions consists in measuring the results of a given reaction and comparing them with the results of what is in effect the same reaction with the time reversed. This means comparing (1) the reaction in which a, combining with b, produces c and d with (2) its inverse reaction, in which c and d combine to produce a and b. When both reactions proceed under the appropriate conditions, they represent time-reversed situations. A definite relation can be predicted between the two sets of measurements.

One such pair of reactions that has been studied in detail involves the use of a beam of particles from an accelerator to bombard two kinds of magnesium target. In the first reaction the target is composed of the magnesium isotope Mg^{24} and is bombarded by a beam of deuterons. Some of the atoms in the target are transformed into the isotope Mg^{25}, and the transformation is accompanied by the emission of protons. This strong nuclear reaction is written $d + Mg^{24} \rightarrow Mg^{25} + p$. The physicists at the Nuclear Physics Laboratory of the University of Washington who conducted the experiment measured the number of protons of a given energy coming off the target at a given angle and related these measurements to changes in the energy of the bombarding deuterons.

They next studied the inverse reaction: the target was composed of the isotope Mg^{25}, and protons were used as the bombarding particles. Exactly the opposite event occurred: some of the Mg^{25} atoms in the target were transformed into Mg^{24} atoms and deuterons were emitted. When measurements of the emerging deuterons were compared with the measurements of the protons that emerged in the first reaction, the results agreed closely with values predicted under the assumption that time reversal is invariant [*see illustration on page 91*].

Several other inverse nuclear reactions have also been measured with a high degree of accuracy. In addition, a variation of this approach involves analyzing the spin polarization of scattered particles. Several experiments of this kind have also been performed. In all cases there has been good agreement between the measurements of the primary reaction and those of the inverse reaction. The method has been used to study the strong interaction between nuclear particles in some detail; the best measurements agree to within an error of .3 percent, indicating that time-reversal invariance in strong interactions is valid to about the same degree.

The inverse-reaction method can also be used to study electromagnetic interactions. A particularly good example is the disintegration of a deuteron by a gamma ray, which results in a neutron and a proton. Measurements of this reaction can be compared with those for a neutron-proton collision, which results in a deuteron plus a gamma ray ($\gamma + d \leftrightarrows n + p$). The presence of the gamma ray indicates that the reaction is an electromagnetic one. Such experiments have been performed, and analyses of the measurements obtained are currently under way.

Inverse-reaction analysis fails in practice as a method for investigating weak interactions. Because the weak force is the only one known to violate both C and P invariance, it is logical to suspect that it violates T invariance as well. This means that the chief manifestation of weak interactions—the decay of unstable particles—is an important field for study.

An example of such a weak process is the decay of the lambda particle (which is always uncharged, or neutral) into a proton and a pi meson ($\Lambda^0 \rightarrow p + \pi^-$). Although in principle we could compare the decay with the inverse process ($\pi^- + p \rightarrow \Lambda^0$), the interaction is so weak that its inverse has never been observed. Another method of attack must be used.

This method involves the discovery of measurable phenomena—"physical observables," as they are called—whose very existence would constitute a violation of time-reversal invariance. It is the only method used in the study of weak interactions, and it is also a valuable addition to the inverse-reaction method in the study of electromagnetic interactions. Since the application of the method is not as obvious as the study of inverse reactions, I shall illustrate its use in a study of time-reversal invariance with respect to the lambda-decay interaction I have already mentioned. The study has several features that are common to time-reversal tests in general. Because I participated in it. I believe I can give the reader some feeling for what was involved in such an experiment.

The test for time reversal in lambda decay is made by determining the orientation of the spin of the decay proton. Consider the decay of a lambda particle whose spin vector points upward [*see illustration on opposite page*]. Assume that decay has resulted in the emission of a proton at an angle of 90 degrees to the lambda spin vector, say out from the page toward the reader. The proton has its own intrinsic spin, but the orientation of the spin vector is unknown. (In fact, the purpose of the experiment is to determine the orientation.) Until the spin vector is known, then, we shall arbitrarily assign it three components—α, β and γ—along three mutually perpendicular directions. The possible spin component lying parallel to the proton's direction of motion we shall call α. A second component, lying parallel to the lambda spin vector, we shall call γ. The component along a direction perpendicular to each of the others we shall call β. One can determine values for each component experimentally by observing the scattering of a large num-

PARTICLE	MASS	LIFETIME	MAGNETIC MOMENT
ELECTRON AND ANTIELECTRON	10^{-5}		10^{-5}
MU MESON AND ANTI-MU MESON	10^{-4}	10^{-3}	10^{-6}
PI MESON AND ANTI-PI MESON	5×10^{-4}	10^{-3}	
CHARGED K MESONS AND CHARGED ANTI-K MESONS	10^{-3}	10^{-3}	
NEUTRAL K MESONS AND NEUTRAL ANTI-K MESONS	10^{-14}	10^{-3}	
NEUTRAL LAMBDA PARTICLES AND NEUTRAL ANTI-LAMBDA PARTICLES	5×10^{-2}	10^{-1}	

EQUALITY between the properties of particles and their corresponding antiparticles, a key prediction of the *CPT* theorem, has been demonstrated within close limits for the six pairs listed in this table. Each number indicates the upper limit on the deviation from unity observed for each pair with respect to mass, lifetime and, in two instances, magnetic moment. For example, the difference in mass between a charged K meson and its antiparticle, an anti-K meson, is no more than one part in 1,000 and the difference in lifetimes is the same.

STRONG INTERACTIONS	
MAGNESIUM 24 + $d \rightleftarrows$ MAGNESIUM 25 + p	3×10^{-3}
MAGNESIUM 24 + $\alpha \rightleftarrows$ ALUMINUM 27 + p	3×10^{-3}
OXYGEN 16 + $d \rightleftarrows$ NITROGEN 14 + α	3×10^{-3}
POLARIZATION = ASYMMETRY IN PROTON-CARBON SCATTERING	1×10^{-2}
PROTON-PROTON TRIPLE SCATTERING	5×10^{-3}
WEAK INTERACTIONS	
$n \rightarrow p + e^- + \nu$	$\phi < 2.5 \times 10^{-2}$
NEON 19 $\rightarrow$ FLUORINE 19 + $e + \nu$	$\phi < 3.5 \times 10^{-2}$
$K^\circ \rightarrow \pi^- + \mu^+ + \nu$	$\phi < 5 \times 10^{-2}$
$\Lambda^\circ \rightarrow p + \pi^-$	$\phi < 7 \times 10^{-2}$
ELECTROMAGNETIC INTERACTIONS	
RUTHENIUM 99 $\rightarrow$ RUTHENIUM 99 + γ	$\phi < 2 \times 10^{-3}$
IRIDIUM 193 $\rightarrow$ IRIDIUM 193 + γ	$\phi < 4 \times 10^{-3}$
RHODIUM 106 $\rightarrow$ PALLADIUM 106 + $e + \gamma + \gamma$	$\phi < 2 \times 10^{-2}$
ELECTRON-DEUTERON SCATTERING	$\phi < 9 \times 10^{-2}$
ELECTRON SCATTERING FROM POLARIZED PROTONS	$\phi < 9 \times 10^{-2}$
ELECTRIC DIPOLE MOMENT OF NEUTRON	$< 5 \times 10^{-23}$ e-cm
ELECTRIC DIPOLE MOMENT OF ELECTRON	$< 3 \times 10^{-23}$ e-cm

THREE KINDS OF INTERACTION have been studied by the means indicated in this table for possible violations of time-reversal invariance. No violations have been found. The first of the strong interactions listed is the one illustrated on page 91. As with the others, the experimental upper limit on time-reversal violation is only of the order of a few tenths of a percent. In the case of the weak and electromagnetic interactions, time-reversal invariance predicts a value of zero for the angle ϕ. The experimental upper limits show no deviation from zero to within an experimental accuracy of a few percent. The very small values shown for the last two electromagnetic interactions are in good accord with the prediction, also based on time-reversal invariance, that the particles cannot possess a dipole moment.

ber of decay protons as they strike carbon targets. This is possible because when spin-up protons are scattered, they scatter preferentially to the left rather than to the right.

Consider now what happens to our decay diagram if we perform a time-reversal operation on it. Changing the direction of time flow sends all the particles moving in the opposite direction. Hence the proton that was coming toward the reader is now going away. Moreover, since clockwise rotations become counterclockwise under time reversal, the spin vectors will be reversed in direction. This requires changing the direction of the lambda spin vector from up to down and also reversing the directions of the three arbitrary vector components assigned to the proton.

If we now want to compare the time-reversed diagram with the original, we find it a bit clumsy: the proton is approaching in one case and retreating in the other. We can make the comparison easier by in effect taking the x–x' axis of the time-reversed diagram in both hands and rotating the diagram through 180 degrees. Now both the time-reversed proton and the original proton are traveling in the same direction. Such an axial rotation does not change anything physically; physical processes are indifferent to the orientation of coordinate systems in space.

When we now compare the original diagram and the time-reversed one, we see that all the spin-vector arrows are aligned in the same direction except for the spin-vector component β. In a time-reversed world the proton spin component along the direction of β changes its sign. Thus if we insist there is to be no difference in nature when time is reversed, we must demand that the value of vector component β always be exactly equal to zero. Conversely, if it is found experimentally that β is not equal to zero, we would have discovered a physical observable that is, say, positive in the world of forward-flowing time and negative in the world where time is reversed. This would be a violation of time-reversal invariance.

Because of preferential scattering it is possible to measure the value of β experimentally. One simply compares the number of protons scattered along the direction of the lambda spin axis with the number scattered in the opposite direction. If time reversal is invariant, the number of protons scattered in each direction will be the same.

The preceding argument is, of course, oversimplified. When it is made more rigorous with respect to theory, two important considerations appear regarding the value of β. Both are common to all time-reversal tests involving the search for a physical observable that by its very nature exists only if time-reversal invariance is violated.

The first consideration is that for some particle decays one will find by experiment a value equal to zero for β for reasons that have nothing at all to do with time reversal. It turns out that the physical observables that might represent invariance violations are those resulting from processes characterized by what is known as the interference of two amplitudes. Decays that are not characterized by two amplitudes cannot provide a test of time-reversal invariance. From earlier work with lambda particles my associate in the experiment, Richard F. Roth, and I knew that their decay involved two such amplitudes, making our proposed test valid in this respect.

The second consideration is that, although lambda-particle decay is due to the weak interaction, the resulting proton and pi meson nonetheless interact strongly at the moment of decay. The strength of the interaction makes it necessary to add a small correction that gives β a value unequal to zero even if the invariance of time reversal were valid. From earlier data on the scattering of protons and pi mesons we could confidently calculate an appropriate value for the correction. When it came time to present the results of the experiment, we would be able to compare them with this corrected value of β. If the two did not agree closely, we would have observed a violation of time-reversal invariance.

Roth and I conducted our experiment during the summer of 1965 when we had access to the Princeton-Pennsylva-

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Large section boron wing flap skins now possible from "broadgoods" sheets • Spark sintering produces beryllium and titanium parts rapidly and to controlled density • High reliability interconnect matrix modules developed for Polaris and Poseidon programs • Laser alignment system improves accuracy in massive tooling operations.

Manufacturing research, one of the least publicized areas of activity in the aerospace industry, is also one of the most important. New materials and concepts coming out of current R&D efforts require new techniques to turn them to practical use. Manufacturing research provides these needed techniques and processes. The following is a report on some new methods developed by Lockheed for the handling, forming, cutting and processing of new materials and tools.

Large structure boron composites. Boron, combined with epoxy, one of the most promising of the new composite materials, would seem to be an ideal material for such structures as wing slats. But the properties of boron make it difficult to fabricate into large structures. It has a modulus of elasticity of 60 million psi. It is twice as stiff as steel, at less than half the weight. Under an Air Force contract for the design, development, testing and fabrication of boron composite wing slats for ten C-5 airplanes, Lockheed has devised a technique for producing 10x22 foot "broadgoods" sheets of boron composites. A special machine, converted from a conventional lathe, applies 3-inch wide boron filament composite tape continuously on Mylar film to make these sheets. Several pieces of these sheets with specified filament orientations are placed in contoured fixtures for autoclave curing, thus producing the finished wing slat skins.

As a result of this fabrication development, boron composite wing slats are now being made for performance testing and evaluation. Manufacturing research has given aircraft designers freedom to think in terms of large section boron composites for superior stiff-

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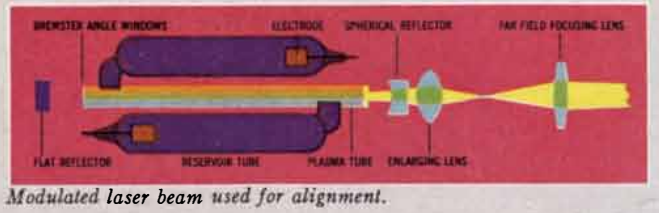
ness and strength with no accompanying weight penalty.

Spark-sintered beryllium. Lockheed is utilizing a breakthrough in the powder metallurgy processing of exotic materials to achieve significant benefits. Simple-geometry parts and specimens are now being produced for a number of customers and require only minor machining to provide finished dimensions. In a new facility, components of beryllium, tungsten-carbide, titanium and other exotic material powders are displaying improved mechanical properties over those found in conventional hot-pressed blocks of the material. The one-shot process has also lowered the fabrication costs of various complex parts, providing controlled and uniform densities with specific strength, thermal, electrical, nuclear and other properties. This is a good example of how manufacturing research turns a new process to practical use, with lowered costs and eventual broadening of applications.

Interconnect matrix modules. New laminated assembly techniques have produced significant advances in the reliability of circuitry for Polaris and Poseidon. These high reliability interconnect matrix modules have virtually no possibility of contact resistance or breakdown and are far superior to conventional printed circuits. In this new process, conductor pattern layers are photoengraved onto .020 thick sheets of phosphor bronze and then chemically milled. The milled patterns are gold-plated and positioned into a machine-recessed epoxy glass substrate. They are temporarily bonded pending final lamination. Connector tabs placed outside the circuit areas from the layers can be positioned in the same plane as the conductors or diverted in the opposite plane through holes punched in the epoxy substrate. Problems associated with the close proximity of traces at the junction crossovers were eliminated by major redistribution of plane configuration and the addition and deletion of circuitry to avoid complex overlapping. Modules are now being manufactured with 20 to over 1000 interconnections within 42 laminations. Manufacturing research combined a variety of techniques to arrive at this new process, then developed new test equipment to check out these modules, insuring that they would meet stringent requirements for continuity, current carrying capacity, insulation resistance, and voltage breakdown with mechanical strength.

Laser alignment. As larger and larger aircraft are built, tooling jigs become more massive and present difficult alignment and handling problems. A new laser alignment



Modulated laser beam used for alignment.

system at Lockheed has demonstrated exceptional gains in both accuracy and cost savings over conventional optical tooling methods. First tests indicate that the laser system is approximately five times as accurate as the optical system on tools of 60 feet and longer. It is accurate to five-thousandths of an inch at 200 feet, whereas optical systems are accurate to that degree only to 70 feet because of the limitations of the human eye. In comparative tests for cost factors, six major jig test fittings were precisely positioned to the jig test frame. 163 man hours were required to set and inspect all six fittings by conventional methods. In the same test, but using laser alignment and hydraulic positioning controlled by the laser, only 37.3 man hours were required to set and inspect. In subsequent tests, this time dropped to 28 man hours. Here again, manufacturing research was involved in a chain of development. New materials make possible larger aircraft, which require huge tools to build, which require, in turn, new techniques of positioning and handling. This sequence of opportunity and demand led to the laser alignment system.

The activities described here are only a few of the current Lockheed programs in manufacturing research. 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.

Venture: Use a love call to count bacteria.

The *lampyridae* beetle family. Delight of small boys. Biological light bulb. And prime source of raw material for another Du Pont innovation.

Luciferase, an enzymatic protein with intriguing properties, obtainable only from fireflies. *Luciferin,* an organic molecule also found in fireflies, but synthesizeable. *Adenosine triphosphate* (ATP), a common energy-yielding substance found in all living cells.

Those are the three main ingredients in lampyridae's love light. And because ATP is common to all living cells, university researchers discovered they could produce an artificial glow by mixing luciferin and luciferase wherever life is present.

Noting that phenomenon, Du Pont scientists and engineers went on to develop it into a practical analytical system. Correlating the intensity of the artificial "glow" with the amount of ATP present in bacteria, they designed a means of measuring the reaction.

The result is the luminescence biometer—the first really basic improvement in bacteria-counting methods since the days of Louis Pasteur. Rather than waiting days for a culture to demonstrate growth density, a doctor or technician can now get a digital readout of bacteria concentration in minutes.

Other potentially lifesaving uses for the biometer are being suggested every day—such as diagnosing metabolic rates, enzyme deficiencies and nerve damage.

Innovation—applying the known to discover the unknown, inventing new materials and putting them to work, using research and engineering to create the ideas and products of the future—this is the venture Du Pont people are now engaged in.

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nia accelerator as a source of bombarding particles. Our apparatus consisted basically of three spark chambers combined with four scintillation counters [*see illustration on page 90*]. A beam of energetic pi mesons from the accelerator passed through a pair of scintillation counters to enter the first spark chamber, where collisions in a group of polyethylene inserts produced the lambda particles for the experiment. A third scintillation counter separated the first spark chamber from the second, and a fourth counter separated the second chamber from the third, which contained a number of half-inch-thick carbon plates.

The scintillation counters were interconnected so that they automatically triggered a discharge of the spark chambers whenever an interaction of possible interest occurred. The system worked as follows. When the first and second counters fired, it was evidence that a pi meson had entered the apparatus. If the third counter then did *not* fire, it was evidence that the meson had interacted in the polyethylene insert, creating a neutral lambda particle in the process. Lambda decay into a proton and a pi meson occurred in the second spark chamber, and passage of these charged particles into the third chamber fired the scintillation counter in front of it. Each time this 1–1–0–1 sequence took place the spark chambers were triggered, and the trails left by the scattered particles were recorded on 35-millimeter film for later analysis.

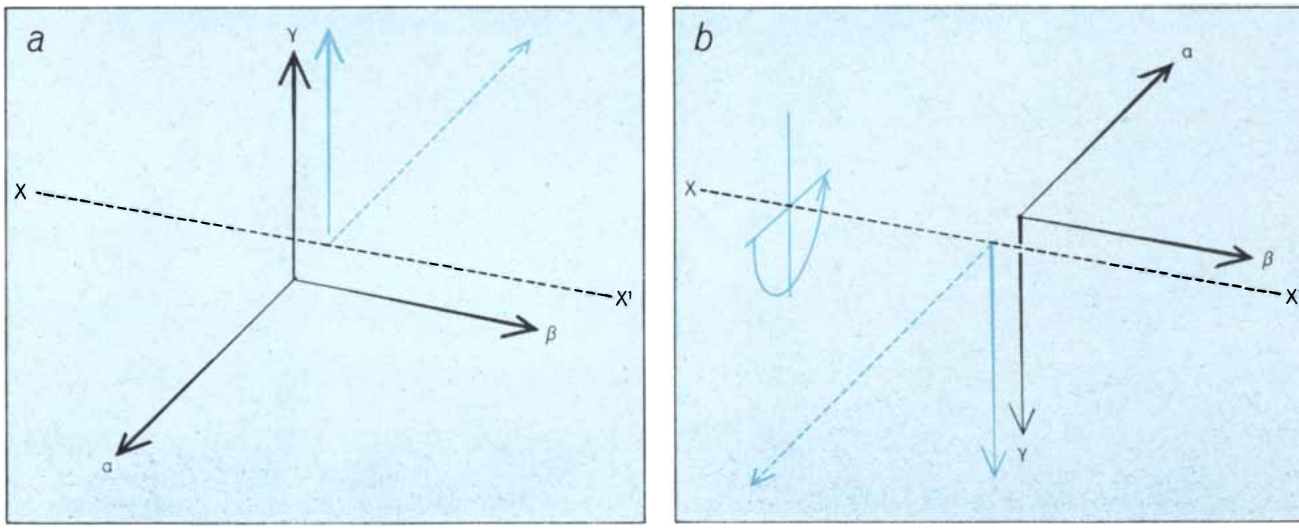
We took more than 1.2 million pictures during the experiment, exposing 16 miles of film. Because interactions other than the one of interest to us could produce the same scintillation-counter sequence, only 25 percent or so of our photographs represented unambiguous lambda decays. Of these 300,000-odd photographs only 10,000 showed proton scatters that provided information about the particle's polarization. Such a low yield is typical of experiments of this kind, where the desired event results only from the compounding of a series of very improbable processes. Actually the overall odds were considerably worse: only one out of every 100 trillion particles given full energy by the accelerator produced an event of interest. On the other hand, as a comment on advances in experimental techniques, we did manage to record nearly a third of a million lambda decays in the course of one summer, whereas 10 years earlier the total world sample of recorded lambda decays was less than 1,000.

Our experiment required about three months for assembly, another three months to run at the accelerator and a year and a half for analysis. When the beam was available at the accelerator, data were taken day and night. Once the equipment was tuned up, we hired undergraduates to help keep things running. Because the equipment proved reliable and the students were on summer vacation, they generally worked the shift from midnight to breakfast. When data-collection at the accelerator was completed, the film was turned over to trained scanners at Princeton, who searched it for good events. The next task, undertaken at the University of Michigan, was to make detailed measurements of the events in our final selection of 10,000 photographs. Measuring machines recorded the information on punch cards, which were then fed into a computer that had been programmed to give a full analysis of each event.

We found that our experiment showed no evidence of any violation of time-reversal invariance, at least within the reliability limits of a study based on 10,000 events. Assuming that time-reversal invariance is valid, the predicted value of β is $-.07 \pm .02$. Our results gave a value for β of $-.10 \pm .07$, which is not significantly different. A dozen physicists in international cooperation have since repeated the experiment at the CERN accelerator in Geneva, and our findings have been confirmed.

As far as symmetry operations other than time reversal are concerned, the results for lambda decay can be predicted by applying the same type of analysis we used for time reversal. Since the parity operation reverses the direction of linear momenta but leaves angular momenta, or spins, unchanged, it is easy to show that, if parity is conserved in lambda decay, α must always be equal to zero [*see illustration below*]. We found an experimental value for α equal to .65, meaning that parity is indeed violated in this decay, as is typical of weak-interaction processes.

Similarly, it can be shown that if both conjugation and parity (*CP*) are conserved in this decay, the anti-α for anti-



PARITY VIOLATION in lambda decay was discovered by another analysis of proton spin-vector components. The parity operation changes the direction of linear momenta but not the direction of spin, so that a parity-reversed decay would send the proton away from the reader (*a, colored broken arrow*) rather than toward him but would not affect the direction of the three spin-vector components (*solid black arrows*). When the reversed case is rotated 180 degrees about its x–x' axis for purposes of comparison (*b*), it is apparent that to conserve parity the value of the α component must always be zero. The value of α proved to be equal to .65 instead.

lambda decay should be equal in magnitude but opposite in sign to the α for lambda decay. Experimental evidence for or against this prediction is not available because it is not yet known how to produce antilambda particles with their spins oriented in a particular direction or how to analyze the spin components of the decay antiprotons. This is a major stumbling block in the way of studying *CP* violations: a particle decay must be compared with its antiparticle decay and, in the present state of the art, it is difficult to obtain large numbers of antiparticles, particularly in the case of the heavier ones.

As for time-reversal invariance, careful searches have also been made involving other processes and all have failed to find any violation. From the experiments performed so far, it appears that for weak and electromagnetic interactions the upper limits on time-reversal violation are of the order of a few percent. For the strong interactions they are a few tenths of a percent [*see illustration on page 94*]. Unfortunately our theoretical understanding of these problems is not much enhanced by negative results that give only upper limits. A positive detection of a violation is eagerly being sought. More sensitive tests of all interactions are desirable, and many are under way.

Thus the search continues as physicists seek to understand better the implications of the *CP* violation observed in neutral-*K*-meson decay. Is *CP* symmetry violated elsewhere? Is *T* violated? Is the *CPT* theorem exact? Only experiment can answer these questions. Presumably the violations we are seeking are small, and the experiments must be quite refined to detect them. There is even the real possibility that the violations are so extraordinarily small as to be undetectable with present techniques.

The chances are nonetheless quite good that time-reversal invariance is violated in one of the fundamental forces. It is most important that all promising cases be investigated. We certainly cannot expect to understand the details of the basic forces of nature if we do not know their general properties with respect to basic symmetries. Moreover, our entire concept of the universe around us, our basic concepts of space and time, are strongly dependent on which conservation laws and symmetry principles we find are respected by nature. One thing appears certain: If it does make a difference whether time is coming or going, only the future will tell.

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The Physiology of the House Mouse

This small rodent, bred to desert conditions, has evolved efficient mechanisms for conserving water and energy that allow it to thrive as a commensal of man, living in his buildings and sharing his food

by Daniel S. Fertig and Vaughan W. Edmonds

The house mouse (*Mus musculus*) is remarkably well suited to live with man as a commensal, an animal that shares man's dwelling places and food. Its small size (five to eight inches in length and less than an ounce in weight at full growth) enables it to live and travel with man unobtrusively. Its nocturnal habit also keeps it out of man's way and out of his sight. It is restless, energetic and aggressive enough to chase off competitors for its niche in the human world. Because it is omnivorous it can feed on any food man stores (and on other stored materials man does not eat). What is particularly notable is the ability of the house mouse to subsist on a diet of dry food, which can be hoarded without spoiling.

The disservices of the mouse to mankind are, of course, notorious. Mice cost us many millions of dollars annually in consumption and contamination of our food, destruction of our materials and the expense of our attempts to mouseproof buildings. As carriers of bacteria and parasites the mice act as vectors for a number of human diseases, including food poisoning, "rat-bite fever," tularemia and plague. Yet it can be argued that the benefits the house mouse has conferred on the human species through its services as an experimental animal more than compensate for the damage it does. There is scarcely an area in basic biology, medical science or pharmacology that has not profited from its extraordinary convenience as a laboratory research subject.

The ability of the house mouse to get along with a minimum of water and thus to thrive in very dry environments may in small part be due to habits developed during its millenniums of commensalism with man. For the most part, however, its unusual ability to conserve water depends on innate mechanisms inherited from its ancestors in the wild.

The house mouse belongs to the Muridae, the largest rodent family. It is believed most of the house mice in the world today, wherever found, are descended from a wild subspecies (*M. musculus wagneri*) that is still widely distributed over the dry steppelands of central Asia and the areas in Turkestan and northern Iran where man's earliest agricultural settlements have been unearthed. These mice were in the right place at the right time to take advantage

HOUSE MOUSE subspecies studied by the authors ordinarily lives in and around structures built by man, but it may become feral, or wild, when introduced into a suitable natural environment. The animal is pictured in the habitat where the authors trapped their specimens: a coastal salt marsh near Los Angeles characterized by extensive growths of the pickleweed, *Salicornia.*

of the beginning of man's agricultural industry. The mice, as well as Neolithic man, had been feeding on seeds of wild grasses, and as man developed the culture of these grasses the mice shared the new bounty. It appears they may have developed subtle behavioral adjustments that enhanced their ability to use man as a provider. In any case, they later proved able to stand off other small rodents that challenged their position, and they acquired a unique capacity for traveling with man's baggage and produce.

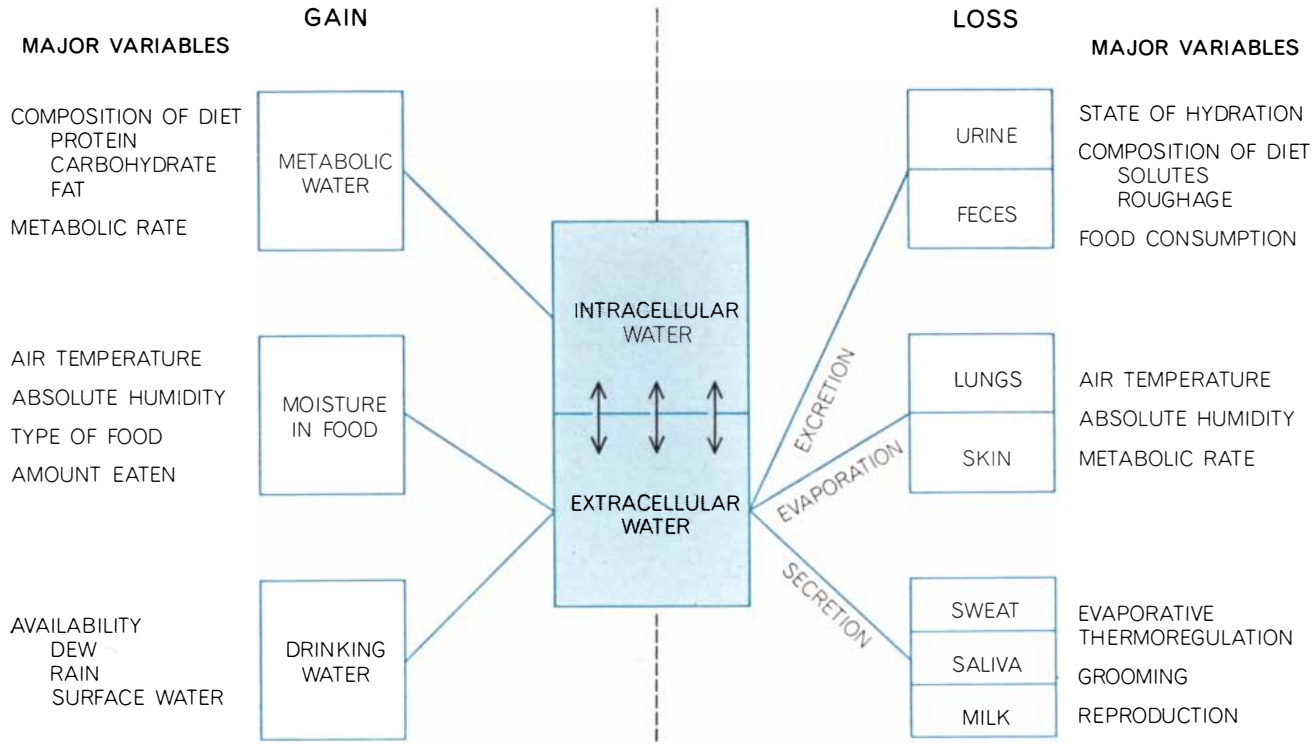
By the beginning of the historic era the house mice had spread widely over the human settlements of the Middle East by way of the trade routes. There is evidence that some lineages traveled westward from Persia through Iraq, Syria and Palestine to Egypt. The ancient Egyptians, indeed, made a sacred animal of the cat, presumably in reaction to the incursion of house mice. (Four thousand years later the frontier farmers of America also held the cat in high regard, for the same reason.) From the Middle East the mice spread around the shores of the Mediterranean and then moved into northern Europe. There they took up permanent residence indoors, particularly in grain shelters, and lived for generations in those artificial arid environments without venturing into the cold, wet outdoors.

In Europe two lineages developed: a northern subspecies (*M. musculus domesticus*) and a southern one (*M. musculus brevirostris*). Both helped to colonize the New World, the northern breed as stowaways in English, French and Dutch ships, the southern breed in ships of Spain and Portugal. Each subspecies tended to remain in the appropriate climate, *domesticus* occupying the northern U.S. and southern Canada and *brevirostris* migrating to the southern states, California and Latin America. In the central U.S. they interbred.

The mice went West in the boxes and barrels of the pioneers' covered wagons. Thanks to their small size, they were able to hide and to feed in nooks and crannies that were inaccessible to their larger commensal relatives, the rat species. As time went on their comfort and speed of travel improved with man's. In the late 19th century they traveled by rail; today they speed over superhighways in produce trucks and furniture vans. Wherever the house mouse goes its ability to establish itself is facilitated by its tremendous rate of reproduction. A female mouse can produce six to 10 litters per year, with six to eight young in each litter. The gestation period is only about three weeks, and the young mature in about 10 weeks. Although the average life-span of a house mouse living with man or in nature is less than a year, the multiplication rate is still impressive. A single pregnant female can initiate a population explosion.

It has long been noted that the house mouse, whether living with man or in nature, does well in dry places. The present-day distribution of wild house mice extends into grassland, savanna and even desert habitats. Mice that wander off from human settlements, revert to the wild state and live off the natural resources of the environment ("feral" mice) have established populations in the deserts of South America, Australia and (to a lesser extent) North America, on arid islands, on coastal beaches and in salt marshes, where they have limited access to fresh water for drinking. It is now clear, in fact, that house mice have a capacity for doing without drinking water like that of the kangaroo rat and certain other rodents [see "The Desert Rat," by Knut and Bodil Schmidt-Nielsen; SCIENTIFIC AMERICAN, July, 1953].

This conclusion emerged from a detailed investigation of the physiological ecology of house mice undertaken at the University of Southern California.



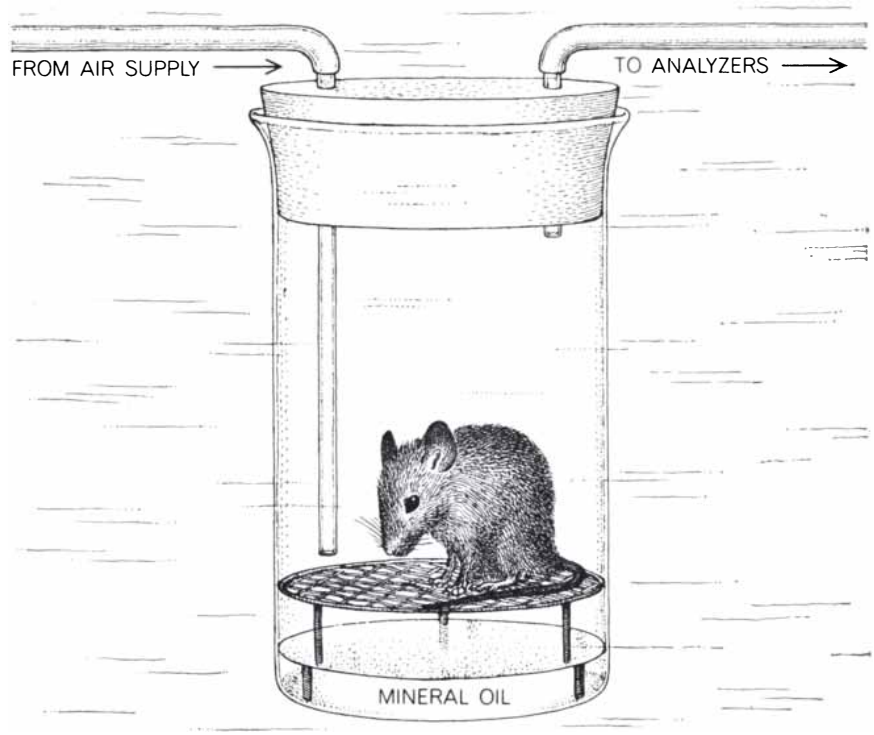
PATHWAYS OF WATER EXCHANGE for a mammal are shown with the major variables affecting each of them. Metabolic water is formed within living cells by the oxidation of foodstuffs; preformed water is obtained from moisture in food as well as by drinking. Water is lost by excretion in urine and feces, by evaporation from lungs and skin and by secretion in sweat, saliva and milk.

The subjects were not domesticated laboratory white mice, which have developed a placid temperament and coddled way of life, but feral mice of the species, which we collected from a salt marsh near Playa del Rey in Los Angeles County and examined under various conditions of feeding, temperature, water loss and so forth. The mice were housed in gallon jars covered with wire mesh and containing a bed of dry litter. The air in the jar became humid, simulating the condition in a typical mouse burrow, so that the mice suffered little loss of water by evaporation. For experiments the mice were moved either to stoppered one-liter beakers with a controlled air supply or to wire-mesh cages in which the circulation of air kept the humidity at the same level as that in the laboratory (about 50 percent relative humidity).

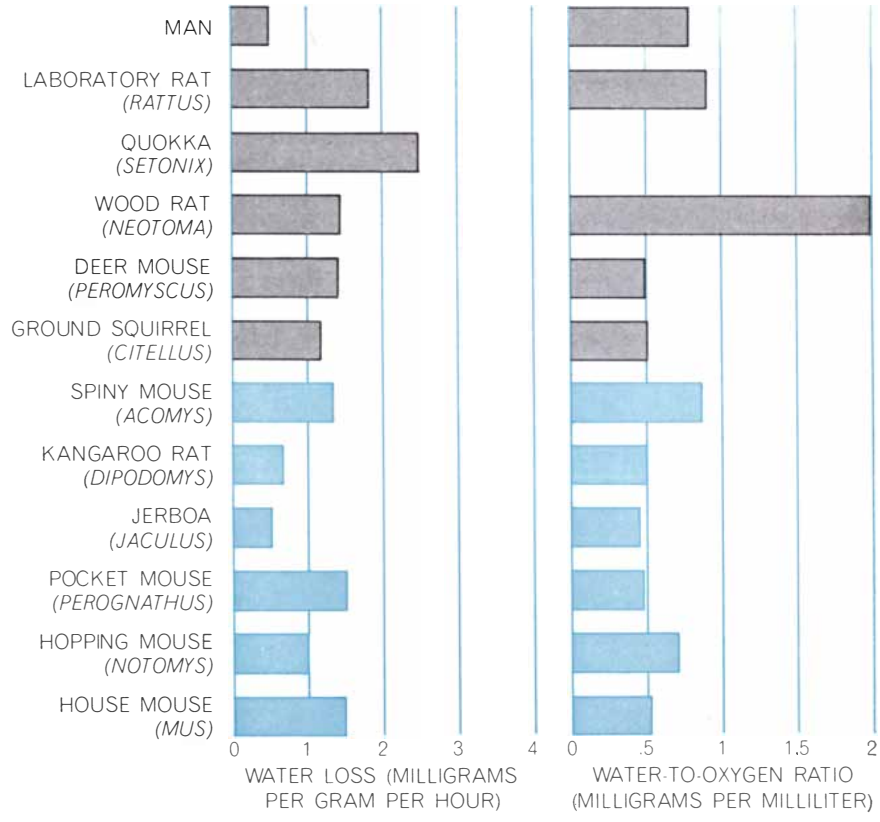
Let us consider first the results of feeding experiments. In the marsh the mice had had access to succulent plants, which have a high water content, and sometimes to water from rain and dew. Even in a dry indoor environment mice can feed on insects that provide some water. Dry seed or grain itself typically has a 10 percent content of water by weight. And of course the body produces water by metabolizing food; the oxidation of one gram of carbohydrate, for example, generates about six-tenths of a gram of water.

In their jars, where they lost little water by evaporation, the mice maintained themselves at full body weight on a "natural" diet consisting only of dry seeds. Even in the lower humidity of the cages they lost little weight on this diet. When the diet was changed, however, to one with a high content of protein or roughage, the mice, if deprived of drinking water, reduced their caloric intake of food. The metabolic processing of large quantities of protein increases the excretion of urine, and the processing of roughage increases the loss of water by way of feces. Hence in order to conserve water the mice on such a diet ate less, thereby subjecting themselves to slow starvation. Thus for a house mouse unable to obtain drinking water a high-protein or high-roughage diet is essentially lethal.

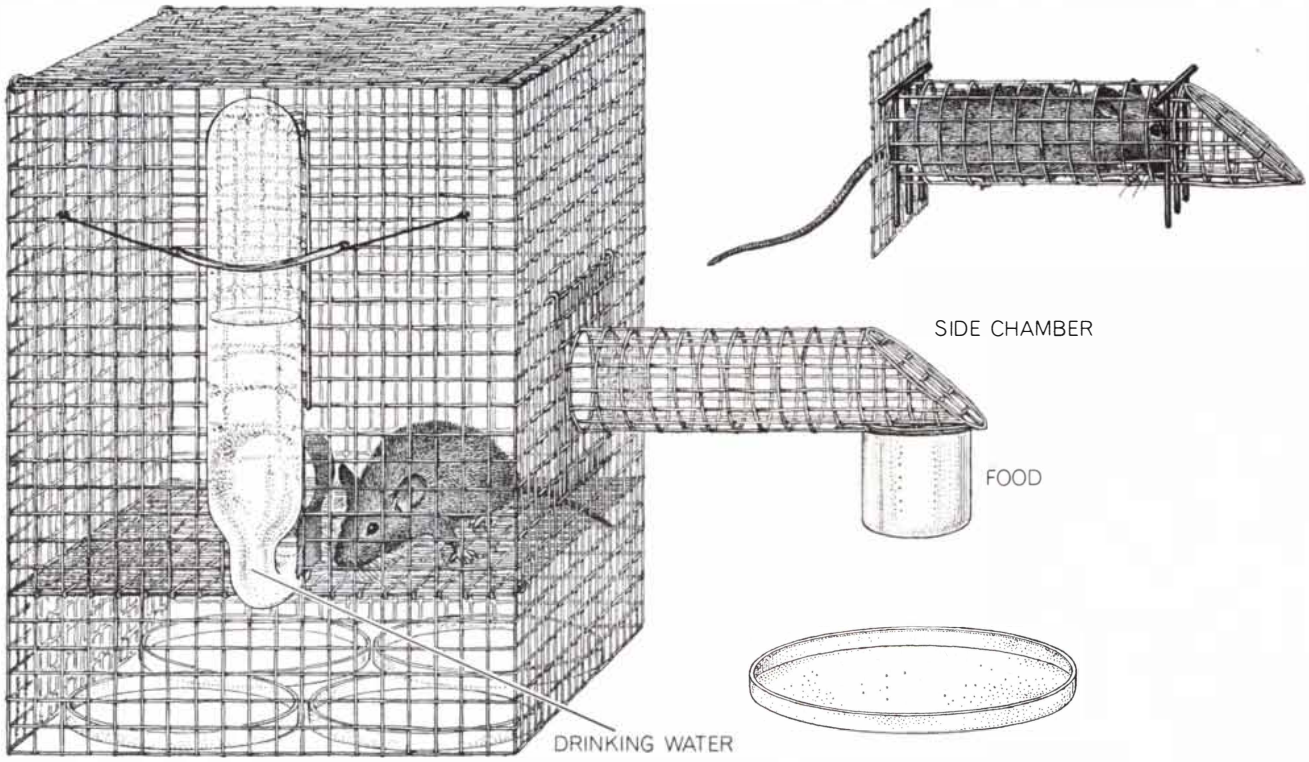
On the "natural" diet of dry seeds, without drinking water, the mice were able to maintain their body weight at a stable level about 10 percent below normal. They were unable, however, to stabilize body weight on the Purina Chow diet usually fed laboratory mice unless this was supplemented with water. With this diet they needed about



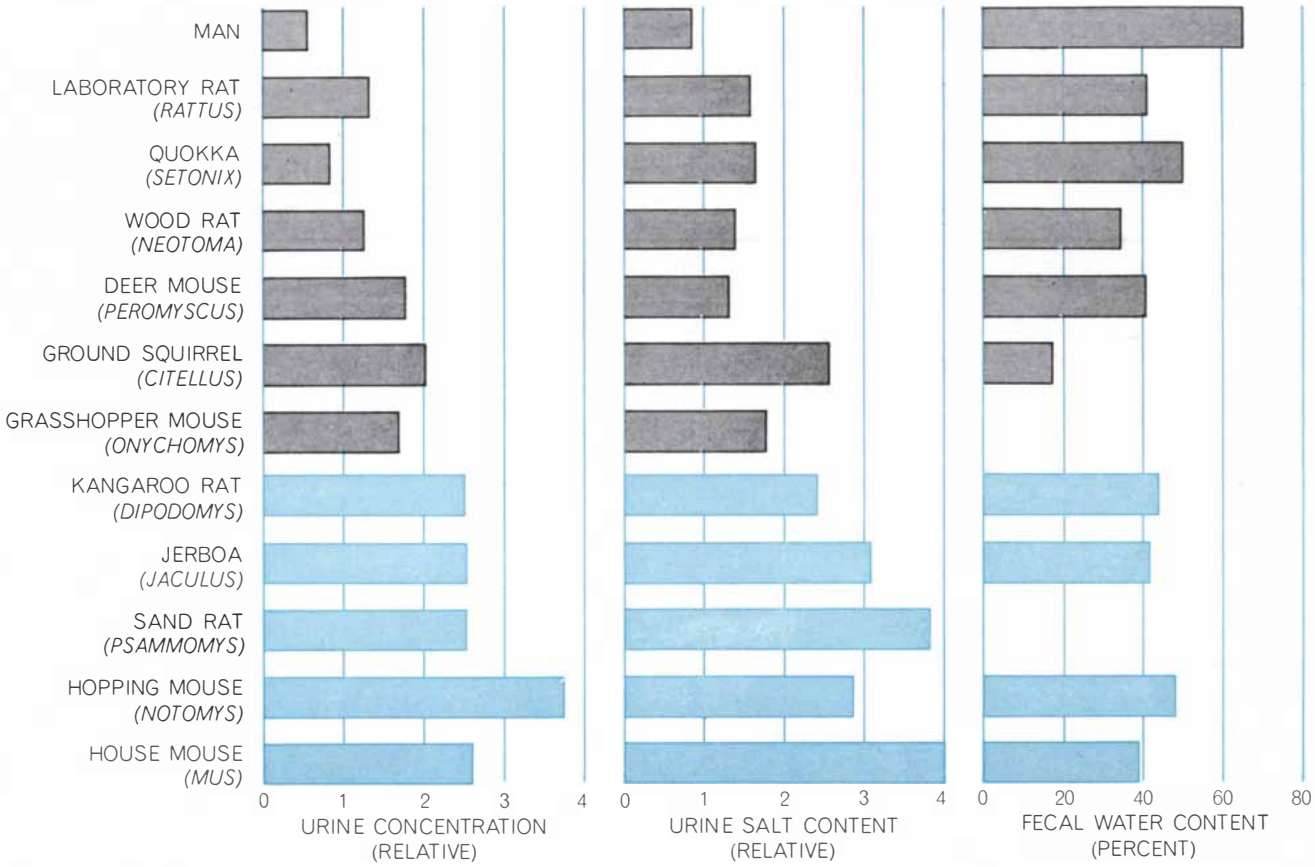
MICE WERE HOUSED in stoppered one-liter beakers, immersed in a constant-temperature water bath, to measure their evaporative water loss and oxygen consumption. Dried air was introduced into the beaker (*left*) and air leaving the beaker was analyzed for moisture and oxygen content. The animal's urine and feces were collected under mineral oil.



EVAPORATIVE WATER LOSS (per gram of body weight) and its ratio to the amount of oxygen consumed are compared in man, the laboratory rat and some desert animals including the house mouse. These minimum recorded rates suggest that the house mouse is comparable to other desert animals. In genera indicated in color, most species can get along on the moisture in air-dry foods. Data for the water-to-oxygen ratio in the quokka are not available.



WIRE-MESH CAGE designed by the senior author housed mice during the experiments on weight loss and excretory water loss. The tubular extension (*right*) served as a feeding chamber and, when it was removed from the cage (*top right*), as a weighing chamber.



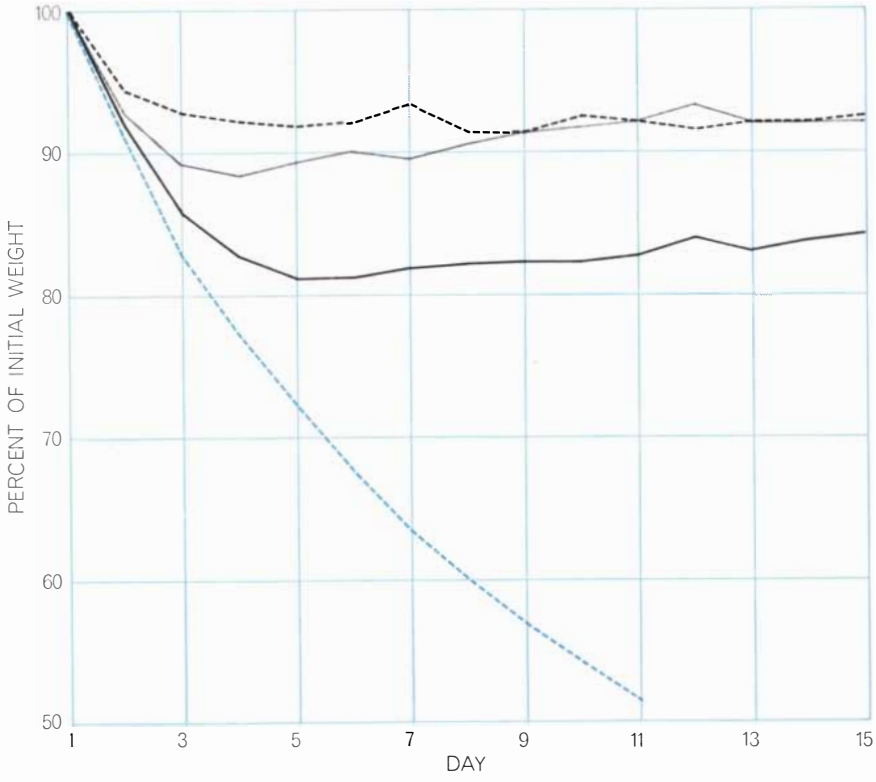
EXCRETORY WATER LOSS in house mice is compared with that of other species in three ways: maximum urine concentration (osmolality) and salt content and minimum water content of feces. (As in the bottom illustration on the preceding page, data are from experiments conducted by various investigators and may not be directly comparable in detail.) Again, colored bars indicate genera in which most species require no water beyond what is in air-dry foods. Data on fecal water content are not available for two species.

half a milliliter of water per day, about 12 percent of the amount they would consume when allowed to drink freely. When they were given the small water allowance, they ate substantially more Purina Chow than when they were deprived of water entirely.

In the laboratory, with no intake except dry seeds, the mice were able to survive for months in apparent good health. No doubt the house mouse rarely has to endure a regime as severe as this in its usual habitats. It appears, therefore, that the mouse can live through almost any naturally occurring drought or dry season if it has access to a stored supply of seeds or grain and can establish a den where limited air circulation keeps the relative humidity high. We found that dehydrated mice could tolerate a temporary loss of body weight of about 40 percent. When they were returned to a full ration of water, they recovered full body weight in a short time—within 40 hours on the average. In this respect they resembled other small animals that have been studied and somewhat resembled the camel, which can make a dramatic recovery from its emaciated appearance with a single long drink [see "The Physiology of the Camel," by Knut Schmidt-Nielsen; SCIENTIFIC AMERICAN, December, 1959].

What mechanisms account for the house mouse's considerable ability to conserve body moisture? The main pathways by which mammals lose water from the body are by evaporation from the lungs and skin and by excretion in the urine and feces. It is well known that animals vary greatly in the amount they discharge by each of these routes. The golden hamster and the guinea pig, for example, provide a familiar study in contrasts. The hamster's small excretion of urine and production of dry feces account in considerable part for its popularity as a children's pet, whereas the guinea pig excretes water so copiously that it is not generally welcomed as a house guest.

Small rodents generally lose little water by way of evaporation from the skin. They can, however, lose substantial amounts of water for a short time by evaporation of saliva applied to their fur and some increase of evaporation from the lungs in breathing. We learned that the house mouse loses less by this route than most other mammals do. At moderate temperatures (between about 60 and 75 degrees Fahrenheit) and very low relative humidity (6 percent) the mouse evaporates water by way of its exhaled air at a rate of about two milligrams of

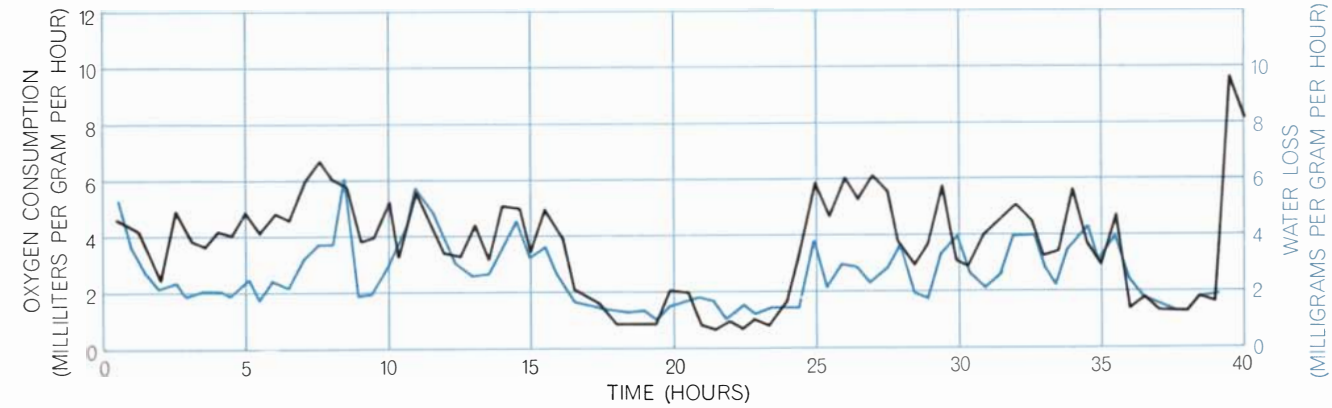


CHANGE IN BODY WEIGHT reflects the ability to tolerate stress. Mice were fed either a lethal diet (inadequate for survival without water) or one of various nonlethal diets. Body weight became stabilized even on a lethal diet with seawater. (Colored curve, which is in part a weight-loss index, tends to overstate loss.)

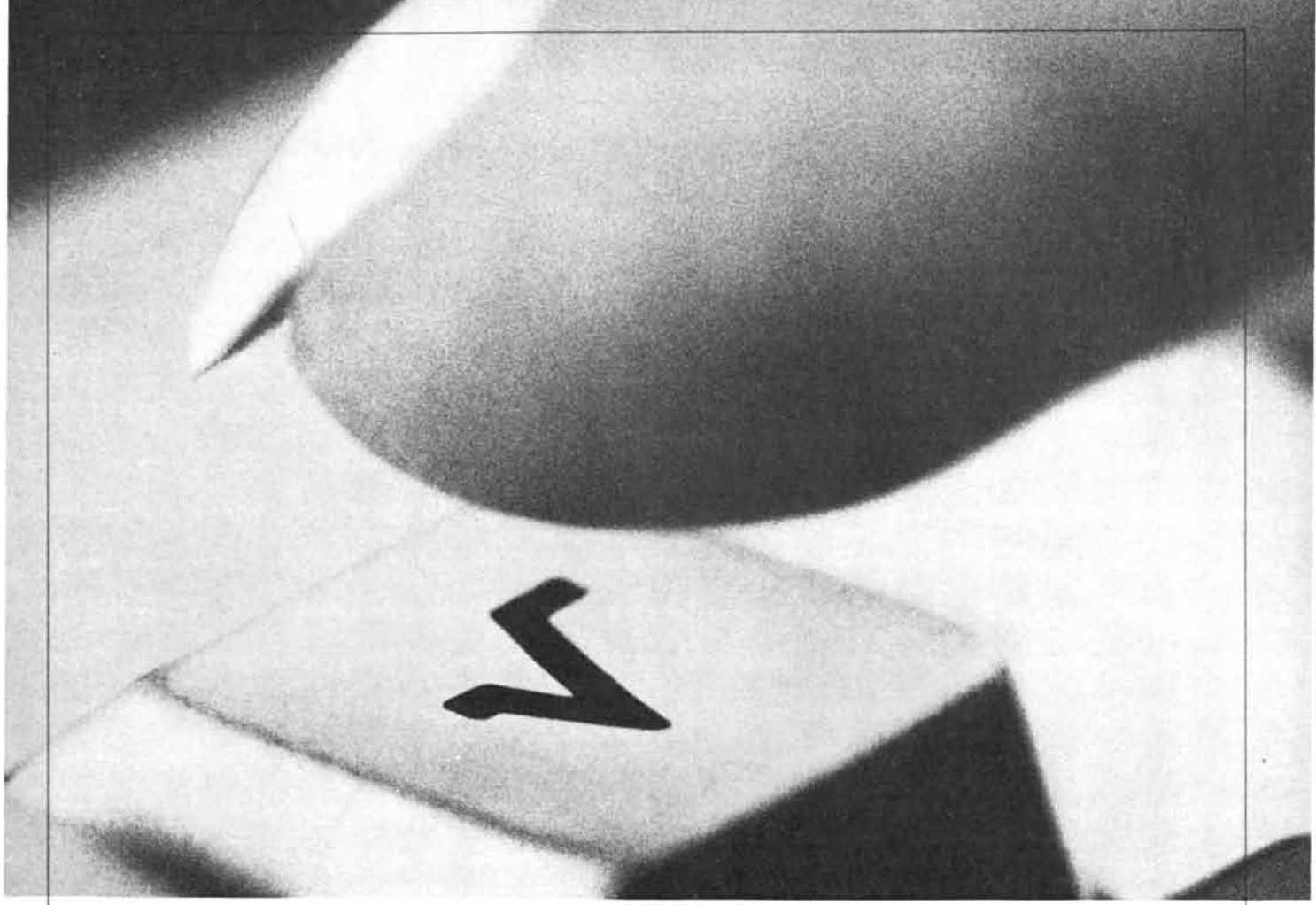
water per gram of body weight per hour —a comparatively low rate for a small mammal. Curiously, the rate does not vary much with temperature at air temperatures below 95 degrees F., probably because the rate of metabolism and of breathing slows as the temperature (and speed of evaporation) rises. Estimating the water loss in breathing by another measure—the ratio of evaporative loss to the body's consumption of oxygen—we found that the house mouse again shows only a small relative loss compared with that of most other mammals. Indeed, it turned out that at ordinary temperatures the mouse loses very little of its body heat through evaporation. It gets rid of its metabolic production of heat mainly by means of radiation, conduction and convection. Moreover, the mouse's selection of living space helps to minimize its loss of water by respiratory evaporation. In the well-insulated nests into which it burrows it creates a warm, moist microclimate, so that the air it inhales is nearly saturated with water.

One wonders about the considerable expenditure of water by a female mouse in milk when she is nursing her litter. It may be that in nature the mouse breeds mainly in seasons when its habitat is relatively moist and food is abundant. Yet we know that mice do breed in buildings or other places where nothing but dry food is available. They have even been observed to breed in a granary where their only source of food and moisture was flour. Part of the explanation of their ability to give milk to the young in such situations lies in the fact that the milk of the house mouse has an unusually high fat content, hence a relatively low content of water. (Interestingly enough, the same thing is true of the milk of such marine mammals as whales and porpoises.) It is also quite clear that the house mouse possesses efficient physiological mechanisms for conserving water under stressful conditions.

It had been noted that in house mice, as in some other animals capable of living in arid habitats, the renal papillae, the elements of the kidney in which urine becomes concentrated with waste products, are unusually long. Our analyses showed that the house mouse can produce urine that is as highly concentrated as that of the kangaroo rat and other desert animals such as the sand rat and the jerboa. House mice deprived of water or fed a high-salt diet also reduced their loss of water by way of the feces; the water content of this waste matter dropped to less than 40 percent. Furthermore, under severe dehydration the mice underwent a reduction of the water content of the blood. They were able to



MOUSE UNDER STRESS (on a lethal diet for a week) and in an ambient temperature of 68 degrees F. entered a state of torpor, as indicated by reduced oxygen consumption, in order to conserve energy (*black curve, scale at left*). During periods of torpor it also reduced its evaporative water loss (*colored curve, scale at right*). After arousal (*right*) its body temperature rose from 75 to 98 degrees.



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tolerate an increase of about 12 percent in the concentration of plasma, chloride ions and red cells in the blood.

The kidneys of the house mouse are so efficient in eliminating salt that our marsh mice were able to drink seawater and even considerably saltier solutions without harm. Mice that were fed only dry seeds and were thirsty for water drank solutions containing concentrations of sodium chloride as high as 1.8 molar, more than three times as concentrated as seawater. This is perhaps the highest salt tolerance for a drinking solution ever recorded for a mammal. The tolerance of the mice depended on the humidity of the environment and the type of diet. In jars, with the humidity at a higher level, mice that were fed Purina Chow could drink a 1.3-molar solution of sodium chloride; in cages at lower humidity they were unable to tolerate such a high salt concentration but could drink seawater (.54 molar). On seawater and Purina Chow they were able to maintain their body weight at 80 percent of the original weight.

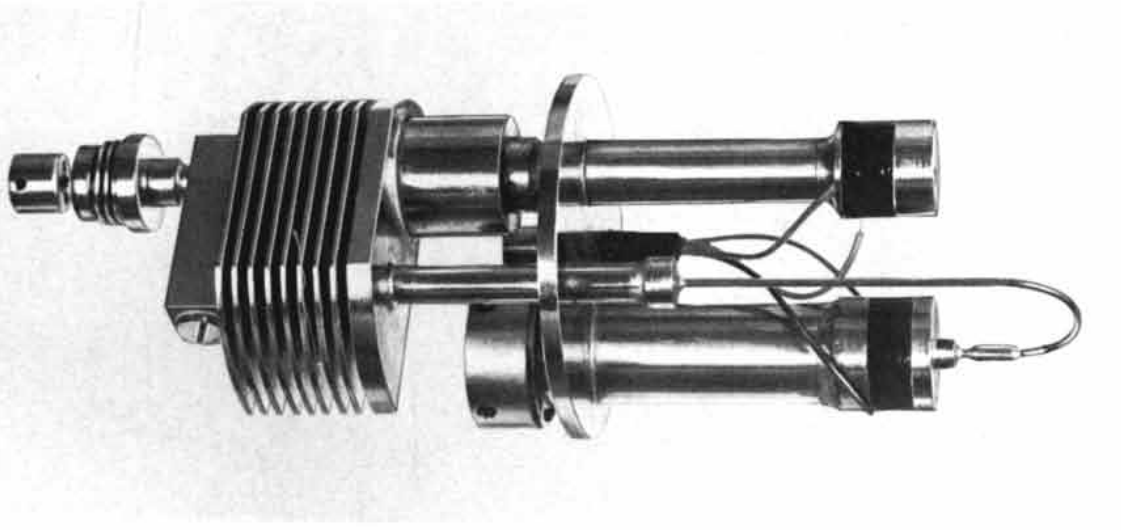
When the mice drank seawater, they produced urine in which the salt concentration was as high as two and a half times that in seawater itself. On drinking saltier solutions they sometimes excreted urine that was almost four times saltier than the sea. They were also able to eat succulent marsh plants that contained not only salts but also potentially toxic substances. We tried feeding them pulp from the cholla cactus, which is reputedly toxic to laboratory rats; the marsh mice ate this desert plant readily and apparently suffered no ill effects.

We examined still another physiological mechanism that enables house mice to conserve water. Laboratory workers have often observed that when mice are subjected to cold and are inadequately fed, they may lapse into a state of torpor. Their life processes slow down markedly, evidently as a conservation measure. These mice recover their normal activity spontaneously or when they are disturbed. Feral mice were tested by being subjected to food and water shortages and cool temperatures, and the effects on their temperature, consumption of oxygen and loss of water through evaporation were observed.

Ordinarily when a mammal or a bird is exposed to cold it speeds up its metabolism (and oxygen consumption) to compensate for its increased loss of heat to the environment. At an air temperature of 68 degrees F. an active mouse may raise its rate of oxygen consumption to twice that at an air temperature of 84 degrees. We found, however, that when we exposed the stressed house mouse to air temperature at 68 degrees it soon fell into a torpid state in which its body temperature, normally about 100 degrees, dropped to 75 degrees and its consumption of oxygen sometimes declined to as little as 10 percent of the basal rate, reflecting a corresponding drop in its rate of metabolism. At the same time its loss of water by evaporation was much reduced [*see bottom illustration on page 108*]. This reaction in the house mouse gave a clear indication that it possesses a protective mechanism in the form of dormancy for conserving food and water when it is placed under stress.

To sum up, the physiological ecology (environmental adaptation) of feral strains of the house mouse helps to explain the enduring success of this mouse in sharing the man-made environment and exploiting rigorous natural habitats. For this purpose *Mus musculus* is equipped with a number of helpful special capabilities: the ability to tolerate severe water restrictions, to get along on certain diets without water, to use salt water for drinking, to reduce the water content of its urine and feces to low levels, to restrict the loss of water by evaporation and to subside into a lifesaving torpor when it runs short of food and water. Thanks primarily to these capabilities and its small size, the species has found in man's arid building interiors a haven where it is provided with comfortable housing, has access to abundant supplies of stored food, easily hides from its hostile host and is secure from its natural predators.

GEOGRAPHIC DISTRIBUTION of house mouse subspecies has been influenced by man. *Mus musculus wagneri*, still found in Iran and Soviet Turkestan, is one of four wild subspecies. The map indicates the spread of *wagneri*'s Western descendants, two of which were introduced into the Americas by human migration from Europe. The two subspecies met and interbred in the central U.S.



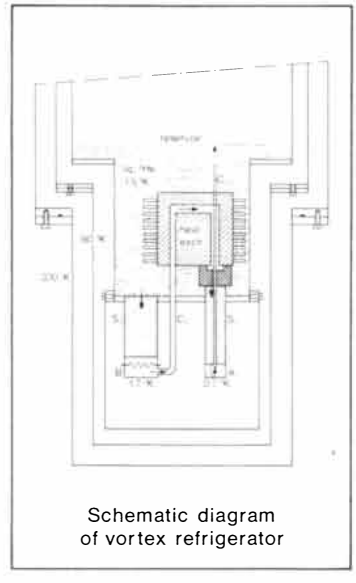
Actual size

A simple method of catching cold

Scientists wanting to carry out experiments at temperatures around 1° K, had to pay heavily for the privilege. They had to fit a helium cryostat with bulky man-high boosters and backing pumps or use expensive ^{3}He.

A new, compact vortex refrigerator exploits the fundamental flow properties of superfluid helium to reach temperatures well below 1°K — fast. At temperatures below the λ-point (T = 2.17° K), ^{4}He becomes a system of two interpenetrating fluids- a viscous normal fluid and a superfluid. The normal fluid carries the entropy. Consequently, heat flow is associated with a normal fluid flow.

The superfluid is non-viscous and may flow persistently in a circuit, if its velocity is below a critical value. Above this value, quantized vortex lines appear. These interact with the normal fluid, dragging it along with the flow of superfluid. After studying this phenomenon, Dr. F. A. Staas of Philips Research Laboratories, Eindhoven, the Netherlands, decided to apply it in a simple cooling method. The diagram shows the "vortex fridge" designed by Dr. Staas and Mr. Severijns. It is mounted on the base plate of a cryostat containing a liquid helium reservoir at a temperature below the λ-point (e.g. T = 1.5° K). The refrigerator part proper consists of a series connection of superleak S_1, chamber A and capillary C_1. A superleak is a porous plug which lets superfluid pass without friction, but reduces the flow of normal fluid to zero. It is known that motion of quantized vortex lines in the superfluid is associated with a gradient ot the thermodynamic potential: grad $\mu = \frac{1}{\rho}$grad P - S grad T. A superleak is analogous to a hard superconductor, in which the vortices are pinned. As vortex motion is then impossible, the thermodynamic potential is constant throughout the superleak. If a generator of thermodynamic potential (e.g. a pump) is connected to the series connection S_1, A and C_1, the thermodynamic potential is seen only across the capillary, in which vortex motion occurs. If there is no temperature gradient along the capillary, the gradient of thermodynamic potential appears as a pressure gradient. This pressure gradient causes a flow of viscous normal fluid from chamber A and thus cools it. Most of the initial pressure gradient is then converted into a temperature gradient along the capillary. The pump, necessary as a thermodynamic potential generator could be an ordinary centrifugal pump. However, in order to avoid moving parts, Dr. Staas chose to apply as a pump a series connection (S_2, B, C_2) similar to the one just described for the cooling part, but now with reversed action. The superleak S_2 is connected to the heating chamber B and the capillary C_2. Heating of B then results in cooling of A. With the new apparatus, in the absence of a thermal load, heating B from 1.5°K to 1.7°K, cools A from 1.5°K to below 0.7°K. The cooling capacity is considerable, for example at T = 0.8°K it is approximately 10 mw. Its dimensions are only 15 cm high and 5 cm wide. Dr. Staas' colleagues now can do low temperature experiments on their own laboratory benches. Cool man, real cool.



Schematic diagram of vortex refrigerator

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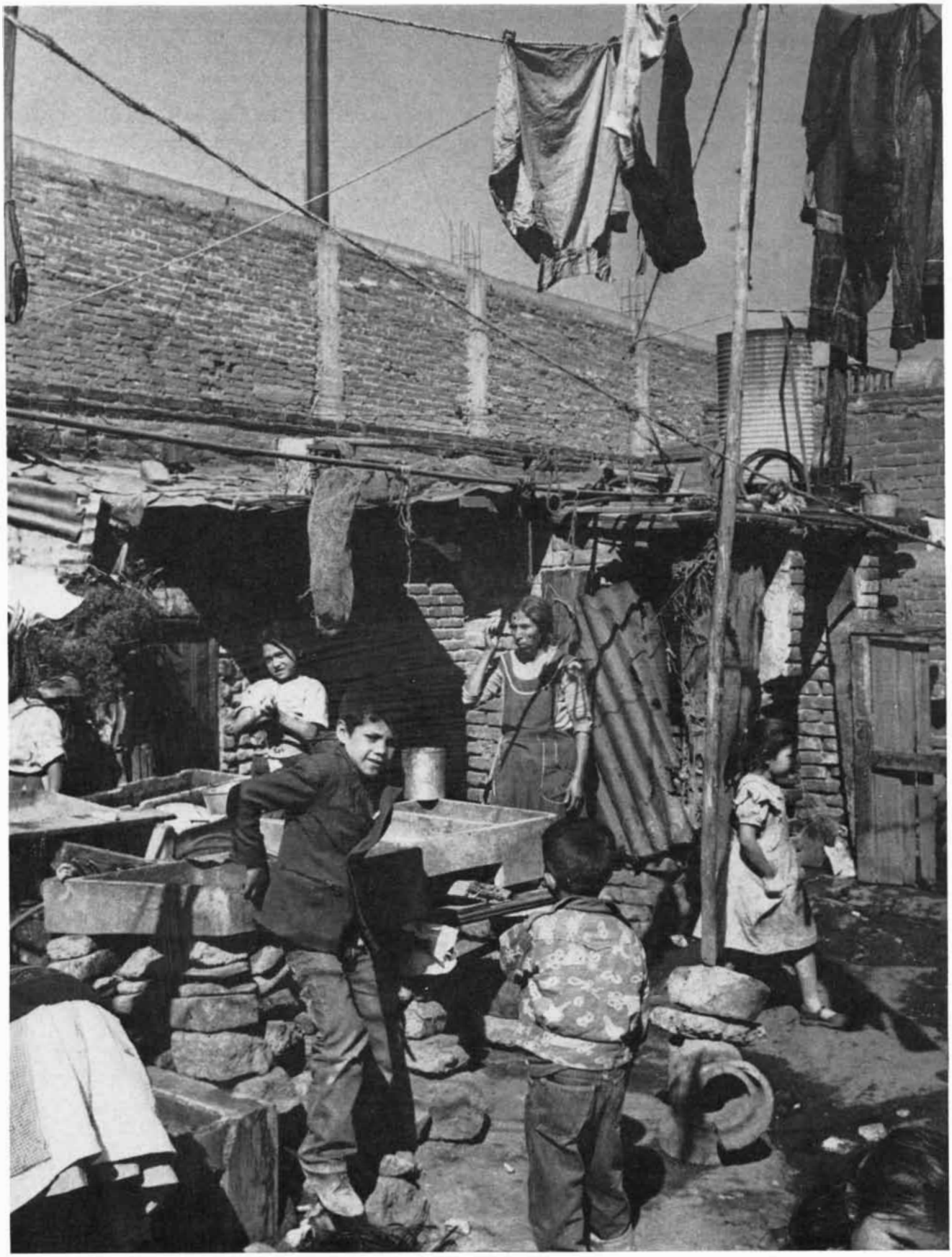


PLAZA OF THE *VECINDAD*, or tenement, in Mexico City where the author and his colleagues made their inventory of the material possessions of the inhabitants is an unpaved area that serves as a communal playground, laundry, workshop, barnyard and bath. In the background is the adobe-brick wall of the tenement itself, which consists of 14 one-room apartments in a row. Each apartment is occupied by one family. The population of the tenement at the time of the study was 83, an average of about six per apartment.

THE POSSESSIONS OF THE POOR

The combined value of everything from ashtrays to underwear owned by 14 families in a Mexico City tenement came to an average of $338 per family. What does such material want reveal about poverty in general?

by Oscar Lewis

We all recognize poverty when we are confronted with it, but it is not easy to define the condition in objective terms. Income itself is not an entirely adequate measure because it does not tell us how people actually live. We come closer to describing what poverty is when we define it as the inability to satisfy one's material wants or needs. It occurred to me that it might be interesting and useful to study the material possessions of poverty-stricken people as a concrete expression of the lives they lead. In the hope of finding new insights into the nature of poverty, I undertook a systematic examination of the possessions of a group of poor families living in a Mexico City slum tenement.

In many respects such a survey is analogous to an archaeological examination of the material remains of a civilization. From an analysis of material objects the archaeologist can learn much about a people's history, achievements, cultural influences, values and ways of life and can make important generalizations about the society. Similarly, a quantitative analysis of the material possessions of a living society should tell us many things, including information that might escape notice in a direct study of the people themselves. In the case of a living people we have the advantage of being able to supplement the story told by the material objects by questioning the people about their possessions.

The inquiry opens up a mine of interesting questions. What proportions of their income do poor people spend on furniture, on clothing, on religious objects, on luxury items, on medicines? How much of what they buy is new? How much is secondhand? To what extent do they depend on gifts or hand-me-downs? (Welfare contributions did not enter into the picture in my study, as there was no public welfare system in Mexico City.) How do families in poverty finance their purchases? Where do they do their shopping? How wide are their choices? What is the physical condition of their possessions? How long do they manage to hold on to them? I was able to obtain rather detailed information on all these matters.

The scene of my study was a small *vecindad* (tenement), one of the poorest in Mexico City, that housed 14 families totaling 83 people (an average of about six persons per family). The tenement consisted of a row of 14 windowless one-room apartments built of adobe brick and covered with a cement roof that joined them all together. Each apartment had a small entranceway with a makeshift roof of tar paper or metal and a door so low that one had to stoop to enter. These entrances also served as kitchens. A walk of rough stone slabs laid by the tenants to combat the mud ran parallel to the row of apartments and was cluttered with laundry tubs, pails, chamber pots and articles set out to dry in the sun. Firewood, covered with old gunnysacks or pieces of cardboard, was stored on the roof. Some of the tenants, who plied their trade at home, had built flimsy sheds as workshops against the front of their apartment; the sheds were used to store piles of materials and tools. In the yard was a large cement water trough that served all the tenants for washing dishes and laundry and for bathing children. Toward the back of the yard there were two common toilets, dilapidated adobe structures curtained with pieces of torn burlap.

Clotheslines strung on forked poles crisscrossed the yard, and the ground was strewn with rocks and pitted with holes dug by the children. In the daytime the yard was filled with half-naked babies and ragged youngsters playing in the dirt.

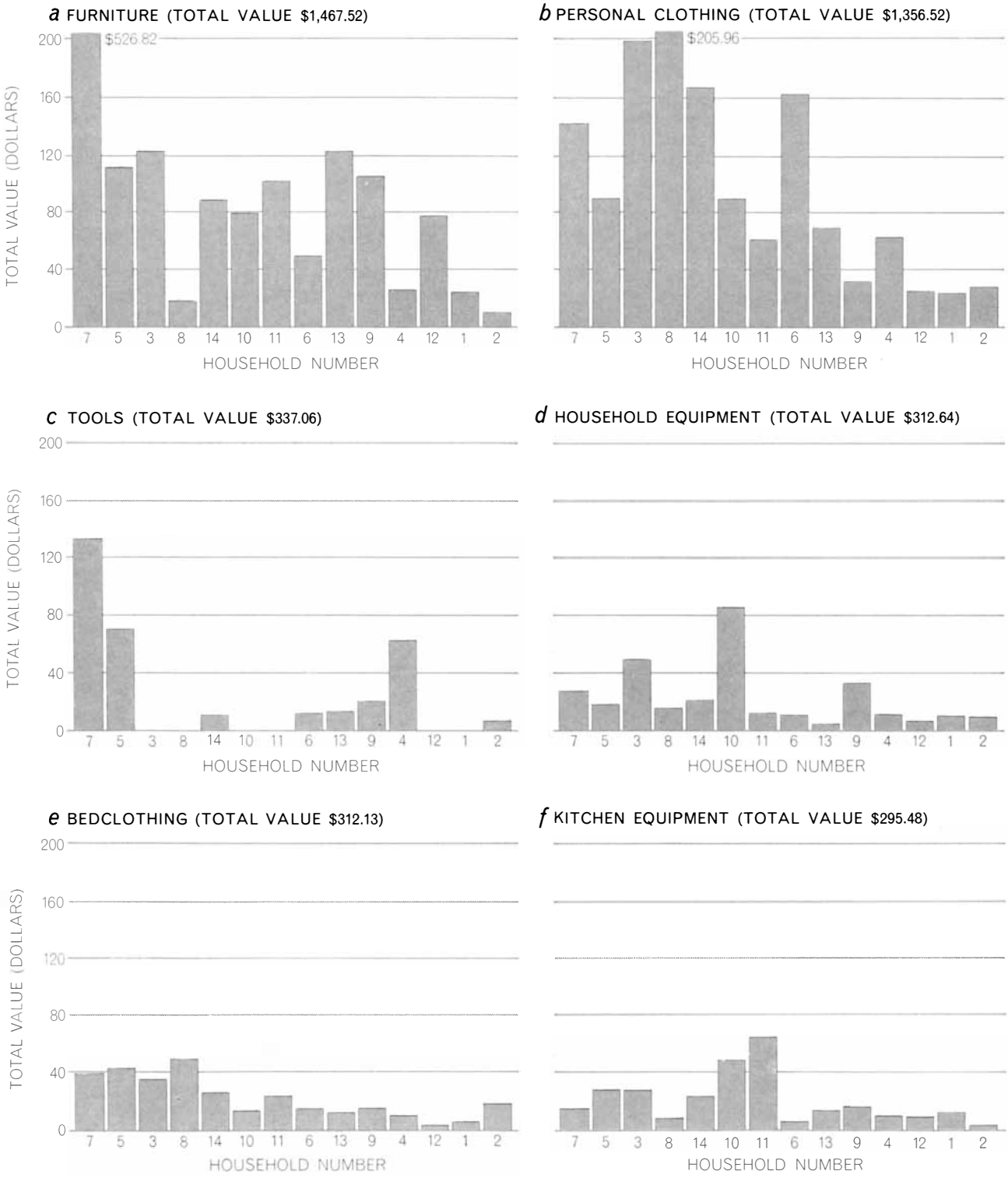
The impression of extreme poverty given by the *vecindad* was amply substantiated by my inventory of the possessions of the 14 households. The total value of all their belongings (based on a detailed estimate of the cost or value of each item) was about $4,730 in U.S. dollars, or an average of about $338 per household. There was considerable variation among the households: the amount ranged from $119 for the poorest household to $937 for the "wealthiest." Twelve of the 14 households owned less than $480 worth of goods.

For purposes of analysis I classified the family possessions into 13 categories: furniture and furnishings (including radios and television sets), personal clothing, bedclothes, household equipment, kitchen equipment, household decorations, jewelry and other items of personal adornment, religious objects, toys (including bicycles), medicines, animals, plants, and the tools and materials of those householders who carried on trades at home [*see illustration on next two pages*]. I shall first mention some general findings and then discuss the categories in more detail.

Not surprisingly, my inquiry showed that substantial proportions of the people's possessions had been bought secondhand; this was true, for example, of about 35 percent of all the furniture and 13 percent of the personal clothing owned by the 14 households. Less than 15 percent of all their goods had been purchased in shops; most of their possessions (60 percent) had been bought in open street markets. The tenants' shopping area was narrowly circumscribed: 66 percent of all their purchased possessions had been bought either within the

tenement itself or within the neighborhood, and about a fifth of the purchases had been made in markets in nearby neighborhoods. Thus about 85 percent of the purchases were made within a radius of less than a mile from the tenement. Of the remaining purchases 8.9 percent were made in distant neighborhoods of Mexico City and 5.6 percent were made outside the city. Although the tenement was within a few minutes' walk of Mexico City's downtown shopping center, comparatively few of the tenants' possessions had been bought there or in more distant places. (Indeed, apart from occasional religious excursions to pilgrimage centers, most of the families had traveled very little, either within the city or outside it.)

The tenants' principal possession was furniture, accounting for about a third

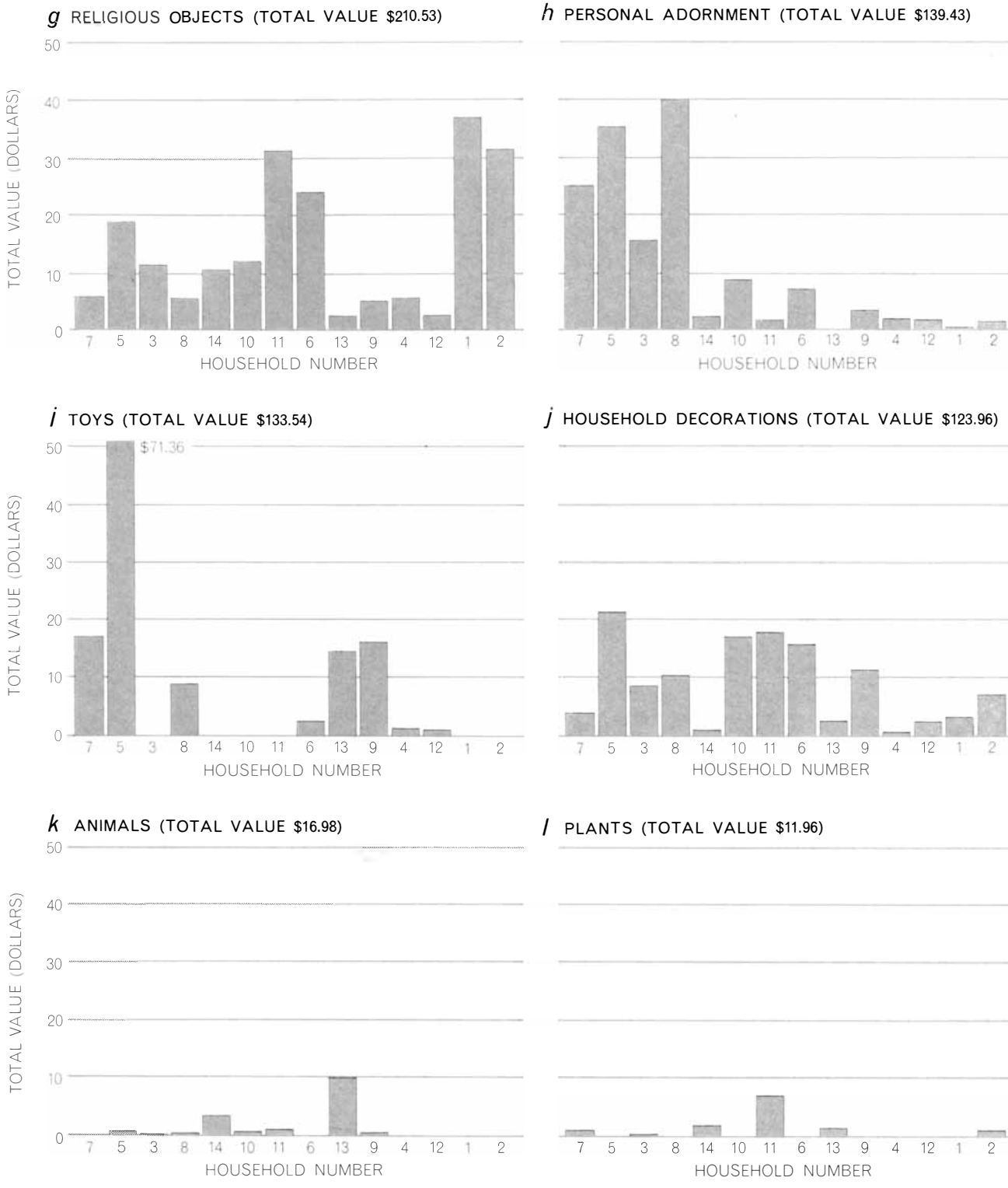


VALUE OF POSSESSIONS in 14 tenement households showed a steady decline from best-off (No. 7) to poorest (No. 2) but varied greatly from family to family. Furniture (*a*) was the most valuable possession and personal clothing (*b*) the next. With a total valuation of more than $2,800, the two were worth more than all other possessions combined. More than 90 percent of the best-off family's investment in furniture, however, was in a $480 television set, and nearly half of the value of all the toys (*i*) owned by the

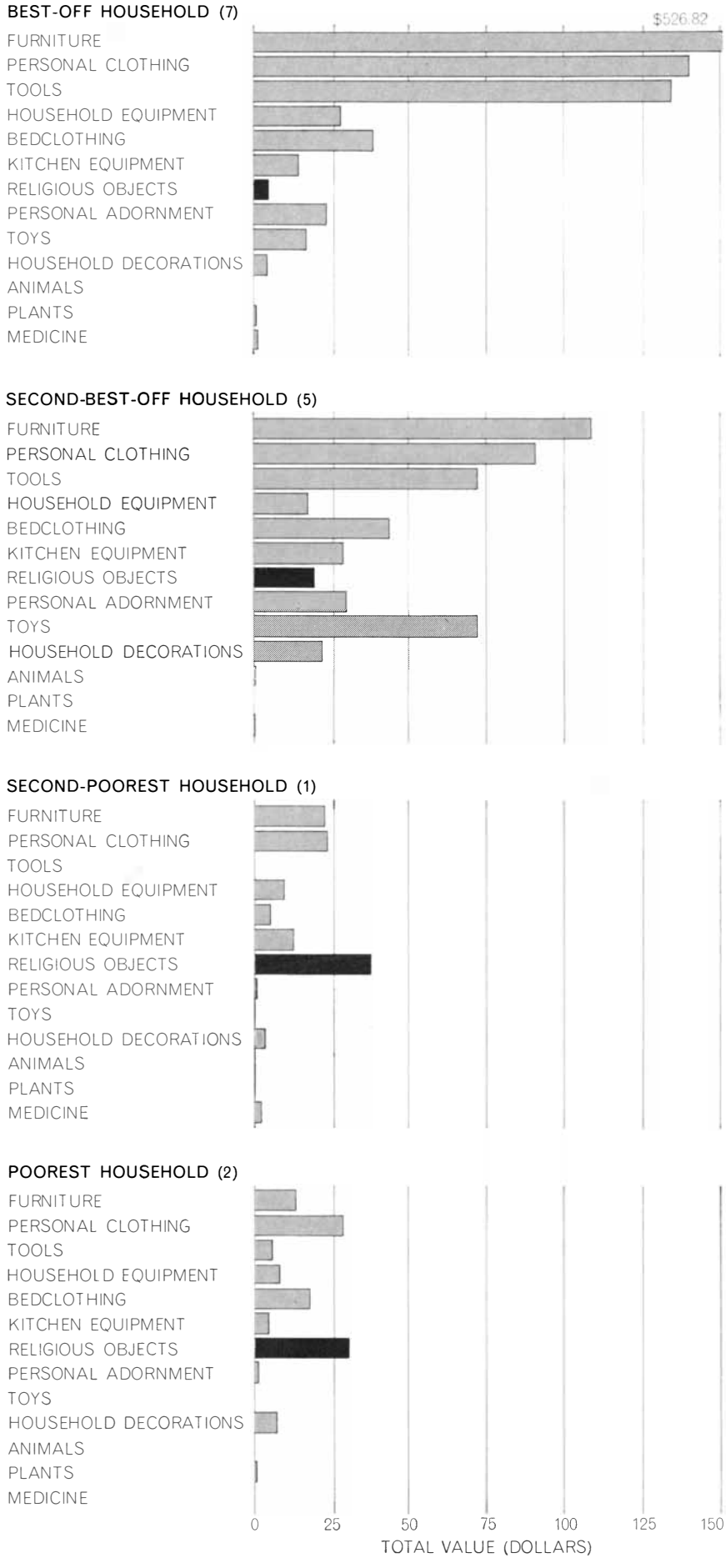
of all their expenditures on material goods. At the time of my inventory each family had among its furnishings at least one bed, a mattress, a table, a shelf for an altar and a set of shelves for dishes. They considered these items to be the minimal essentials, although most of the families had lived without some or all of them in the past.

The 14 households owned a total of 23 beds for their 83 members, so that in most of the households some members (usually the older sons) had to sleep on straw mats or rags on the floor. Of the 23 beds, seven had been bought new, 13 secondhand and three had been received as gifts. The new beds ranged in price from $4.40 to $12.

The bed or beds usually took up most of the space in the one-room apartment. During the day the bed was used for



families that had children was represented by the $64 bicycle in household No. 5. Unevenness in the decline from best-off to poorest in household equipment (*d*) is because households No. 3, No. 10 and No. 9 had sewing machines. Not only clocks but also wristwatches were found in four of the seven better-off households, but the seven poorer ones had no clocks at all. All, however, had electric light and an electric iron. Only one had no chairs, only two had no wardrobe for clothes and only three had no radio.



sitting, for work, for sorting laundry and for many other purposes, including a play area for the children. In families in which a night worker had to sleep during the day, he slept on one side of the bed while the other members of the family sat, worked or played on the other side.

The average length of ownership of a bed among these families was only four years eight months, not because the beds wore out rapidly but because for one reason or another—prolonged illness, family separations, death or economic emergency—the families occasionally had to pawn or sell their furniture to raise money for food and other necessities. The instability of bed ownership was only one instance of the brief and uncertain possession of furniture items among these families. The mean time of possession for all the pieces of furniture in the tenement was only four and a half years, although a majority of the families had lived there for more than 15 years. The brevity of possession was frequently due to the inability of the families to meet the installment payments on furniture bought on credit.

The poverty of the possessions is perhaps most vividly illustrated by the mattresses on which the people slept. Most of the mattresses were of cheap quality and stuffed with lumpy cotton or straw; only four families had invested relatively heavily (from $22 to $44) in better-quality mattresses with springs. The condition of many of the mattresses was incredibly bad because of hard wear and lack of any protective covering. They were almost all stained, torn and infested with bedbugs and fleas. Of the 26 mattresses in the *vecindad,* 14 had been bought new, two were gifts and 10 had been bought secondhand, their poor condition notwithstanding. In spite of the low price of the used mattresses (ranging from 56 cents to $2.40) the total amount invested in mattresses ($178) was higher than the amount invested in

SHARP CONTRAST in value between the possessions of the two best-off and the two poorest households, although it was predictable, had one surprising element. All the possessions in the two poorest households were worth less than half the value of those in No. 5, the second-best-off household, and those in No. 7 were worth nearly twice as much as those in No. 5. The value of holy pictures and other religious objects in either of the poorest households, however, far outstripped the value of such objects in the best-off: combined, they constituted 33 percent of the total value of such objects in all 14 households in the tenement.

WASHING CLOTHES, a tenement housewife combines traditional and modern methods. The cement trough with its pounding stone is a part of the past, as is the decorated pitcher. The tub and buckets of galvanized iron form a part of the residents' inventory of more contemporary equipment. Although dishpans were scarce, the families owned a total of 43 buckets and 21 tubs.

beds ($132). The average duration of mattress ownership was three years eight months.

Each household had at least one shelf for votive candles dedicated to the saints, even if it was only a small board hung with string from nails on the wall. The altar was often loaded with a clutter of nonreligious objects: needles, thread, razors and other things that had to be kept out of reach of children. On holy days it was cleared and decorated with colored tissue paper.

Kitchen shelves were also found in every household, although many of the families had at one time been unable to afford them and had had to keep tableware and food on the floor. The shelves were inexpensive, none costing more than $1.20. The majority of them had been bought secondhand, received as gifts or built by members of the household.

The fifth essential article, a table, was also owned by every family. Some of the better-off families had two or three tables and had managed to paint or varnish them or cover them with oilcloth. The majority of the tables were cheap unpainted wood ones; the most expensive cost $5.20, and three-fourths of them were valued at $1.20 or less. None had been bought in a store; most had been acquired at street markets or from relatives or acquaintances.

In addition to the five indispensable articles of furniture, nearly all the families considered three others to be necessary for a decent standard of living. One of them was a chair. Only one household had no chairs at all; the adults there sat on the bed and the children on the floor. One family had eight chairs; another, seven; most had at least two. The chairs made the single small room of the apartment very crowded indeed. In the tenement as a whole, however, there were only 52 chairs for the 83 residents; at mealtimes many had to sit on the bed, on a low stool or on the floor. Like the other furniture, all the chairs were inexpensive; none had cost more than $2.

A wardrobe for clothing also was regarded as a necessity, since none of the apartments had a closet. Twelve of the 14 households had a wardrobe; in the other two clothes were hung on nails or kept in boxes. A wardrobe represented a relatively large investment, and the families considered it to be a prestige item. It was often a wedding gift from the husband to the wife.

Most of the wardrobes had been bought new, at an average cost of $16.80, and they were generally the longest-held article of furniture in the apartment. Some had been there for as many as 15 years. In all but a few instances the wardrobe was in poor condition—battered and with the door mirrors either cracked or missing. Only one family had been able to afford to replace its broken mirrors.

Every family considered a radio essential, and at the time of my study 11 of the 14 households had one. One family had two radios. The radio was usu-

ally the family's most expensive piece of furniture. More money ($414) had been invested in radios than in any other item except for two television sets. Most of the radios had been bought new on credit, at prices ranging from $20 to $74. Because of the precariousness of the tenants' financial situation, the radio tended to be only a briefly held possession; its ownership averaged less than three years. Frequently the radio had to be given up because the family could not meet installment payments on it or could not afford to have it repaired when it broke down. Many radios were pawned, usually in a clandestine pawnshop that charged 20 percent interest per month on the loan. After losing the radio most families would buy another as soon as circumstances permitted.

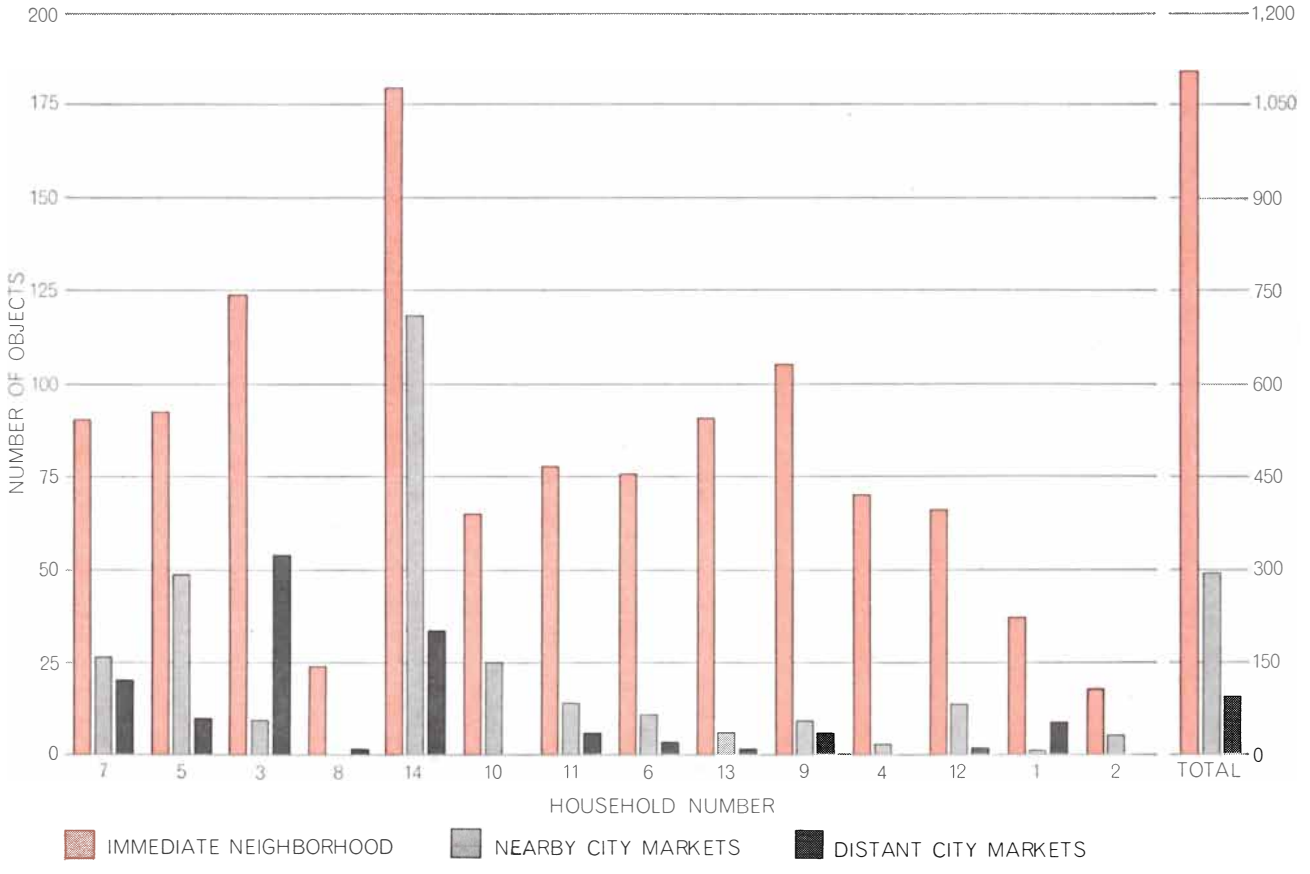
Only one of the families was able to buy and hold on to a television set. This family, financially the best-off in the tenement, was managing to keep up the payments on a set costing a little more than $480—an amount greater than the combined value of all the family's other material possessions and greater than the total personal property of 12 of the other tenants. A second family had a television set when I began my study, but it pawned and lost the set before I had completed the investigation. The family bought another set later, committing itself to paying $24 a month for several years; it would be a most extraordinary achievement if the family succeeded in maintaining the payments. Needless to say, everyone in the tenement, particularly the young people, would like to have a television set, but few other families have attempted to buy one.

Some of the families in better economic circumstances had extra items of furniture such as glass-fronted dish cabinets and, in one case, three armchairs. These articles apparently were esteemed by their owners more for prestige value than for utility; in the one-room apartment they were impractical and they crowded the small space to a point of extreme inconvenience. The owner of the armchairs was a young shoemaker who was trying hard to raise his standard of living. He had bought a television set and the first and only gas stove ever used in the *vecindad,* but he had lost both by pawning one and not meeting the time payments on the other.

In nearly all cases furniture items (such as new mattresses, wardrobes and radios) that cost more than a few dollars were bought on credit. The public markets or itinerant salesmen from whom they were bought did not require a down payment, but for the privilege of paying in installments the buyer had to pay twice as much as the cash price of the article. The tenants were aware of this, but their cash resources were so small that they could obtain these articles only by buying them on credit. The weekly installments were usually low, averaging 80 cents, and often extended over more than a year for a single article.

The purchases of secondhand furniture were usually made from relatives or friends, most often within the same tenement. Since 11 of the 14 households were closely related, there was considerable opportunity for intrafamily commerce, usually at bargain prices.

Kitchen equipment in the 14 households was generally restricted to inexpensive items. The largest total in-



BUYING HABITS of the tenement families were analyzed by finding out where some 1,600 objects had been bought. In every case, buying in the immediate neighborhood and within the tenement itself outweighed purchases at nearby or more distant city markets. In part this reflects buying from itinerant peddlers who visited the tenement regularly. Two households contained more than four objects obtained outside Mexico City; some had come from as far away as Guadalajara, Acapulco and the state of Chiapas.

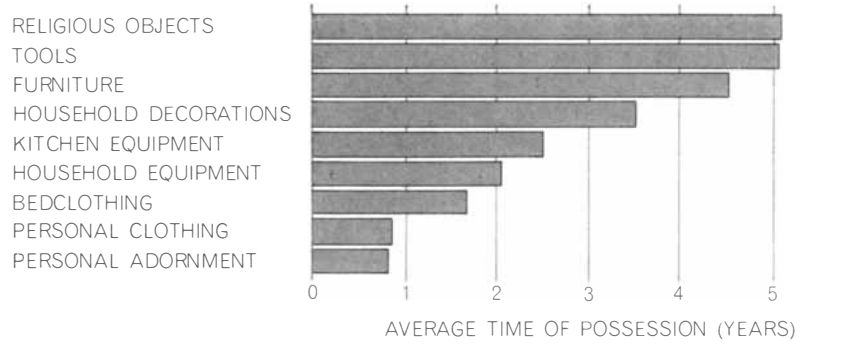
vestment in this category by any family was $42.63, and the aggregate for the 14 households was $230.36. None of the apartments had a refrigerator. The principal item of kitchen equipment was usually a stove. Eleven apartments had kerosene or petroleum stoves; in the other three cooking was done on a brazier or an earthenware plate over a charcoal hearth on the floor. The cooking vessels were generally inexpensive *ollas* or *cazuelas* (narrow-mouthed or wide-mouthed vessels of clay). Only two families had aluminum pots and only five had copper kettles. Twelve owned frying pans.

Every family had a few spoons that were used for cooking and for eating soup. There were few other eating utensils; only two families owned forks and only seven had table knives. Solid foods were usually eaten with the fingers, often with the aid of a tortilla to wrap or scoop up the food. The eating plates were most commonly "tin" ones (costing from eight to 16 cents); one family had a six-piece place setting of china, which it had owned for 14 years. Because glassware was a favorite gift item in the community, particularly on Mother's Day, the households had more glasses than traditional Mexican clay cups. One family owned 76 glasses. Some families also had serving trays and other "luxury" items that had been received as gifts.

Almost 90 percent of the kitchen equipment had been bought new because it was relatively inexpensive. In spite of the breakable nature of much of it this equipment had a better record of durability (the average was two and a half years) than many of the other articles in our inventories.

Other household equipment, although more meager in quantity than kitchen utensils, was placed in a separate category of study. Household equipment for all the families totaled $294 in value and ranked fourth in the list of categories. Three sewing machines owned by three families accounted for about a third of this total. One of the sewing machines had been pawned three times in three years to pay debts.

All the women in the community sewed; many of them mended and made clothes and bedclothes for the family, much of it from flour sacks. All owned at least one needle and most owned a pair of scissors, although on occasion the scissors might be pawned. Only seven of the households had a thimble, and none of the women owned a sewing basket for storing thread and needles. They usually bought thread in small quantities, sufficient only for the job at hand. Each family had at least one electric iron, in most cases bought second-hand. Two better-off families had ironing boards; in the other households the women ironed on the table.



AVERAGE LENGTH OF TIME that objects remained in a tenement household was at its maximum in the case of pictures of saints and other religious items, which were often considered heirlooms. This was also true of tools, which were a source of livelihood for the tenement households that engaged in manufacturing. On the other hand, items that were easily pawned, such as jewelry, or quickly worn out, such as clothing, were soon let go.

In the entire tenement there were no wastebaskets and only two ashtrays, although most of the men and many of the women smoked. Nine of the 14 households had no garbage can for the kitchen. Cigarette butts and all other trash were simply thrown on the dirt or cement floor of the room and were eventually swept out. Every family had a broom, generally a crude handmade affair that had to be replaced frequently because of constant use.

Two water taps in the yard were the only source of water for the apartment and every family required several buckets or containers for fetching water. The 14 households had a total of 43 pails. They also owned a total of 21 tubs, some of them quite large, for laundering and for bathing. Fewer than half of the families owned dishpans; only four had a washstand. Toothbrushes were a luxury; in only three families did each person have a toothbrush of his own. Among the more unusual items were three douche bags, a syringe and three eyecups.

Awareness of time and of schedules was increasing among the slum dwellers, and most of the families felt the need of a clock—for feeding babies, giving medicine, getting children off to school on time or listening to favorite radio programs. Still, only half of the families, and only the better-to-do ones, owned a clock. The others kept track of the time either by their radio or by asking their clock-owning neighbors.

All the apartments had electric light. Three households owned gasoline or kerosene lanterns for use in their workshop at night. One household owned an electric heater; for all the others the only source of heat on cold nights was the cooking stove.

As they did in other respects, the families of the tenement varied considerably in the poverty of their household equipment. The better-to-do families not only owned more items in this category (165 articles for the upper seven families compared with 104 for the lower seven) but also had a wider range of objects. One family (the second-poorest) owned no washtub, no clothespins, no scissors or thimble, no storage receptacles, no dishpan, no floor brush, no clothesbrush, no toothbrush and of course no sewing machine or clock. In the tenement as a whole the length of possession of household equipment was very brief, averaging only two years.

Bedclothes, the fifth most costly material goods in the community, accounted for a value of $279.99, or 6.8 percent of the total. This relatively high figure was due mainly to the expensiveness of blankets and quilts; the number of items was actually quite small. No family had more than 30 articles of bedclothing, including sheets, pillows, pillowcases, blankets and quilts. The best-off family owned a silk bedspread. Much of the bedclothing had been bought new, mainly on credit, but a large proportion was homemade. The women of the *vecindad,* even in the better-off families, usually made their sheets from flour sacks. Four sacks made an average-sized sheet. The length of possession of bedclothing averaged only 1.7 years. This was partly because of wear and partly because even bedclothes sometimes had to be sold to meet more urgent needs.

I shall merely summarize briefly here

the inventory of the other five categories of general household goods: decorative objects, religious objects, animals, plants and medicines. The principal investment in decoration was expended on photographs of family members. There was an average of more than seven photographs per apartment. They were usually framed and often in color and represented a total cost of $82.38. Most of the apartments were also adorned with pictures of saints and with colorful calendars, usually religious ones that had been obtained free. A few households had different types of pictures, painted vases, china figurines of animals and other items.

The investment in religious objects by these impoverished families was remarkably large. A total of 147 pictures of Catholic saints and Biblical scenes, an average of more than 10 pictures per household, hung on the walls of the tenement apartments. There were also flowered vases, candles, small religious figures and a variety of other religious objects displayed on the altars. In the tenement as a whole the total investment in religious objects was $210.53. About half had been bought by the residents themselves and half had come as gifts.

The emphasis on religious objects was greatest among the poorest families. The family that ranked lowest in total investment in material possessions actually stood highest in the value of its religious objects. This family and the next-poorest had spent almost as much on religious articles as on furniture. If we include the religious gifts they received, their religious possessions represented nearly twice the total value of their furniture. Nearly all the religious objects in the 14 households had been bought new and were kept for an average of 5.07 years, longer than possessions in any other category.

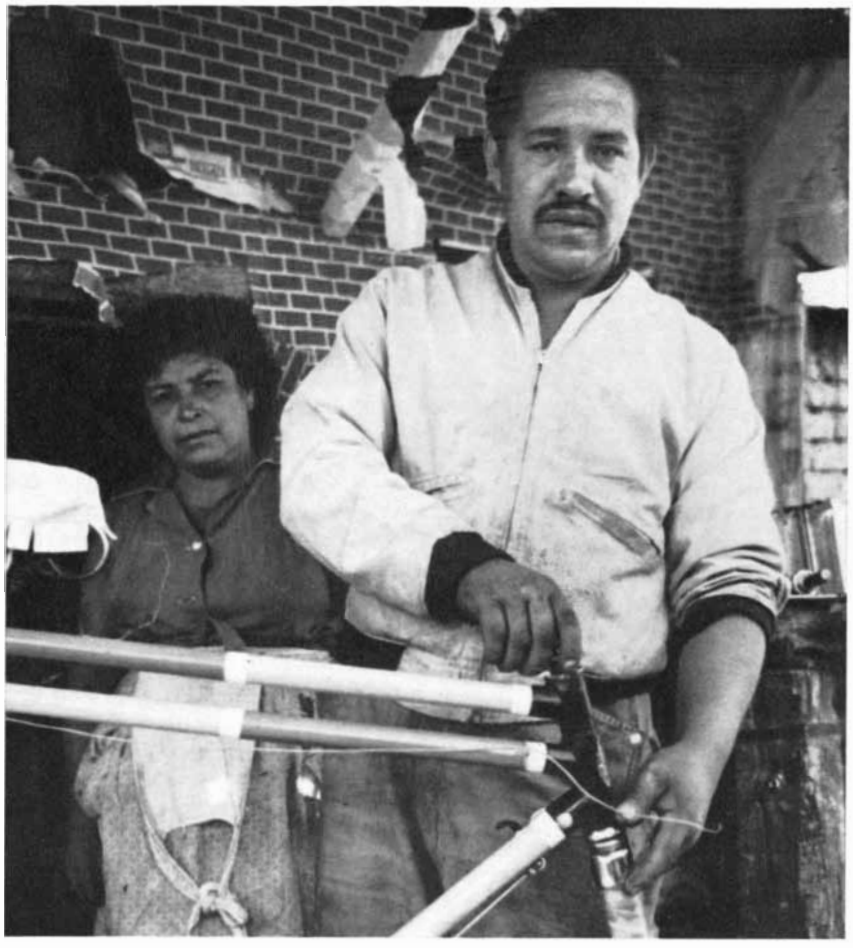
The investment in the other categories of general household belongings—animals, plants and medicines—was so small that it calls for little comment. The tenement residents loved animals; almost every family had a cat or dog (partly as protection against rats and thieves) and some tenants also kept chickens, pigeons and other birds. Their total cash investment, however, was only $15.94 for animals and $10.20 for plants. The 14 families' entire investment in the medicines on their shelves amounted to $7.76.

In the category of personal possessions, clothing was of course the major item. Clothing ranked second to furniture among the 13 property categories, and it accounted for 27.4 percent of the tenants' total investment in material goods. The 14 families had spent a total of $1,127.36 on the clothing they owned at the time of the inventory. About 87 percent of their purchased clothing had been bought new (usually for cash but a third of it on credit); the rest had been obtained secondhand. A substantial proportion of their total of clothing possessions were gifts and clothing made at home.

The families differed markedly in their expenditures for clothes. The poorest families bought very little, relying mainly on gifts from relatives. One family, for example, had spent only $3.92 for clothing and had received $20.72 worth as gifts. The largest outlay for clothing by any family was $192.64. This family ranked near the bottom in furniture possessions. Generally those families that invested heavily in clothing tended to spend little on furniture.

In every household the women supplemented the clothing purchases and gifts with clothing they made themselves, often out of flour sacks or scraps. Most of this home manufacture was for the women and children. For example, the mother in the family with the largest number of children (eight) had produced 42 articles, including 15 items for her youngest baby, 11 dresses, nine slips and seven shirts.

The clothing of all 14 families was limited to a few basic items. Every woman owned at least a dress and a pair of shoes, usually only one pair, so that much of the time she went barefoot. The adult women had an average of fewer than four dresses apiece; the young girls averaged six apiece. Nearly all the women had a *rebozo,* the traditional Mexican shawl, and most of them also owned a sweater, two or more slips (often homemade), underpants (an average of about three pairs per woman) and brassieres. About half of the women had skirt-and-blouse outfits; none wore slacks. There were only 15 pairs of stockings in the entire community; these belonged mainly to teen-age girls. One woman and five girls had coats, one woman had a bathrobe and one owned



INSTALLMENT-PLAN BICYCLE, undergoing repair in this photograph, was bought as a Christmas present for his son by the head of household No. 5. The $64 that it cost was met by monthly payments of $4.80. To recoup some of the money the father rented it out.

a pocketbook. Handkerchiefs were rare; among the 83 residents in the tenement the only people who had this item were two men and two young girls.

The children and men of the community were better shod than the women. The basic wardrobe of the men consisted of shoes, undershorts (often homemade), a pair of pants, one or more shirts and a jacket or coat against the cold. There were only two suits in the community, belonging to two boys who had worn them at their confirmation. A number of men had no socks or undershirts. No male in the tenement owned a necktie. A few men had working overalls, several had a cap or a straw hat and one owned a bathing suit.

The clothing of this community, generally of poor quality and subjected to frequent wear, had a short lifetime. The average length of possession for all items of clothing was only 9.9 months. Sometimes clothes were sold before they wore out because of a financial crisis. In one instance the man of the household sold much of the family's wardrobe during a prolonged drinking spree, leaving his wife with only a single torn dress.

In the category of personal adornment the list of articles is brief. The entire investment in this category was $126.32, more than half of which was accounted for by five wristwatches owned by comparatively well-off families. Religious medals, finger rings and cheap earrings, also owned mainly by less poor families, constituted the rest of the articles in this category. Women's jewelry was extremely scarce. Not a single woman had a necklace, a bracelet or a brooch. In any case, the possession of such items in this community was ephemeral—averaging only 9.8 months—because of the ready convertibility of jewelry into cash.

Toys were even scarcer than jewelry among these families. Of the total investment of $121.62 in toys, more than half was represented by two bicycles. One had been bought new on installments and was rented out part of the time; the other was a secondhand bicycle without tires. There were also three tricycles in the community, two of them secondhand. Only half of the families in the tenement were able to invest in any toys for their children.

Finally, there were a few households that owned material goods in a special category: tools and materials for manufacturing in the home. In total value this category ranked third, after furniture and personal clothing. Three artisans who worked at home accounted for most of the investment: a shoemaker and two

household heads who made and sold toy water bottles. The shoemaker had a stock of soles, heels, nails and various other things required for shoe repairing. Having little capital, he could maintain only a small supply of materials and had to replenish it every few days. Most of the materials and tools had been bought used. All three artisans had held on to their tools for a comparatively long time (an average of 5.05 years), since the tools constituted the family's means of livelihood and could not be sold or pawned as casually as other household goods.

It is surely significant that two of the three households that had managed to scrape up enough capital to make a substantial investment in income-producing tools and materials were also the most affluent families in the tenement in terms of their total accumulation of material possessions. The best-off family owned $134.38 worth of tools, whereas two of the three poorest families in the tenement had no tools whatever.

What conclusions, if any, can one draw from the inventory of the possessions of these 14 slum families? For one thing, I was struck by the truly remarkable differences within this group of families, all of whom might seem to a casual observer to be living at the same level of poverty. Moreover, the differences in the value of their possessions were greater than differences in their income. If we compare the possessions of the three "wealthiest" families [*Families 7, 5 and 3 in the illustration on pages 116 and 117*] with those of the three poorest families [*Families 12, 1 and 2*], we see that the top three owned a total of $1,754.46 worth of purchased goods, whereas the bottom three owned a total of $250.55—only a seventh as much. The largest differential was in the families' relative investment in furniture and clothing: $1,093.92 for the top three against only $149.49 for the bottom three. There were similar differences in expenditures for luxury items such as jewelry ($71.97 against $2.38) and toys ($86.58 against $13.68).

The only category in which the poorer families had spent more than the better-off was that of religious objects. The difference in amount was small ($23.45 by the poorer families compared with $21.78 by the better-off), but in its proportion to the families' total investment in material goods the contrast was great. Whereas the better-off families had invested only slightly more than 1 percent of their money in religious items, the poorer families had invested nearly 14 percent. Furthermore, religious objects also predominated in the gifts the poorer families had received; such objects represented nearly half of all gifts received, whereas religious objects accounted for less than 15 percent of the gifts in the better-off families.

The fact that the tenement dwellers had held on to religious objects longer than most of their other possessions attests to the crucial role of religion in the lives of the poor. It appears also that religious objects may be the only things they own long enough to establish a real identification with. Yet even these are held for a fairly brief period, an average of about five years. The brevity of possession, and the singular absence of heirlooms passed down from generation to generation, suggest that the life of the very poor is weak in tradition and is oriented almost exclusively to day-to-day concerns.

It might be supposed that for lack of funds people in poverty are driven to making their own goods such as clothing or furniture. I found, however, that the better-off families in the tenement were the most productive in this sense because only they owned sewing machines or work tools and could afford to buy the materials. These families produced five times as much clothing (in value) as the poorer families did. By the same token they were also able to buy more of their goods new. Whereas about 25 percent of all purchases by the three poorest families were secondhand, only about 7 percent of those by the three best-off families were secondhand. The contrast was greatest in furniture purchases. The poorer families bought three-quarters of their furniture secondhand; the better-off families bought three-quarters of theirs new.

The study of possessions, while confirming some previous findings about the poor, raises questions about others. For instance, there has been reason to believe that the mobility of poor people is highly restricted, that they rarely venture out of their immediate neighborhood. The analysis of the 14 families' possessions, however, showed that the objects came from 43 different markets or localities, some of them at considerable distances from Mexico City. Eight of the families owned objects that came from 14 marketplaces outside the capital. One family had possessions that were bought in 28 marketplaces, 11 of which were in distant cities, one as far away as Chiapas. It therefore appears that at least some of the Mexican urban poor may move about more widely than has been supposed.

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MATHEMATICAL GAMES

A numeranalysis by Dr. Matrix of the lunar flight of Apollo 11

by Martin Gardner

After the historic completion in July of the *Apollo 11* moon mission it occurred to me that the famous numerologist Dr. Irving Joshua Matrix might have some enlightening comments about it as well as some insights into the approaching end of the 1960–1969 decade. I sent a letter to the last address I had for him, but the peripatetic doctor and his half-Japanese daughter Iva had already left for parts unknown. My letter was forwarded five times, to various European and Asian cities, before it finally caught up with him. His reply has arrived just in time for my October column.

I had asked Dr. Matrix a series of questions. They follow, together with slightly cut but considerably edited versions of the great numerologist's replies. The statements in brackets are my own.

Question: Have you observed any remarkable numerological aspects of the *Apollo 11* mission?

Dr. Matrix: The key symbol of the "moon landing" (note the 11 letters) is, of course, 11. It can be interpreted in two ways: as the number 11 and as a pair of 1's.

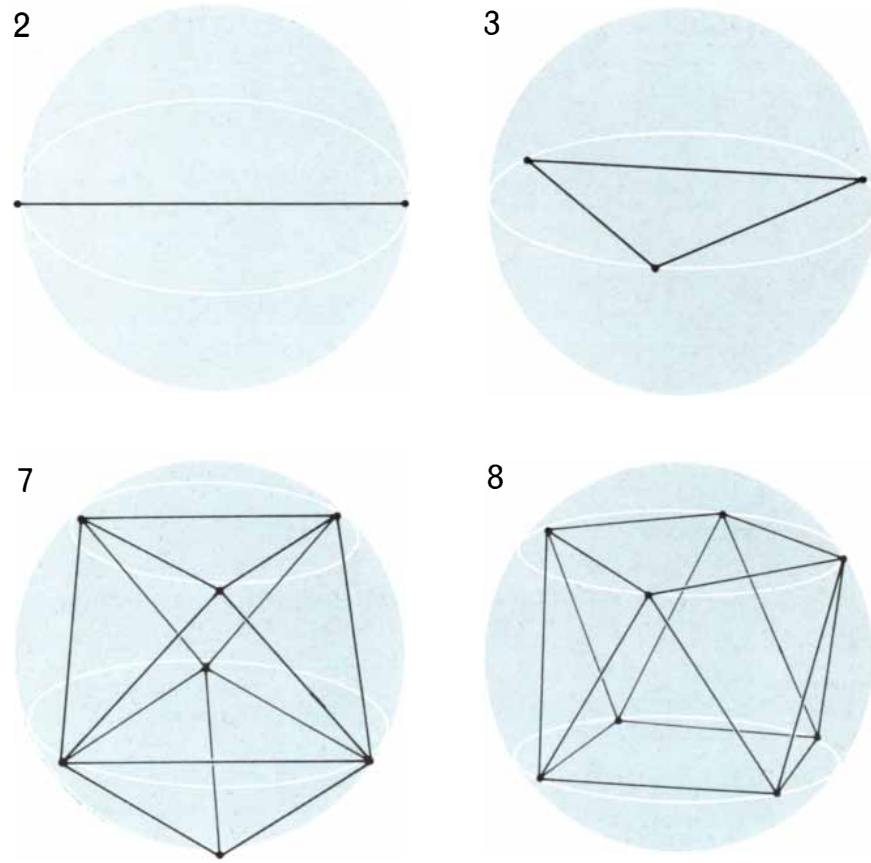
Consider it first as 11. The 11th letter of the alphabet is *K*. Surely it is no coincidence that President Kennedy initiated the Apollo project and that the liftoff of *Apollo 11* was from Cape Kennedy. Eleven is the smallest prime factor of 1,969. The landing was in the Sea of Tranquility and "tranquility" has 11 letters. The first message received from lunar soil, Neil Armstrong's "That's one small step for man, one giant leap for mankind," has exactly 11 words. (Armstrong later said he'd said "for *a* man," but so strong was 11's power that the message was received without the *a*.) Armstrong was then 38 and 3 plus 8 is 11. When the three lunar explorers splashed down in the Pacific, they landed 11 miles from the recovery ship, the carrier *Hornet*. On the carrier they were given buttons to wear that read "Hornet plus three." The six letters of "hornet" added to the five letters of "three" equal 11. These are only a small fraction of the 11's involved in the *Apollo 11* flight.

Now consider 11 as a pair of 1's, symbolizing the first two men to walk on the moon. *A* is the first letter of the alphabet. Is it not significant that the first two men to put their footprints on the moon, Armstrong and Edwin Aldrin, both have last names that start with *A*? Note also the two *A*'s in NASA. If we write Armstrong's name as Neil Arm Strong, Astronaut, we obtain NASA as an acrostic.

Andrei Voznesensky's clever Russian palindrome [reported in *The New York Times,* July 21], "*A luna kanula,*" meaning "The moon has disappeared," was written, the Russian poet explained, so that one can travel letter by letter to the moon and back. Note that the palindrome has exactly 11 letters, which include four *A*'s and the two *L*'s of "Apollo." Armstrong's middle initial is *A*, so that the first men on the moon actually had three *A* initials between them; the palindrome's extra *A* is for Andrei. There are also three *A*'s in "United States of America." Perhaps it was because of the double *A*'s in Armstrong's initials, symbolized by 11, that he was the first to set foot on the lunar surface.

Edwin Aldrin (11 letters) has *E* as a middle initial, providing two *E* initials. We all saw the astonishing "ease" with which Aldrin bounded over the lunar soil. His youngest child, Andrew, is 11 and has the initial *A* for his first name as well as his last. Edwin Aldrin's mother's maiden name was Moon. Colonel Michael Collins (Mike Collins has 11 letters) was the astronaut who remained to pilot the command module. Can it be coincidence that his last name, "command" and *Columbia,* the name of his ship, all begin with *C*?

At the time I write, *Apollo 12* is planned for November, with the moon walk to be made by astronauts Alan L. Bean and Charles Conrad. Thus the *A* walk of *Apollo 11* will be followed by the *B* and *C* walks of *Apollo 12,* the *B*



How to space lunar bases as far apart as possible.

being symbolized by the 2 of 12, the *C* by the sum of 1 and 2.

Finally, your readers may enjoy finding the appropriate single 11-letter word that can be formed by rearranging the 11 letters of "moon starers."

Question: Do you have a digital problem related to space travel?

Dr. Matrix: No sooner had the three astronauts returned to the earth than Vice President Agnew proposed that the U.S. begin immediate plans for a landing on Mars before 2000. It is numerologically significant that among the 10 letters of "Spiro Agnew" no letter is repeated. Multiply SPIRO by the mystical digit 7—the seven-day week of creation mentioned by President Nixon in his ebullient welcome to the returning astronauts in July, the seventh month—and let AGNEW be the product. (The total number of symbols is now 11.) This produces the following cryptarithm:

$$\begin{array}{r} \text{SPIRO} \\ \times\quad 7 \\ \hline \text{AGNEW} \end{array}$$

Assuming that each letter stands for a different digit and, as is customary in such problems, that neither five-digit number begins with 0, the cryptarithm has one and only one solution. Your readers may derive pleasure from finding it. You can see at once that S must be 1; otherwise the product would have more than five digits. For the same reason *P* must be either 0, 2, 3 or 4. Further reflection will show that *A* must be 7, 8 or 9, and that *O* cannot be 0, 1, 3 or 5. (One would duplicate the 1 of S, 3 would cause *W* to be 1, 0 or 5 would duplicate *O* and 5.) The problem becomes tougher from here on, although it can be solved easily without the help of a computer. If the multiplier is 0 or 6, there is no solution. Any other single-digit multiplier except 7 has more than one solution. [Next month I shall give Dr. Matrix' answer, together with references bearing on the problem.]

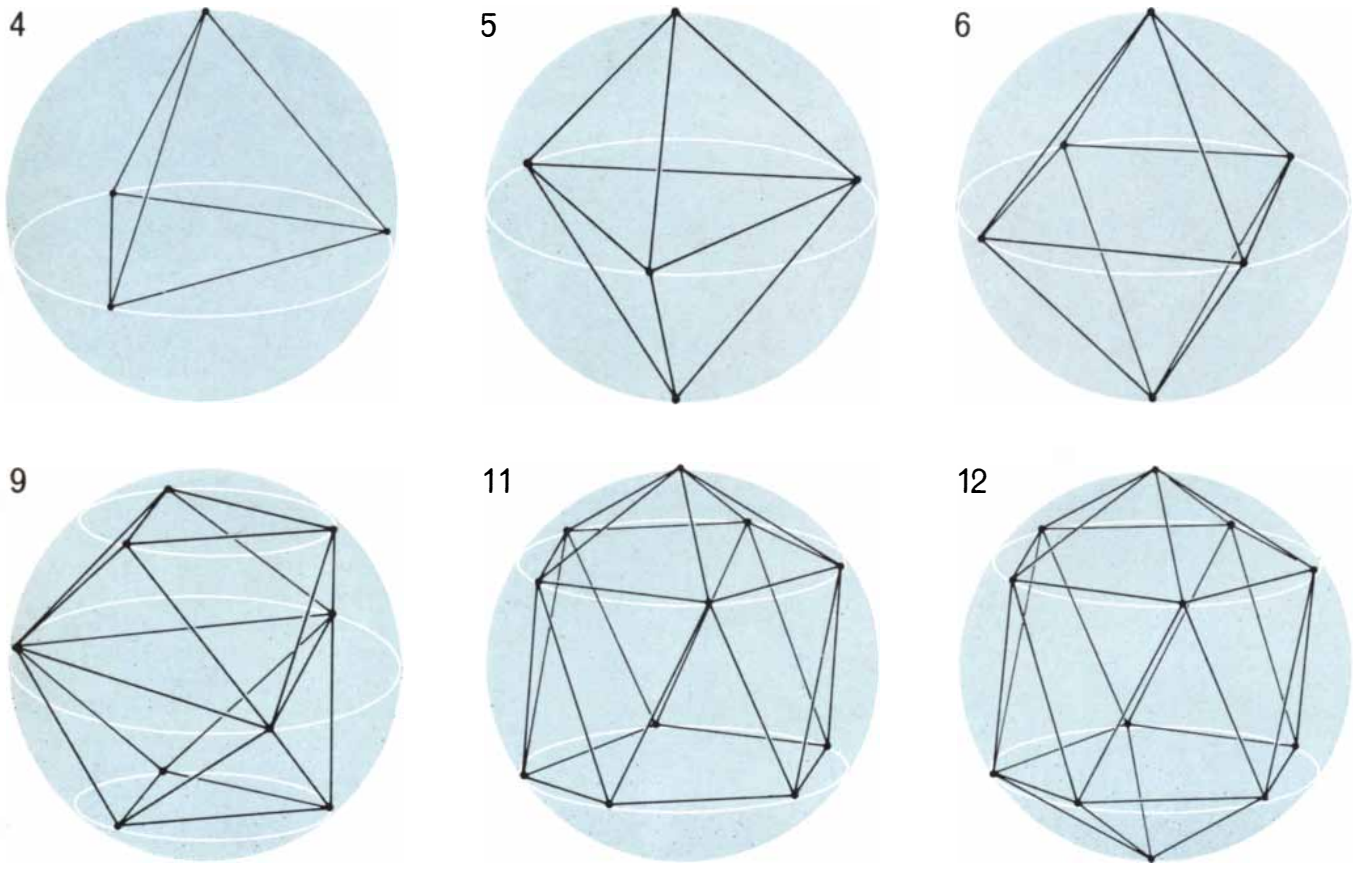
Question: The approaching end of 1969 will terminate the sixties. Do you have any numerological comments?

Dr. Matrix: As you may recall, you once quoted me as saying that the decimal expansion of pi, properly interpreted, conveys the entire history of the human race. The sixties have been 10 years of unprecedented change and variety. The 10 decimals of pi from the 60th through the 69th are 4592307816. [The first 100,000 decimals of pi were published in *Mathematics of Computation,* Vol. 16, January, 1962, pages 80–99. In 1967 this was extended to half a million decimals by the computer program of a French mathematician, Jean Guilloud.]

What is significant about 4592307816? They are the first 10 consecutive digits in pi that contain each digit exactly once! It is infuriating that the first two digits are not reversed; then there would be alternating odd and even digits for the entire series. The 70th decimal is 4, the same digit that begins the series. I predict that a major event, involving the number 4 and closely related to a 4-event of 1960, will occur in 1970.

Computer expert Donald E. Knuth has called my attention to another fantastic fact that strengthens my interpretation of pi's decimals 60–69. The 1,960th through the 1,969th decimals are 5739624138. Here there is no 0 because of the repetition of 3, but all digits from 1 through 9 appear. The chance of finding all 10 digits in a given sequence of 10 consecutive random digits is, Knuth tells me, $10!/10^{10}$, or .00036288 exactly. Naturally the probability of finding this as early in pi as decimals 60–69 is not that small, but it is still small enough to deserve earnest meditation.

The decimals of pi from the 70th through the 79th are almost as fascinat-



Solutions are given for two to nine bases, 11 and 12 bases. No solution is known for 10 bases

ing: 4062862089. Observe the curious repetition of the same four digits in adjacent middle quadruplets and note that the first nine digits are even. Something exceedingly odd undoubtedly will take place in 1979.

The last three digits of 1,969 are the 17th tetrahedral number as well as the age of Methuselah when he died. [Genesis 5:27.] This was pointed out to me not long ago by Elvin J. Lee of Oak Ridge, Tenn., who has made some recent discoveries about amicable numbers. [Lee disproved a conjecture first published in this column in March, 1968, that all pairs of even amicable numbers have sums that are multiples of 9. Lee found nine pairs of counterexamples, all (for some reason as yet unknown) with digital roots of 7. A tetrahedral number is the number of unit spheres that close-pack to form a tetrahedral pyramid. Such a pyramid, 17 spheres on a side, contains 969 spheres.]

One final observation on 1,969, discovered by Maxey Brooke of Sweeny, Tex. Square 1,969, circle the last four digits of the product, then view them upside down. You will be surprised by what you see. Aside from the trivial case of the year 1, can your readers determine the earliest A.D. year with the same property? [The number of circled digits must be the same as the number of digits in the year. Answer next month.]

Question: Can you provide a problem of nontrivial interest that ties in with moon-exploration plans?

Dr. Matrix: Assume that the moon is a perfect sphere and that we want to establish n lunar bases as far apart from one another as possible. More precisely: How can n spots be arranged on a sphere so that the smallest distance between any pair of spots is maximized? The problem is equivalent [as H. S. M. Coxeter shows in a paper cited in the bibliography on page 148] to that of placing n equal, nonoverlapping circles on a sphere so that the radius of each circle is maximum.

When n is 2, the answer is obvious. The two bases are placed at opposite ends of a diameter. For three bases the solution is to put them on an equator at the corners of an inscribed equilateral triangle. For four bases the unique solution is the corner points of an inscribed tetrahedron.

Let us jump to $n = 6$. Here the only answer is to place the spots at the corners of an inscribed regular octahedron or, what is the same thing, at the centers of the six faces of a circumscribed cube. The case of $n = 5$ has an unexpected answer. The maximum distance turns out to be the same as when n is 6. Simply take the solution for six spots and remove one spot. The result is the best possible answer for five spots. The solution is not unique; two spots must be at opposite ends of a diameter but the other three can be shifted along the equator to an infinity of positions.

There are unique solutions for seven and nine spots. When n is 8, the best placing of spots is not, as one might guess, at the corners of an inscribed cube but at the corners of a square antiprism. The solution for 10 spots remains unknown. When n is 12, the corners of an inscribed icosahedron give the best solution. In 1958 it was shown that $n = 11$ is similar to the case of $n = 5$: The best answer is obtained from the 12-spot solution by removing one spot, except that in this case the remaining 11 spots are rigid and cannot be varied to provide other solutions [*see illustration on preceding two pages*].

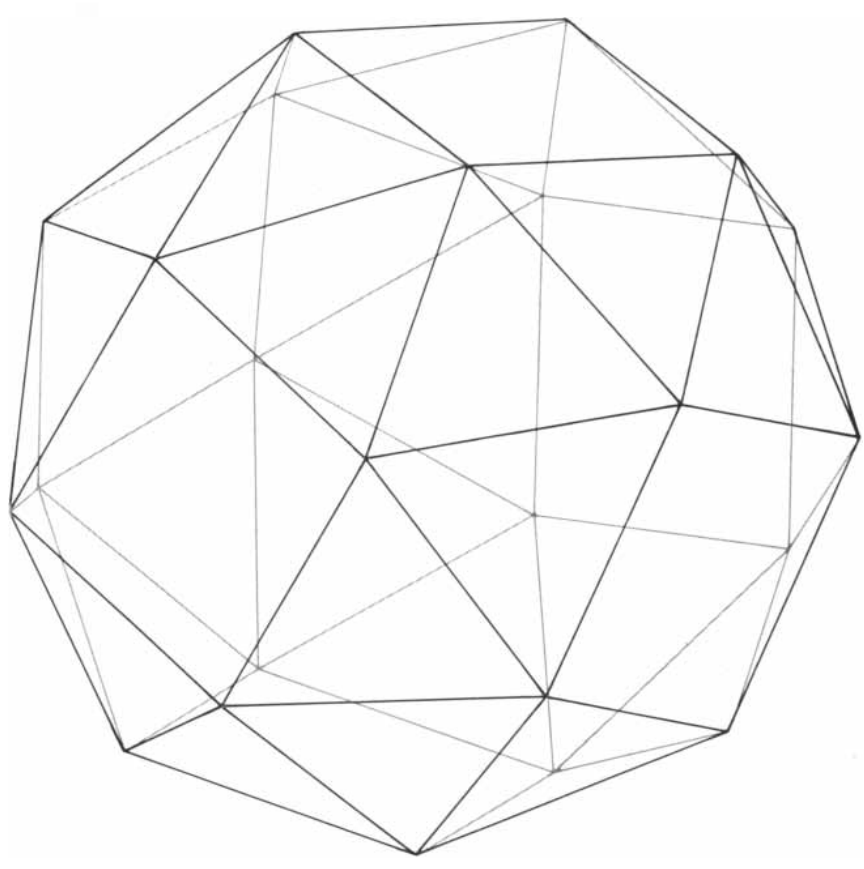
The only other known solution is when n is 24. In 1961 Raphael M. Robinson proved a conjecture of B. L. van der Waerden's that the answer is the vertices of an inscribed snub cube, one of the Archimedean semiregular solids [*see illustration on this page*]. This polyhedron is asymmetric, so that it has left-handed and right-handed forms. Its 38 faces consist of six squares and 32 equilateral triangles. For further details on this problem readers can consult Coxeter's paper and his list of references.

Question: Anything else?

Dr. Matrix: Since you will not receive my reply in time to use it before October, your readers may find it of interest that the next month, November, 1969, is what my friend Kirby A. Baker, a mathematician at the University of California in Los Angeles, calls a "perverse month."

A perverse month is one that has six calendar weeks, requiring six lines on the calendar unless the last one or two days are shown by tiny numerals squeezed into the fifth row. What is the maximum number, Baker asks, of perverse months that can occur in a year? What is the minimum number? Both questions are closely related to the maximum and minimum numbers of Friday the 13th's that can occur in a year. They are 3 and 1. As you may know, it has been proved that the 13th is more likely to fall on Friday than on any other day of the week. Next year will have the maximum number—an ominous omen. The only remaining years of this century with three Friday the 13th's are 1981, 1984, 1987 and 1998.

Baker has shown that the more perverse months, the fewer the Friday the



The snub cube, the 24-base solution

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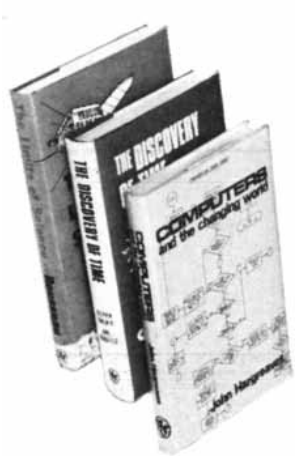

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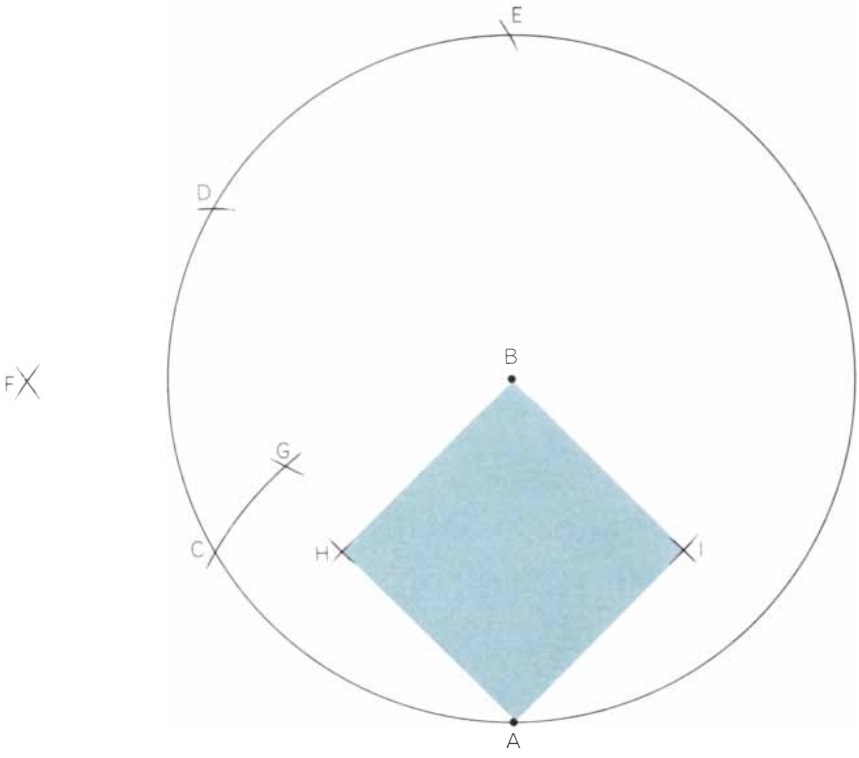
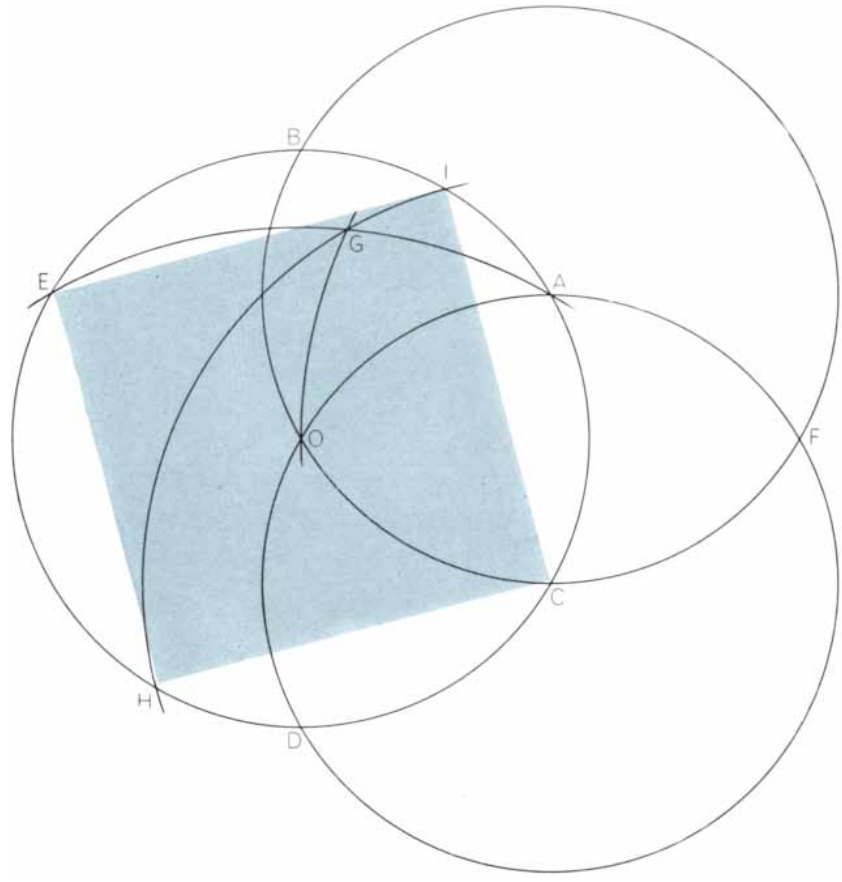


Construction of a square, given diagonal corners A *and* B



Simpler solution for "Napoleon's problem"

13th's, and the fewer the perverse months, the more Friday the 13th's. "Thus," he writes, "a year good for calendar makers is unlucky for the rest of us, and vice versa." [Next month I shall explain the relationship between the two calendar problems and cite references.]

The top illustration at the left shows a nine-arc method of solving last month's Mascheroni problem: Given two diagonally opposite corners of a square, find the other two corners using only a compass. *A* and *B* are the given corners. Draw the circle with radius *AB* and *B* as center. Keeping the compass at the same opening, draw arcs *C*, *D* and *E* (centers at *A*, *C* and *D*). With radius *CE* and centers at *A* and *E*, draw the two arcs that intersect at *F*. With radius *BF* and center at *E*, draw the arc that intersects a previous arc at *G*. With radius *BG* and centers at *A* and *B*, draw the arcs intersecting at *H* and *I*. *A*, *H*, *B* and *I* are the corners of the desired square. Philip G. Smith, Jr., of Hastings-on-Hudson, N.Y., sent a simple proof of the construction, based on right triangles and the Pythagorean theorem, but I leave it to interested readers to work out such proofs for themselves.

Since writing the column on Mascheroni constructions I have learned that the six-arc solution to "Napoleon's problem" given last month is indeed Mascheroni's. Fitch Cheney sent me his paper "Can We Outdo Mascheroni?" (*The Mathematics Teacher*, Vol. 46, March, 1953, pages 152–156), in which he gives Mascheroni's solution followed by his own simpler solution using only five arcs.

Cheney's solution is shown at the bottom left. Pick any point *A* on the given circle and draw a second circle with radius *AO*. With *C* as center and the same radius, draw a third circle. With *D* as center and radius *DA*, draw the arc intersecting the original circle at *E*. With *F* as center and radius *FO*, draw an arc crossing the preceding arc at *G*. With *C* as center and radius *CG*, draw the arc intersecting the original circle at *H* and *I*. *E*, *I*, *C* and *H* mark the corners of the desired square.

Cheney calls attention in his article to the difference between a "modern compass," which retains its opening like a divider, and the "classical compass" of Euclid, which closes as soon as either leg is removed from the plane. Cheney's five-arc solution uses only classical arcs, in contrast to Mascheroni's. Cheney also gives in his article a seven-step classical method of inscribing a pentagon in a circle, two steps fewer than Mascheroni's modern-compass method.

Basic Research at Honeywell
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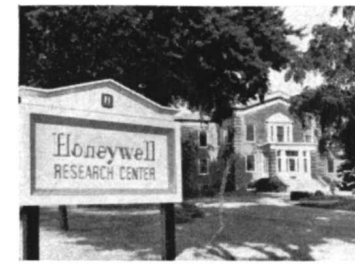


Investigations of Passive Materials for Sonar Devices

Use of new combinations of materials in sonar transducers should make greater ocean depths accessible for investigation and exploitation.

A critical obstacle to full exploitation of ocean resources for both military and commercial applications is the lack of equipment for communication at depths greater than about 2,000 feet. Currently sonar is the only means of communicating underwater, since electromagnetic radiation does not penetrate the sea significantly, and the use of lasers, so far, is strictly experimental. The fundamental limitation on sonar equipment focuses on the materials used within the transducer. These materials must be responsive to slight changes in sound energy, while at the same time resisting the enormous hydrostatic pressures found at increasing depths.

Sonar devices have two main parts—the active element which converts sound energy into measurable electrical signals, or vice versa, and the inactive elements which control the paths sound can travel in the transducer. This directivity pattern of a transducer is especially critical to its proper functioning; it enables the transducer to distinguish sounds from one specific direction from other sounds in the ocean, and to transmit sounds in a given direction.

Thus, transducers are used either as projectors (for active sonar) or as hydrophones (for receivers, or passive sonar). In each type, inactive materials are selected to match or mismatch the characteristic impedance (product of density and sound velocity), of the active materials. Matching materials include those that are transparent, refracting and absorbing; mismatching materials include those that reflect and decouple.

A satisfactory absorptive material, for example, should have impedance equal to that of the active element so the sound will enter the material. The material must neither reflect nor transmit sound; must be chemically stable in sea water, and must be unaffected by temperature changes from 0° to 30°C. Above all, it must remain stable against changes in pressure up to 10,000 psi, while having adequate absorption over the frequency range from 1 KHz to 300 KHz. It is "physically impossible" for a single material to meet all these conflicting requirements, but a compromise is feasible.

Absorber materials with high absorption coefficients at shallow depths in the ocean depend upon air cells to scatter the sound back and forth on a low absorbing matrix material. As the pressure increases, these air cells disappear and so does the attenuation. Other damping materials have been tried using trial-and-error testing in the sonar design. However, most of these materials have little or no attenuation or function poorly as the hydrostatic pressure increases.

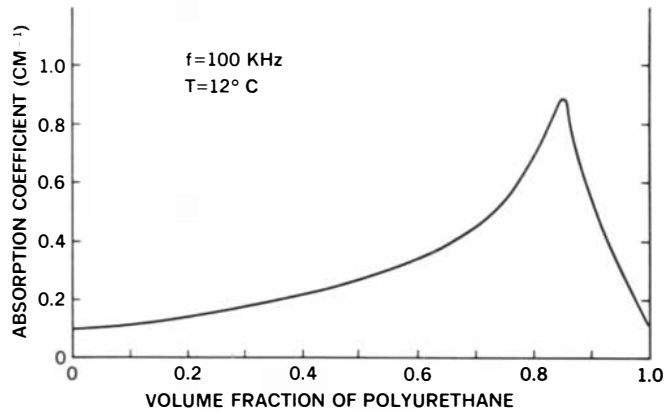
Believing that detailed descriptions of acoustic and mechanical properties would be valuable for future sonar design, Honeywell scientists have been investigating a wide variety of passive materials in the hope that identification of desirable features of absorbers successful at sea level or slightly higher pressures would help in the development of newer, stabler materials.

Using an impedance tube with an RF pulse generation system and small samples, measurements were made of a number of passive materials now in use. Comparing transmitted energy (I) and incident energy (I_o) by means of Lambert's (or Bouguer's) Law $I = I_o e^{-2\alpha d}$, changes in the absorption coefficient, α, with varying frequencies of sound waves and hydrostatic pressure were noted.

Results suggested that combining materials could be one way to maximize absorptive properties. Honeywell has fabricated composite materials that have greater acoustic attenuation than possible in pure materials at the same frequency, and other materials which function in frequency ranges where pure materials have no measurable absorption. Some promising new materials are combinations of metals and polyurethane rubbers. The metals, rather than air, scatter or reflect the energy back and forth through the polyurethane matrix, causing high sound attenuation. The amount of attenuation is varied by changing the composition and the components. In some cases as much as 90% of the sound is absorbed in one pass through an absorber of 1 cm length. Even more important, the absorption coefficient is constant as high as 2,000 psi, which represents a depth of more than 4,000 feet.

Ongoing investigations will evolve more complete descriptions of properties of inactive materials. Future development and fabrication of new materials, particularly combinations of two and conceivably three materials, are aiming for stability at 30,000 feet and below.

If you are working in the area of materials for sonar transducers and want to know more about Honeywell's investigations of passive materials, please contact Dr. Ronald W. Higgs, M.S. C1221, Honeywell Corporate Research Center, Hopkins, Minnesota 55343. If you have an advanced degree and are interested in a career in research at Honeywell, please contact Dr. John N. Dempsey, Vice President Science and Engineering, M.S. G5208, Honeywell Inc., 2701 4th Avenue South, Minneapolis, Minnesota 55408.



Absorption coefficients of various combinations of metal and polyurethane rubber.

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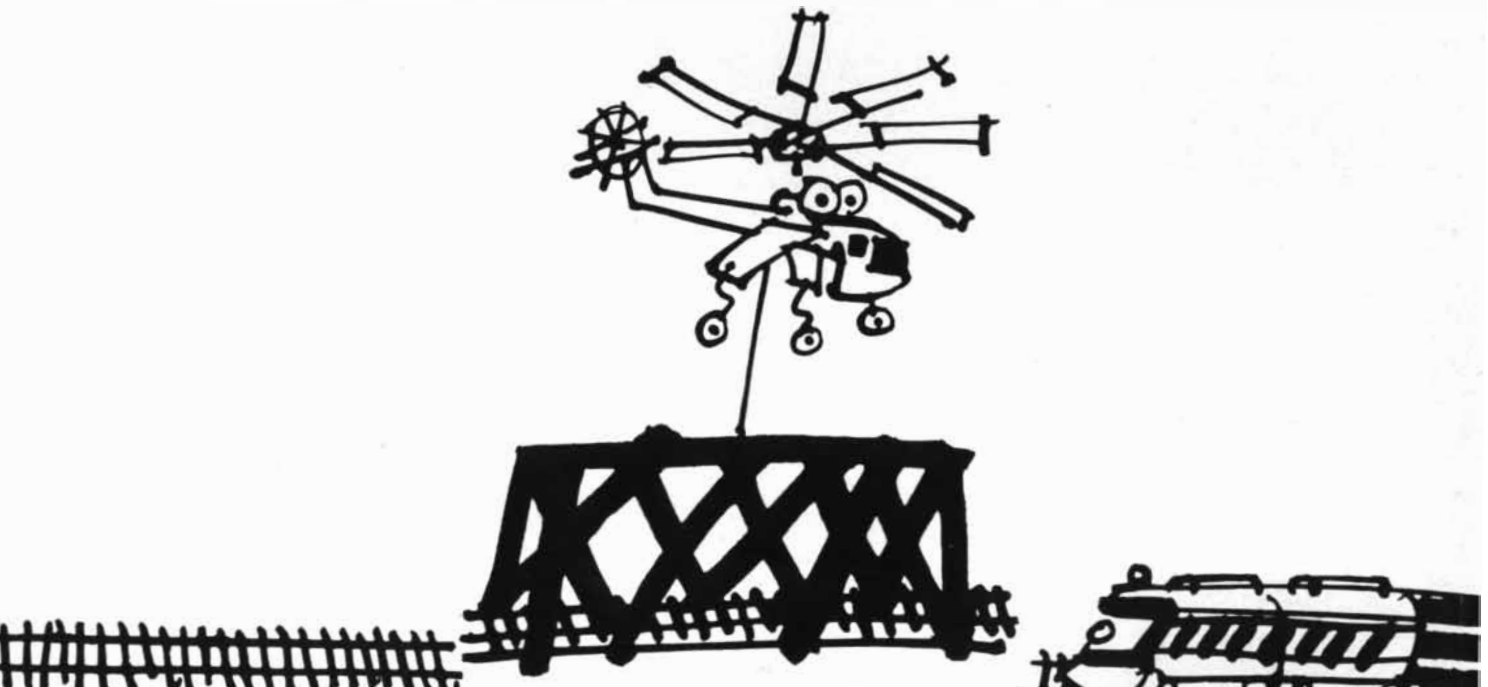
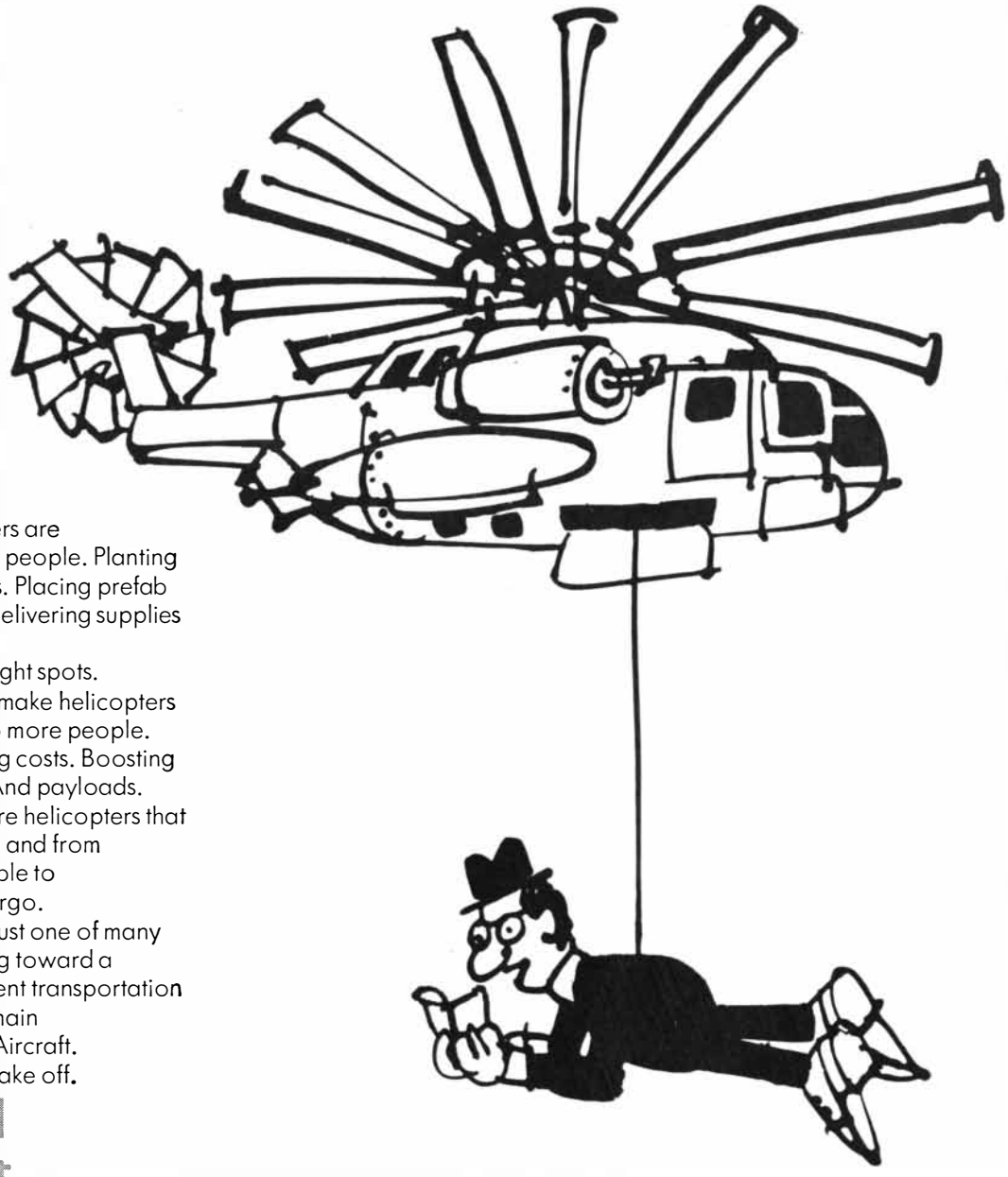
The Helicopter: What's it done for you lately?



For industry, brawny helicopters are speeding ever-heavier loads to where they're needed in a hurry.



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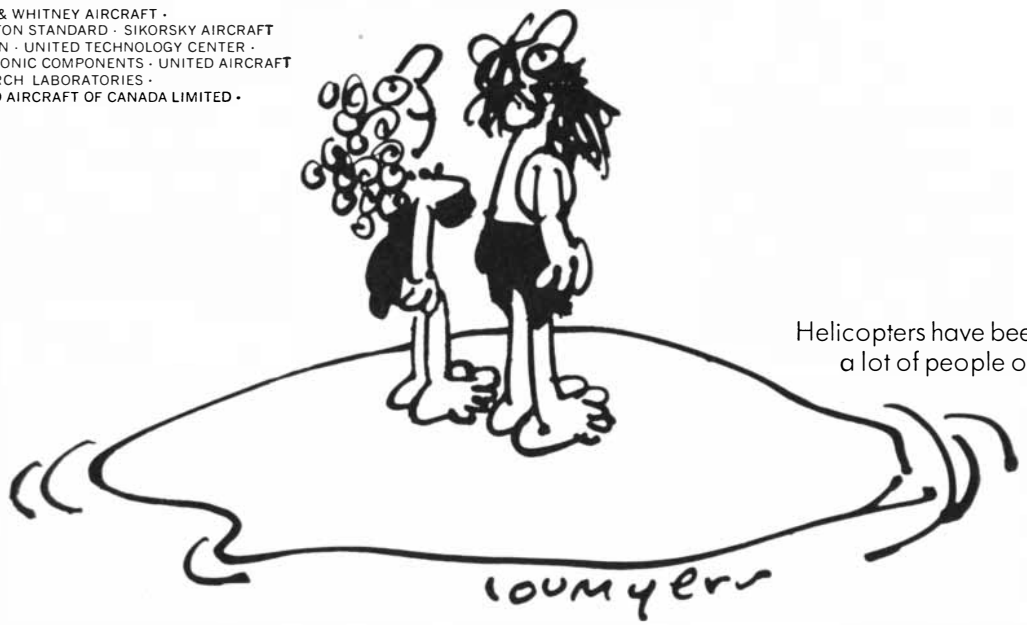


Helicopters have been getting a lot of people out of trouble...

THE AMATEUR SCIENTIST

The flow of blood, weather vanes, telescope mirrors and the conductivity of insulators

Conducted by C. L. Stong

Periodically this department presents short descriptions of projects that illustrate what an enterprising amateur can accomplish with a bit of ingenuity. Four such projects have recently come to my attention. The first one deals with the problem confronting an experimenter who wanted to examine the flow of blood in a healthy animal but lacked a number of essential elements. For example, he did not have access to experimental animals, and although he had the objective lens of a microscope (with its companion eyepiece), he did not have the other parts of the instrument. The experimenter is Julio Santilli of Long Island City, N.Y., who solved the problem by examining the blood in his own capillaries with an instrument that he assembled largely from odds and ends. Santilli writes:

"The idea of doing this experiment came to me one morning while I was shaving. I noticed that the capillaries in the white of my eye are covered with transparent tissue, and I wondered what the blood would look like if I could see it up close. The question itself suggested the kind of instrument I would need: an optically folded microscope. Light from the capillaries of one eye would pass through the objective lens of a microscope and proceed to a distant mirror for reflection to the other eye [*see top illustration on opposite page*]. I had a 10-power objective lens and a 10-power eyepiece. Luckily I also had a small mirror that was silvered on the front side. Mirrors silvered on the back would not work as well because light would be reflected from both the front and the back to create a double image.

"Experimenting with the apparatus, I soon learned that all parts of the system, including the viewer's head, must be rigidly supported because all motions of any part are equally magnified. In my design the objective lens, the eyepiece and the mirror are supported by a wooden box. The box rests on and is attached to the upper end of a lens barrel from an old portrait camera. The barrel has a rack and pinion that serve as a focusing adjustment. The framework holding the lens barrel is made of wood and includes both a head board and a bite board [*see bottom illustration on opposite page*]. These rests are essential. Indeed, I have been tempted at times to strap my skull to the fixture.

"Neither the dimensions nor the arrangement of the parts is critical. The experimenter can be guided by the contents of his junk collection. Focusing can be accomplished by moving the entire optical system up or down, as in my design, or by moving the objective lens alone. I light the capillaries with a spot lamp that I made, and regulate the brightness with a rheostat. I always use minimum light to prevent irritation or damage to the eye, and I usually limit periods of observation to five minutes, with an hour or two of rest between periods.

"What does one see? This depends on the size of the capillaries. I classify the capillaries simply as large, medium and small. The large ones show no flow of blood because the stream is thick and consequently opaque, nor is regular flow observed in the smallest capillaries. Single cells or small clusters of cells spurt irregularly through the smallest capillaries much as random tracks appear in a Wilson cloud chamber. The most interesting flows are found in capillaries of medium size, which are both clearly transparent and supplied with just enough blood to display the streaming red cells to advantage.

"I found viewing my own blood a fascinating experience. Here and there the cells move in synchronism with the pulse, alternately speeding up and slowing down, but the action of the heart is not apparent in all capillaries. In many the flow is constant. Occasionally the blood comes to a complete halt and then resumes in the same direction. Most astonishing are times when the cells stop and reverse direction against the powerful pumping of the heart. Another stop follows, and then the flow resumes in the original direction. Rarest of all are occasions when a capillary empties. This usually occurs during a backflow, when for some reason the blood supply appears to be cut off. The capillary seems to vanish, but it reappears in a matter of seconds with the return of normal circulation.

"Several experiments come to mind. For example, it might be interesting to observe the effects of coffee, tea, beer or tobacco on the circulation. It should also be possible to investigate the influence of aging on the structure of certain capillaries and on the circulation. Such changes could be photographed by fitting the eyepiece with an optical beam splitter to divert part of the light into a camera. The apparatus would similarly lend itself to recording the effects of emotional or mental states on the circulatory system."

The next project is submitted by Cleveland H. Hood of Middlesbrough in England, who makes a hobby of constructing meteorological instruments. He calls attention to an inexpensive device for electrically synchronizing the rotary motion of two mechanically independent shafts. The device consists of two principal assemblies: a transmitter and a receiver.

The transmitter includes a rotatable shaft that carries two electrically insulated wiper arms spaced 180 angular degrees apart. The tips of the arms make sliding contact with a surrounding toroidal coil of resistance wire. A comparable shaft of the receiver supports a bar magnet, much like the needle of a compass, that is free to rotate inside a surrounding configuration of three interconnected solenoids spaced 120 angular degrees apart. Direct current is applied to the wiper arms. From three points spaced 120 angular degrees apart on the toroi-

dal coil leads connect to each of the corresponding solenoids [*see top illustration on next page*].

When power is applied to the transmitter, the resulting current divides into three parts. The amount and the relative polarity of each part depend on the points where the wiper arms make contact with the toroidal coil. These currents induce a corresponding pattern of magnetic flux in the region of space enclosed by the solenoids. The bar magnet aligns itself with this field. Rotation of the transmitter shaft redistributes the current and, in effect, rotates the magnetic field of the receiver. The bar magnet and its supporting shaft turn in step.

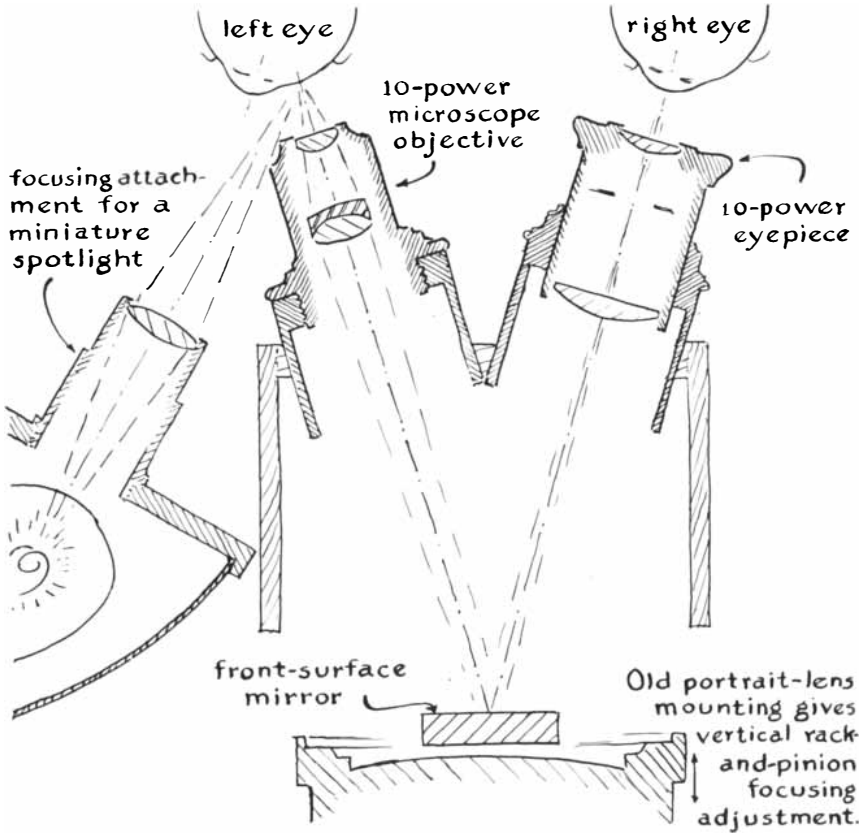
Hood writes: "Any reasonably handy craftsman can construct a version of this synchronizing device, but in Britain (and perhaps in the U.S.) the transmitter and receiver are available on the surplus market. Known as the 'Desynn System of Remote Indication,' they are manufactured for use with airplane instruments by Smiths Industries Limited, Kelvin House, Wembley, Middlesex, England.

"I picked up a set of Desynns in the surplus market for 16 shillings (about $2) for remote display of wind direction at my home weather station. The weather vane is on high ground some distance from the house. The lower end of the vertical spindle that supports the vane assembly is coupled to the Desynn transmitter. The receiver of the Desynn displays on a dial in my study the direction in which the distant vane is pointed.

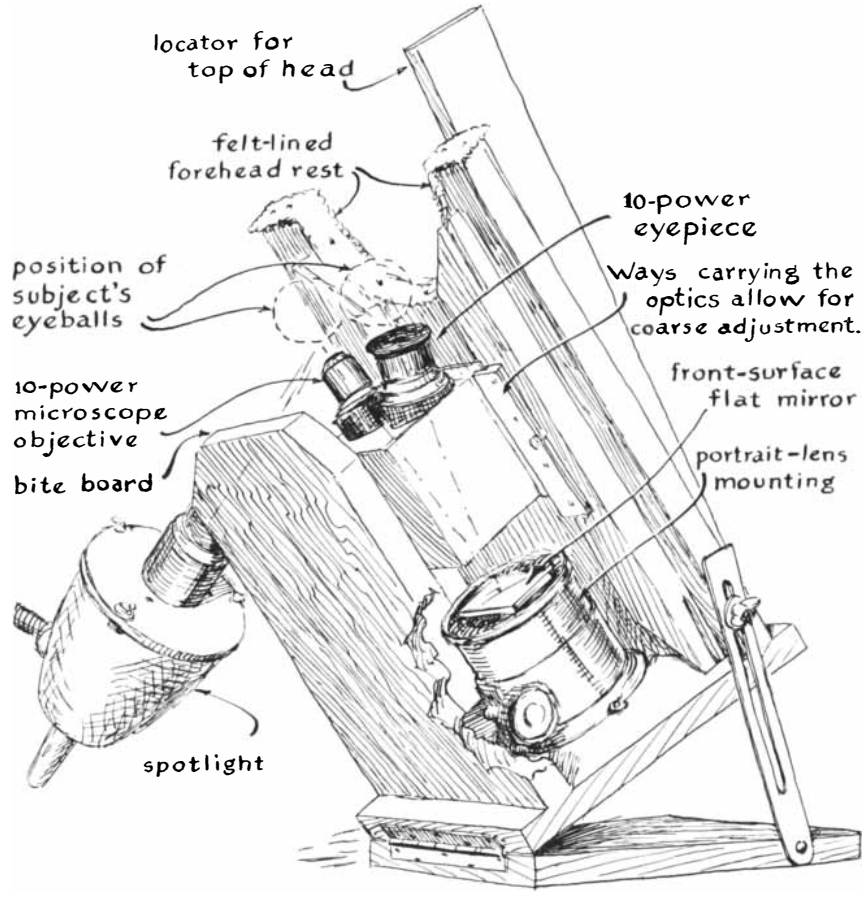
"The design of the vane is novel in that the moving parts float in a container of light machine oil. The spindle passes through and is soldered to the axis of a sealed cylindrical can that functions as a float [*see bottom illustration on next page*]. The oil that supports the float is contained by a glass jar that also serves as the base of the instrument.

"I wedged the Desynn transmitter in the bottom of the jar and joined its shaft by a spline to the lower end of the spindle. A sleeve bearing in the lid of the jar supports the spindle vertically. The perforated lid of a round tin can was soldered to the spindle just above the sleeve bearing to act as a rain shield. The spindle attaches to the balance point of the horizontal arm that carries the vane.

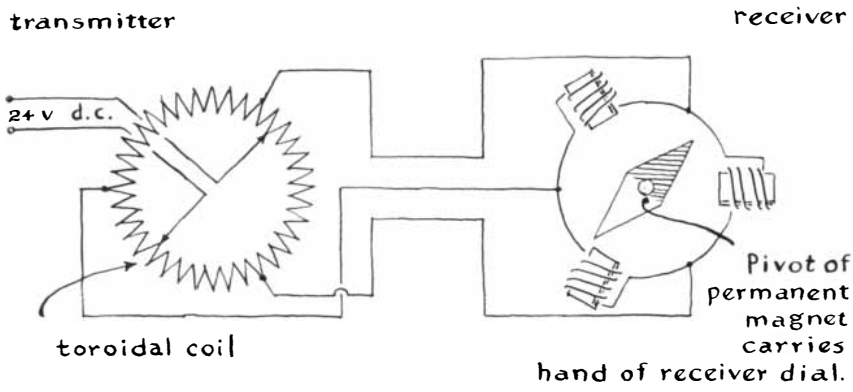
"The buoyancy of the float was adjusted, by putting oil inside, to counterbalance the weight of the rotating assembly. The weather vane behaves as though it were weightless and nearly frictionless, as indicated by the fact that



Optical features of Julio Santilli's folded microscope



The microscope as mounted for viewing one's own eye



Circuitry of Cleveland H. Hood's apparatus for reading a distant weather vane

it responds to an almost imperceptible breeze. It has operated continuously without maintenance in weather of all kinds for more than a year."

A discouraging phenomenon tends to beset those who first attempt to grind and polish the objective mirror for a reflecting telescope. At least one deep scratch mysteriously appears in the glass no matter how carefully the craftsman works. Telescope mirrors are ground to a concave figure by sandwiching an abrasive slurry between two disks of glass and pushing the top disk back and forth. As the grinding proceeds the lower surface of the top disk, which will function as the mirror, becomes increasingly concave and the top surface of the lower disk, which acts as the grinding tool, becomes correspondingly convex.

The worker uses successively finer particles of abrasive and finally polishes the lightly frosted surface of the mirror to a paraboloidal figure by stroking the glass on a disk of pitch coated with a slurry of rouge. All instruction books admonish the beginner to use abrasives of high quality and to maintain scrupulous cleanliness in order to prevent a coarse particle of grit or dust from lodging between the disks and making the unwanted scratch. Although scratches have almost no effect on the optical performance of the telescope, they are irksome to craftsmen who prize excellence in workmanship. T. R. Macfarlane of Regina, Saskatchewan, describes a little-known but reliable method of ending the difficulty:

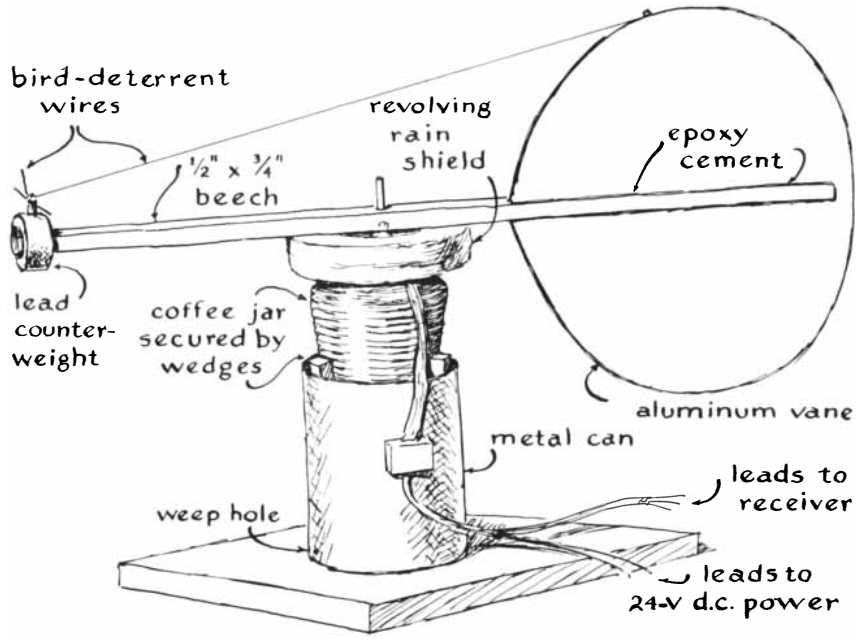
"Scratches are made by lumps that form in all grades of fine abrasive. The lumps plow grooves in the glass just as though they were solid particles. They can be dispersed by a sedimentation procedure that improves the abrasive in another respect. All grades of abrasive contain powdered grit: particles much smaller than those of the maximum size. When the powder becomes wet, it acts like mud in that it retards cutting action. By removing the powder the time required for the final stages of grinding can be cut in half.

"Abrasives are graded by number, ranging from 80 (particles about the size of granulated sugar) to 600 (microscopic particles). The coarser grades do not clump and rarely cause scratches. The difficulty appears with grade 320 and smaller. To purify abrasives you will need a few jars of clear glass ranging in size from a quart to a gallon, small jars with caps to hold the purified abrasive, four feet of rubber hose a quarter of an inch in diameter and a quart of water glass (sodium silicate).

"I put clean water, to which I have added about two ounces of water glass, in a gallon jar until the level is an inch below the top. The water glass serves as a deflocculating agent: it disperses lumps that remain solid in water alone. One ounce of abrasive is thoroughly mixed with the solution and left to settle for 30 minutes. With the rubber tubing I then siphon all but two inches of the fluid into a clean container. I label the container 600–1 and put it aside.

"I refill the settling jar with water containing one ounce of water glass, thoroughly mix the remaining grit and again let it settle for 30 minutes. All but an inch of the fluid is then siphoned into a clear glass container and labeled 600–2. Thereafter I repeat the procedure, progressively reducing the intervals of settling to 15, eight and three minutes. The stored containers are labeled 600–3, 600–4 and 600–5 respectively.

"Finally, I shake up the settled dregs and pour them into a smaller jar. This material settles quickly. A sharp line appears at the boundary between the clear fluid and the suspended grit. When the upper third of the fluid clears, I carefully pour all but a third of the remainder into a clean jar. When this material settles, I pour off and discard the clear fluid. I then refill the jar that contains the dregs and repeat the procedure three times. The collected material is labeled 600–6. To the remaining dregs I add one ounce of the 600 grit as it comes from the manufacturer, process it by the same procedure and similarly treat the remaining stock. After several days, when the grit in all six labeled containers has



The vane assembled

settled, I carefully siphon off the clear fluid and dry the abrasives for use.

"What about the accumulated dregs? To them I add one ounce of 500 grit, proceed as described and then switch to 400, followed by 320. I do not process the coarser grades.

"Purified abrasive easily cuts twice as fast as untreated material. During the final grinding stage, when 600–6 grit is followed by 600–5, –4, –3, –2 and –1, the glass emerges unscratched and with a semipolished surface. Other deflocculating agents and techniques of sedimentation that differ slightly from this procedure are described in *Amateur Telescope Making (Book Three),* by Albert G. Ingalls (Scientific American, Inc.)."

Occasionally an unexpected event such as the flick of a pointer across a dial, a puff of smoke or a flash of light alerts the careful experimenter to a fruitful opportunity. A case in point is reported by W. W. Withrow of Teague, Tex., who recently hit on an inexpensive method of measuring the electrical conductivity of materials ordinarily classed as insulators. He writes as follows:

"Some months ago I received a number of transistors from a cousin who works for a computer manufacturer. The devices had been rejected during tests at the plant. They were designed to conduct current from the emitter to the collector terminals but not in the reverse direction. I decided to measure their resistance in the reverse direction, on the assumption that those of high resistance might be usable. The measurements were made with an inexpensive ohmmeter that has a midrange scale of 150,000 ohms.

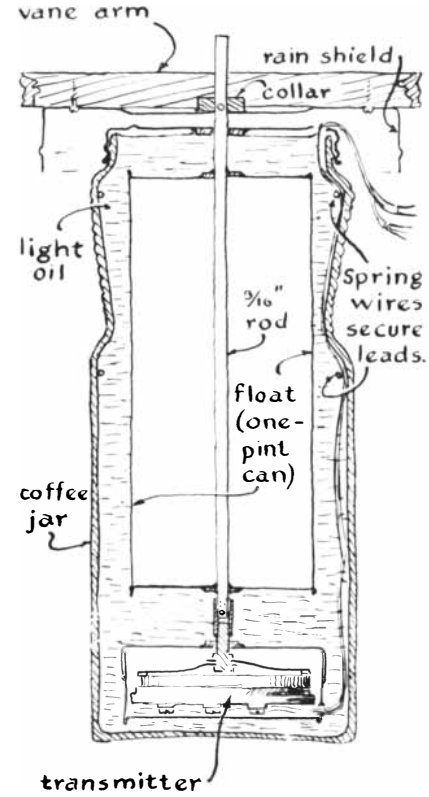
"During all the tests except one the pointer of the meter swung to the top of the scale and stayed there, indicating a usable transistor. In this one case, however, the pointer first swung to the top of the scale, flickered a few times and finally dropped close to zero. Initially I thought the device was defective. Then I became aware that the tip of one of my fingers was touching both the collector and the base terminals of the transistor. When I removed the finger, the pointer swung to the top of the scale, as in the case of units previously tested. Evidently current through my finger was triggering the transistor into its amplifying state. The relatively small current in the base-collector circuit caused a large current in the emitter-collector circuit. It occurred to me that the transistor might be used to magnify the scale of my ohmmeter, perhaps from its normal midrange of 150,000 ohms to several million ohms.

"To test this notion I clipped the positive terminal of the meter to the emitter lead of the transistor and the negative lead of the meter to the collector. (The silicon transistor was of the p-n-p, or positive-negative-positive, type.) I then connected a one-megohm resistor across the collector and base terminals of the transistor. The pointer of the meter promptly swung to 10,000 ohms, which suggested that the transistor had magnified the scale of the instrument 100 times, equivalent to a midrange value of roughly 15 megohms. The thing had worked!

"Why not place another transistor ahead of the first one and get still more magnification? This was done by connecting the base of the first transistor to the emitter of the second one and interconnecting the collector leads. In this circuit the transistors function as a two-stage current amplifier [*see illustration below*]. The circuit again worked, amplifying 10,000 times to yield a midrange scale of 1,500 megohms.

"Rough measurements are of little use. My next step was to calibrate the magnified scale, which can be done with two resistors, one having a known, fixed value and the other being variable from zero to at least 1,500 megohms. The resistor of known value is connected in series with the variable resistor. The variable resistor is set to zero and the fixed resistor alone is measured. The position to which the pointer swings is noted. The fixed resistor is short-circuited by connecting a copper wire across its terminals. The variable resistor is adjusted so that the pointer swings to the previously noted position. With the pointer at this position the value of the variable resistor matches that of the fixed resistor.

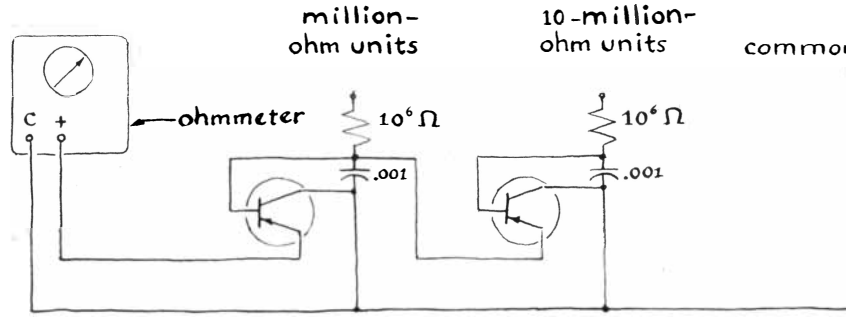
"The value of the fixed resistor can now be added to the circuit by removing the copper wire. The pointer then swings to a new position that is equal to twice the value of the fixed resistor. With the fixed resistor again short-circuited the variable resistor is adjusted so that the pointer swings to the new position on the scale. The cycle of operations is repeated until the expanded scale is fully calibrated.



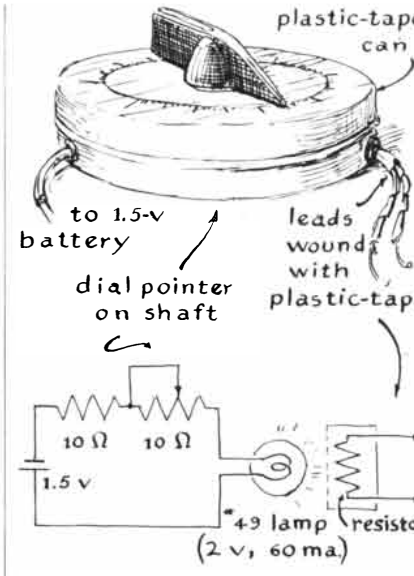
Mounting of the weather vane

"Fixed resistors calibrated to within 1 percent of their rated value are available from suppliers in sizes up to several megohms. Obtaining a variable resistor of the size needed for this job is another matter. Variable resistors of zero to 3,000 megohms are not available commercially. I tried a number of ways to improvise one with several materials in my shop.

"One of my devices seemed promis-



Circuitry of W. W. Withrow's amplifier

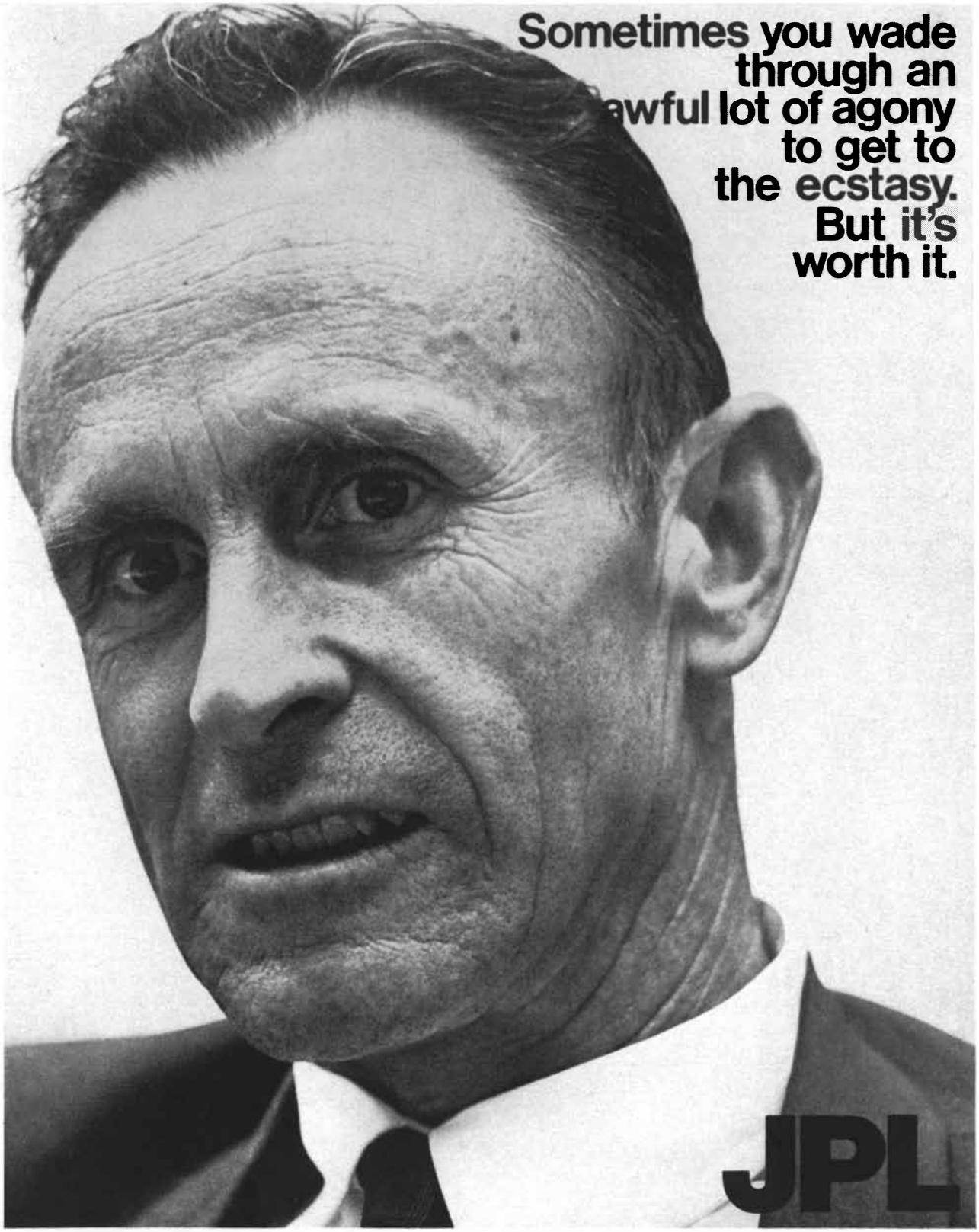


Details of the variable resistor

ing. It was a wood scrap two inches wide and two feet long with a series of steel nails driven in a row down the middle to serve as terminals. The strip had about the right order of conductance, but the conductivity changed faster than I could clip instrument leads to the nails. Evidently current in the wood was carried by absorbed moisture.

"After trying a number of other materials without success I finally hit on the idea of using a cadmium sulfide photocell as a light-dependent resistor. I sealed the photocell in a small, lightproof box along with a miniature lamp bulb, a flashlight battery and a rheostat for adjusting the brightness of the lamp with a knob outside the box [*see illustration above*]. The maximum resistance of the cell in darkness is about 3,000 megohms. All photocells of this type are sluggish: their resistance continues to change for several seconds after each adjustment of the light. Their resistance also changes with temperature and other variables. Even so, if one is patient, the device can be used to calibrate the ohmmeter. Any type of silicon transistor with a current gain (beta) of 100 or more will work in the ohmmeter circuit.

"Resistances up to a billion ohms are normally measured with a 'megger,' essentially a hand-cranked generator, that develops several hundred volts. It is connected to a meter that responds to a few millionths of an ampere. Meggers are costly and inconvenient to use. The same measurements can be made by fitting a $20 ohmmeter with a pair of silicon transistors. I use mine for checking capacitors, insulators and similar electronic components."



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Historic

This is the biggest ship ever to be launched sideways.

She's the Esso San Francisco, hitting the Mississippi at Avondale, Louisiana, last July. And two 76,000-ton sister ships, also ordered by Jersey's affiliate, Humble Oil & Refining Company, will follow her act in the next few months.

228,000 deadweight tons of ships. It's a big order. And it's only part of Humble's current shipbuilding program in the U.S.

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At the beginning of this year, there were 33 tankers on order in nine different countries. Nearly five million deadweight tons. An investment of over $400 million.

This, the biggest tanker-building program in Jersey's history, is necessary to meet the world's ever-growing demand for oil.

And there are some heart-warming stories to tell. For example, at Wallsend in England.

Two years ago, Jersey's British affiliate, Esso Petroleum, decided to build two mammoth 253,000-ton tankers at Wallsend. Then the largest ships ever to be ordered in Europe.

"It's the best news this town has had in years," said Wallsend's mayor.

The Esso Petroleum order guaranteed two years' employment for 3,000 men. It put $7 million a year in wages into the town's economy. And now you can see the effect. More goods in the shops. More cars on the streets. More smiles in the pubs.

splashdown.

Behind this news is an encouraging story.

Only seven weeks before Esso Petroleum placed its order, no British shipyard was in the running either for price or delivery date. And delivery date was particularly tough. Two ships, both bigger than the Queen Mary, to be finished in two years. And ten unions were involved.

The initiative came from the unions themselves. They negotiated agreements that allowed one trade to pitch in on another's job. The more a worker produced, the more he earned. When they and the shipbuilders were sure the job could be done, the banks responded with low-cost loans.

Now Wallsend has more ships on order than anyone could have foreseen.

In fact, since Esso Petroleum broke the ice, there are twenty-one ships to be built there, including a third giant tanker.

We like to think that the splash we made at Wallsend was, in its own way, as historic as the one we made on the Mississippi.

Standard Oil Company (New Jersey)

Esso

BOOKS

Man in his primeval state, the rise and fall of T. D. Lysenko and other topics

by Philip Morrison

MAN THE HUNTER, edited by Richard B. Lee and Irven DeVore, with the assistance of Jill Nash. Aldine Publishing Company ($6.95). NOMADS OF THE LONG BOW: THE SIRIONO OF EASTERN BOLIVIA, by Allan R. Holmberg. The Natural History Press ($1.95). Is man in a state of nature a noble, free and happy being, chained to no onerous social contract? Or is he doomed to a life that is solitary, poor, nasty, brutish and short? It is the measure of the power of science that what was a grand philosophical cleavage is now the subject of empirical test.

But is it? In actuality the issue joined in both of these books remains unresolved. Yet the importance of the question, and the subtlety of the answer, come out in two very different but fascinating ways.

The population of heaven and hell, the total count of all the men and women who have ever lived out their lives on the earth, numbers somewhat less than 100 billion. A large fraction of all the members of our genus have lived by hunting and gathering. Lee and DeVore say nine-tenths, although they appear to overestimate it. If we are ever to understand ourselves, we need to understand that way of life. We know well that our entire biological makeup is adapted to it; all men were hunters up to 10,000 years ago, when they ate of the fruit of agricultural knowledge. What we learn of ancient man from the archaeologist, from all those deftly chipped tools and vigorous paintings, we must seek to test among that .001 percent of our fellow-men who still live as hunters, although they are no longer hunters in a world of hunters.

The main instrument of the inquiry among living hunters (we can extend this notion to our older anthropological colleagues, since the time of Captain James Cook, not to say Aristotle) is ethnography. This is a serious record of the culture of a group of humans. At its best, it is made by a man who lived among them, who spoke their tongue, who held them as friends, who thought deeply of their life while it was his own and who described it clearly in a context of sensible comparisons and explanations. Ethnography does not always reach that level. Too often it is secondhand, won by talking to intermediaries, frequently men who know hunters more as an enemy than as a friend. Even in the best case we expect to learn a way of life through one man's experience, through one observer who cannot, after all, be astronomer and zoologist, economist and sociologist as he trudges naked through the forest.

It is clear that the personal ethnography—all we shall ever have for most hunting groups—is too frail to carry the heavy load of our knowledge of mankind and its way into the world. There is only a little time left for doing better. That is one of the main burdens of the Lee-DeVore book, which reports a symposium of 67 participants (mainly American, but with other countries well represented) who read papers concerned with all continents, presented along with such a vivid, germane and meaty discussion as to set a model for symposium reports.

The paperback *Nomads of the Long Bow* is in contrast a classical one-man ethnography, one of the best. It is particular, genuine and moving. Holmberg's premature death in 1966 gives a poignant quality to the warmth and openness of this little book. It is his own reworking of his doctoral thesis, first published in 1950, eight years after his seasons in the field. He characteristically thanks his skilled companion of the bush, Don Luis Silva Sánchez, in appropriately courtly phrase, and his hosts the Siriono, who "tolerated a naïve but inquisitive anthropologist."

The life of the Siriono is Hobbesian. Wandering through the dense, wet forests, they are often hungry. In the rainy season the land turns into one vast swamp; they choose a stretch of high ground and stay on it. They clear garden plots with fire and digging stick and raise some crops; only maize, which they said had been known to them for 50 years or so, ever produces enough for serious storage. They have no canoes to travel their stream-filled world, little art, one story about the great hero Moon, poor huts, no clothing, numbers up to three. "Fire-making is a lost art"; once they could make it with a twirled stick. In that moist forest the skill was lost, and instead fire is carried from camp to camp in a burning brand made of the spongy spadix of a palm. At least one woman in every traveling band carries the fire.

The Siriono make eight-foot bows—each man makes his own—out of a special palm wood planed with a shell. A man who is busy is either hunting or working on arrows. There is great freedom in the matter of sex, for both men and women, married and unmarried. The dreams of the Siriono, like most of their constant quarrels and wrangles, are about food and drink rather than sex. The children are loved (a photograph of a father watching his young son draw the great bow is the happiest in the book) but the old are held as the burden they are. The people abandon the ill or the infirm without a word of farewell. Old age comes soon.

Holmberg and Silva themselves lived from the forest, but their lives depended on their shotgun and rifle, insect netting and knife. The Indians at once coveted the tools, the machetes in particular. Holmberg later introduced a few implements, a shotgun and the domestic hen. They enriched the individuals who received them, and began to spread to their kinsmen. Some of these very people have by now shifted from the nomadic to a settled way of life based on agriculture. "I am frequently disturbed," writes Holmberg, "by the fact that I had a hand in initiating some of the changes . . . over which neither I nor they had control. . . . Maybe they should have been left as they were."

Holmberg spent his remaining years as a conscious innovator. He bent his anthropology to the service of the people whose ways he studied, notably in

the decade among his friends in the village of Vicos in the Peruvian altiplano. They had been unable to free themselves from the peonage of centuries; today they live as hopeful men and women on their own lands. Their opportunity is also Holmberg's legacy.

The Lee-DeVore symposium, which is of course far wider in scope than any single ethnography, turns on the economics, demography and cultural patterns of hunters. The "devolved" Siriono are not even pure hunters and gatherers, of course. The wandering desert Bushmen, who have no gardens at all, make out contrastingly well. Their calorie intake is by actual count sufficient; they do not press their children to hunt food, nor do they dispose of unproductive oldsters. In one intimate ethnography they are called "the harmless people." They work an average 15-hour week gaining a living (plainly the envy of their hardworking Harvard observers!). This figure held true even during the third year of a severe regional drought.

The main economic basis for this inventory-free affluence appears to be the mongongo nut—abundant, reliable, drought-resistant, nutritious and good to eat even after lying a year on the ground. A Bushman, asked why he did not farm, reasonably answered: "Why should we plant when there are so many mongongo nuts in the world?" By and large hunters do not care for the morrow; they prodigally eat all there is on hand; they sleep a lot. Is that the "confidence born of affluence" or is it the lack of responsibility to their fellows of men who live by an intense individualism? Must we hold with Hobbes or with Rousseau? The answer is mumbled and incomplete, but it seems most unlikely to be unified.

Man is a plastic creature, as he is a powerful one. Only man can swim a mile, walk 20 miles and then climb a tree. There are Indians who can run down horse and deer, the runner making full use both of his physical superiority and of his mental one, in his knowledge of the prey and his planning for a coming day of rest. Professor William S. Laughlin has put it well: man the hunter domesticated only one species, but that was the vital one—himself. Natural selection made the hunter. The inventory he then made for himself was mainly informational; it was stocked in his speech, his pedagogy, his organizing, his skills. We cannot easily recover those things, at least not as easily as we dig up pots or expose the walls of Troy. Yet they lie everywhere, enciphered in the materials of the past, or in our old tales of the earth and the moon, or in the

structures of speech and thought that still hold sway among men, a treasure trove too subtle for the spade.

THE RISE AND FALL OF T. D. LYSENKO, by Zhores A. Medvedev. Translated by I. Michael Lerner. Columbia University Press ($10). The first *Pravda* story about Professor Lysenko, in 1927, draws him thus: "God give him health, he has a dejected mien.... Only once did this barefoot scientist let a smile pass, and that was at mention of Poltava cherry dumplings." So he looks out of his photographs: slight, dour, intense, lined face, cap pushed back, cigarette dangling. He still directs the experimental farm where his expensively fed and much culled Jersey crosses produce more milk but not a higher butterfat content. This book is an authorized, lively but somewhat unfortunately abridged translation of a still unpublished Russian work. It is the 1967 product of an able molecular geneticist; he began it in 1961 and has circulated it widely in preliminary form among Russian biologists. The present version was unanimously recommended for publication in the U.S.S.R. by an Academy of Sciences committee. The work itself has played a real role in the rehabilitation of Russian genetics, after one generation of pseudoscience that has cost the Russian farmer, consumer and medical patient dear.

Lysenko came on the scene, his bearded and robust farmer-father beside him, with the vernalization technique, which sometimes gained winter grain crops from summer plantings. It does not seem to have been a very novel practice, and it died out even in Lysenko's eyes by the end of World War II. Lysenko and his theoretical colleague, I. I. Prezent, gained much from it nonetheless. He appealed explicitly to the deep issues of the truly terrible epoch of 1935: "There were kulaks and their abettors who kept whispering... into the peasant's ears: 'Don't soak the seeds.'... A class enemy is always an enemy whether he is a scientist or not." Stalin was there, and exclaimed, "Bravo, comrade Lysenko, bravo!"

Lysenko could draw big conclusions from a single plant; he and his school were not above falsifying data or censoring classic references, and they systematically attacked opponents at the most overt level of xenophobia and political partisanship. He chose to acquire practical large-scale data with loaded questionnaires directed to frightened or self-serving subordinates rather than by controlled test. There can be no doubt that he was an effective phrasemaker. Khrushchev too heralded him as a national property and the guarantor of abundance.

It is clear that in the absence of public criticism, with a near-monopoly of publication and support, surrounded by an atmosphere of repression and fear, the provocative, self-praising Lysenko could prosper. The author judges him a "provincial experimenter... expressing elements of fanaticism and obscurantism. We have many such people today, and there are many in other countries, but there they are not normally placed at the head of science." Rigid centralization and long isolation had their clear results.

Yet not enough thought is given to what Lysenko offered. He had few practical successes. Branched wheat, cluster planting, anti-inbreeding—all were failures. That both Stalin and Khrushchev should have so vigorously supported him was not predictable. Was it perhaps chance? Or did he supply the public mind with something genetics could not? Professor Medvedev is too close to the issues to say.

The final tide-turning events—there were ebbs and flows—seem to have begun with Watson and Crick and the great successes of molecular biology abroad in 1961 and 1962. It was then that leaders within the Academy of Sciences began to see that the science of genetics hardly existed within the U.S.S.R. A strong scientific campaign for molecular genetics began. Then Lysenko worked not on experiments but on Khrushchev, and by the middle of 1964 a Lysenkoist geneticist ("an exceptionally unpopular personality") was presented for admission to the Academy, where he was subject to confirmation not by biologists alone but at a general meeting. The physicist A. D. Sakharov made a short, strong speech, and the biochemist V. A. Engel'gardt observed that the candidate had no practical successes and no recent research publications. The man was roundly refused, 126 against to 20-odd for.

Chairman Khrushchev was furious, and review committees were charged to look into the Academy itself. The Soviet people did not need such an Academy, he said. It was too late. The entire country was badly off. Grain was bought abroad in 1963, and the crops failed again in 1964, both in Siberia and in the virgin lands. By October, 1964, Khrushchev's energetic, self-guided amateurism was itself done, and Lysenko, to this day never dismissed or punished, resigned as director of the Institute of Genetics and lost the monopoly under which his strange views had cost Russian science and agriculture a generation of progress. "Lysenkoism is far from having been liquidated.... Neither has it lost... people... unwilling to relinquish the primitive collection of dogmas they have so firmly mastered [or] the high posts they [have] occupied for so long." Busts and reliefs of Lysenko are available "at triple discount."

It is a gloomy story, even a tragic one. Medvedev writes, however, as a patriot who retains his faith in socialist legality. There are tales of heroism, like that of the plant breeder D. N. Pryanishnikov, who nominated N. I. Vavilov, already confined in prison, where he was to sicken and die, for a Stalin prize. One bitterly funny story is in a footnote. The vindictive Prezent demanded the expulsion from the party of certain Leningrad Morganists as "abettors of fascism." A listener objected that "these comrades of whom you speak spent nearly the whole war under arms, fighting fascists, and were decorated with military awards." "This is no argument," replied Prezent; "they fought fascism only empirically."

INFRARED SYSTEM ENGINEERING, by Richard D. Hudson, Jr. John Wiley & Sons, Inc. ($19.75). In the early 1950's "those shady figures who have intelligence for sale" traded at high cost in the latest information on the infrared. Analytical infrared spectroscopy (the most important domain) apart, this well-organized and skillfully written book now tells it publicly like it is, or at least like it just was, in the entire civilian and military field of infrared. There are no classified references, of course. One should expect some lag, probably in such matters as the abilities of satellites (which these days regularly carry infrared optics of three-foot aperture). What is here is a wide-ranging approach to the overall design of working infrared systems, a book practical in outlook yet knowing in physical and analytical methods. The author teaches the material—and plainly enjoys himself—to the design engineers of Hughes Aircraft, a firm long expert in the art. Military infrared is by an order of magnitude or more a bigger industry than the civilian. Infrared is first of all a way to see in the dark and second a means of long-range sensing of uncooperative men and engines. (There is even a citation of the best-known Chinese work on tactics, although its author's name is wrongly abbreviated; it should be written as T.-T. Mao.)

To see in the dark it is enough to use the near-infrared wavelengths, beyond the limit of the visible red around .75 micron up to a few microns. All the ma-

jor powers had developed such gear by the end of World War II, usually for signals or for the use of riflemen. One used one's own invisible light source. The current standard U.S. infrared rifle sight has a range of 200 yards and weighs 11 pounds including the light source. It costs about $2,000. Nowadays the emphasis is on search and guidance, against such sources as jet engines (the U.S. alone has seven different production airborne missiles of this kind) or even smaller sources such as cooking fires or parked trucks with their engines cooling slowly. The far infrared has a clear "window" of atmospheric transmission in a band around 10 microns; more than that, it contains most of the energy radiated by objects at room temperature or close to it. This is the band that is important for medicine, meteorology, crop surveying, water-current studies and the detection of submarines and thermal pollution.

Infrared optics cannot use glass lenses past two or three microns. Ingenious mirror systems were the answer 20 years ago; now there is a long list of special materials suitable for lenses, prisms and windows. They include silicon and germanium and such exotic compounds as hot-pressed thallium bromide-iodide and cadmium telluride.

Photography works into the infrared with dyed emulsions, but only as far as 1.3 microns, a limit already reached in the 1880's. That is one octave past the red; there are nine to go. The first detectors were only heat-sensors, elegant and sensitive thermometers of various kinds, slow to respond and very broad-band. Nowadays, with signal-chopping and image-scanning the favorite means of fighting noise and feeding amplifiers, fast narrow-band detectors are needed. Solid-state science has met the need, providing a variety of semiconductors for any wavelength out to 40 microns, where one uses germanium artfully doped with just the right few parts per million of zinc or cadmium to supply a few easily freed electrons.

Cooling of detectors and of filters is helpful too, and it is indispensable for the far infrared; there is now a sophisticated technology of small refrigerators using the once-through flow of high-pressure gas, and even more elegant compressor cycles that cool down to liquid-nitrogen temperatures for a few watts of power and a few pounds of weight. Image tubes, with a scanning beam feeling out the conductivity changes of the detector target, just as the Vidicon used for closed-circuit television in the visible does, are developed to

some extent. Ingenious thermal devices (depending on evaporation of a thin oil film in a vacuum to produce film-thickness changes made visible by optical interference colors from the film) have been used widely, for purposes ranging from military mapping to locating human tumors by the increased capillary blood flow marking the higher metabolic rate of the malignancy.

A Boeing 707 jet could be picked up effectively at a distance of 60 or 70 miles by a system here designed before one's eyes in one chapter as a worked-out example. The system weighs less than 50 pounds, cooling included, and needs less than a kilowatt of power. It works in the four-to-five-micron window.

The marvelous development of high-resolution infrared interference spectroscopy is alluded to but is not fully treated. The astronomy of the extreme infrared is a topic still not engineered. The sun could barely be detected in the dry air of the high Andes at wavelengths of between 40 and 400 microns even by a quite modern apparatus. Mist and fog, but not haze and smog, stop all infrared. Too much water. All human beings, whatever their hair color or their genes for melanin formation, have skin of one and the same color if they are viewed at wavelengths beyond two microns. We are all brothers by the blood's radiation.

WALLACE AND BATES IN THE TROPICS: AN INTRODUCTION TO THE THEORY OF NATURAL SELECTION, edited by Barbara G. Beddall. The Macmillan Company ($5.95). This thoughtful little book presents a joint biography of the two men, friends and companions of "this wandering life" on the Amazon. Most of the volume consists of excerpts from their great traveler's accounts of about a century ago, set in a clear, sometimes ingenuously simple exposition of the history of evolution. These two fast friends met as a result of their love for collecting. Wallace wrote: "He asked me to see his collection, and I was amazed to find the great number and variety of beetles ... almost all ... collected around Leicester." Wallace was a schoolmaster and Bates a workman. In those days the universities trained only for the great professions; Darwin, Lyell, Hooker and Huxley all studied some medicine or law, or hoped for posts in the clergy or the armed services. Bates and Wallace came from social origins so poor that they could not aspire to life in college; they each left school at 14, Wallace apprenticed to a railway surveyor and Bates to the knitwear trade. It was the Mechanics' Institute and the books of the Society for Promoting the Diffusion of Useful Knowledge that were their Oxford and Cambridge. It all sounds like a paradigm of the Victorian career. Inspired by an "unpretending volume" by an American amateur collector who went briefly up the Amazon, they decided jointly to see the world. The British Museum assured them that almost any specimen they might collect could be sold to pay their expenses. They aimed to keep duplicates for their own study as a path "toward solving the problem of the origin of species."

Off they went to the Amazon. Bates spent a decade there and returned to a lifelong career as an officer of the Royal Geographical Society, with a widely read traveler's journal to his credit and 8,000 species new to science. The swarm of species in the ancient rain forest remains its greatest wonder. Batesian mimicry, the aping of a bad-tasting species by an edible one, is Bates's best scientific coinage.

Wallace returned from the Amazon after only four years. Forced to flee a fire at sea, he spent 10 days in an open boat and lost nearly all his collections. After a year and a half writing and talking in London, he concluded that the "very finest field for an exploring naturalist was to be found in the great Malayan Archipelago." He spent eight years in these islands, making 60 to 70 separate excursions. Once he kept a baby orangutan, which did not thrive because "I had no milk to give it, as neither Malays, Chinese, nor Dyaks ever use the article, and I in vain inquired for any female animal that could suckle my little infant."

He acquired a taste for the durian, that huge king of fruits reminding him of "a rich butterlike custard highly flavored with almonds [and] wafts of flavor that call to mind cream cheese, onion sauce, brown sherry, and other incongruities.... The more you eat of it the less you feel inclined to stop." He made his base in the island town of Ternate in a "rather ruinous" house with four rooms, two verandas, "a wilderness of fruit trees" and pure cold well water. A high, smoking volcanic cone recalled the earthquakes that had many times wrecked the town, but there he found peace to write the famous brief paper on natural selection that he sent off to Darwin to initiate public knowledge of the great theory. On his final voyage to London he took home with him two live birds of paradise. He fed them on roaches, except that on the Peninsular and Oriental steamers (a high testimonial!) the bugs were scarce, and he had to set traps and hunt an hour every night in the forecastle to win his birds a single daily meal.

The big, leisurely books of Bates and Wallace were both reprinted in 1962, Bates's by the University of California Press and Wallace's by Dover. This account will send many a vicarious traveler to those amply flowing sources out of another time.

MESSIER'S NEBULAE AND STAR CLUSTERS, by Kenneth Glyn Jones. American Elsevier Publishing Company, Inc. ($22.50). A well-known British amateur astronomer has indulged himself and his readers with a thick, useful, attractive, digressive volume on the famous list of nebulae and star clusters prepared by a professional comet-seeker, a civil servant to the navy in Paris, who patiently swept the skies for more than 50 years under the Bourbons, during the Republic and on into the Empire. Charles Messier might have been the first to announce the predicted return of Halley's comet in 1759, but his chief mistrusted the claim and Messier was scooped by a German amateur. He lived to discover 13 other comets; for these discoveries he earned praise and modest honors. He computed no orbits; his merit was careful, patient observation, not theory or inventiveness. His fame rests entirely on the list of nebulae and clusters that he slowly compiled and published as a guide to comet-seekers. One key to priority in comet-finding is not to have to waste hours watching some faint fuzzy object that in the end does not move and is no comet after all.

Messier's list of 100-odd objects, all visible with a three- or four-inch telescope, includes most of the brighter northern close galaxies, globular and galactic clusters, planetary and diffuse nebulae and the famous supernova remnant Messier 1, called the Crab Nebula. This volume is that list written very large, with the needed simplified astronomical background, a couple of pages of comment on every object and its nature, a finding chart and a drawing of each object as it is seen in a small telescope, a fine set of big-telescope pictures of most of the objects, plenty of auxiliary history, disputes, asides, practical hints, uncertainties and prehistories, and a collection of brief biographies for almost all the people mentioned in the text. The illustration showing M (for Messier) 31, the Great Nebula in Andromeda, from a Persian manuscript copy of Al-Sufi's book of A.D. 964, is a plum.

The book is replete with tables, maps and indexes.

INDEX OF ADVERTISERS

OCTOBER 1969

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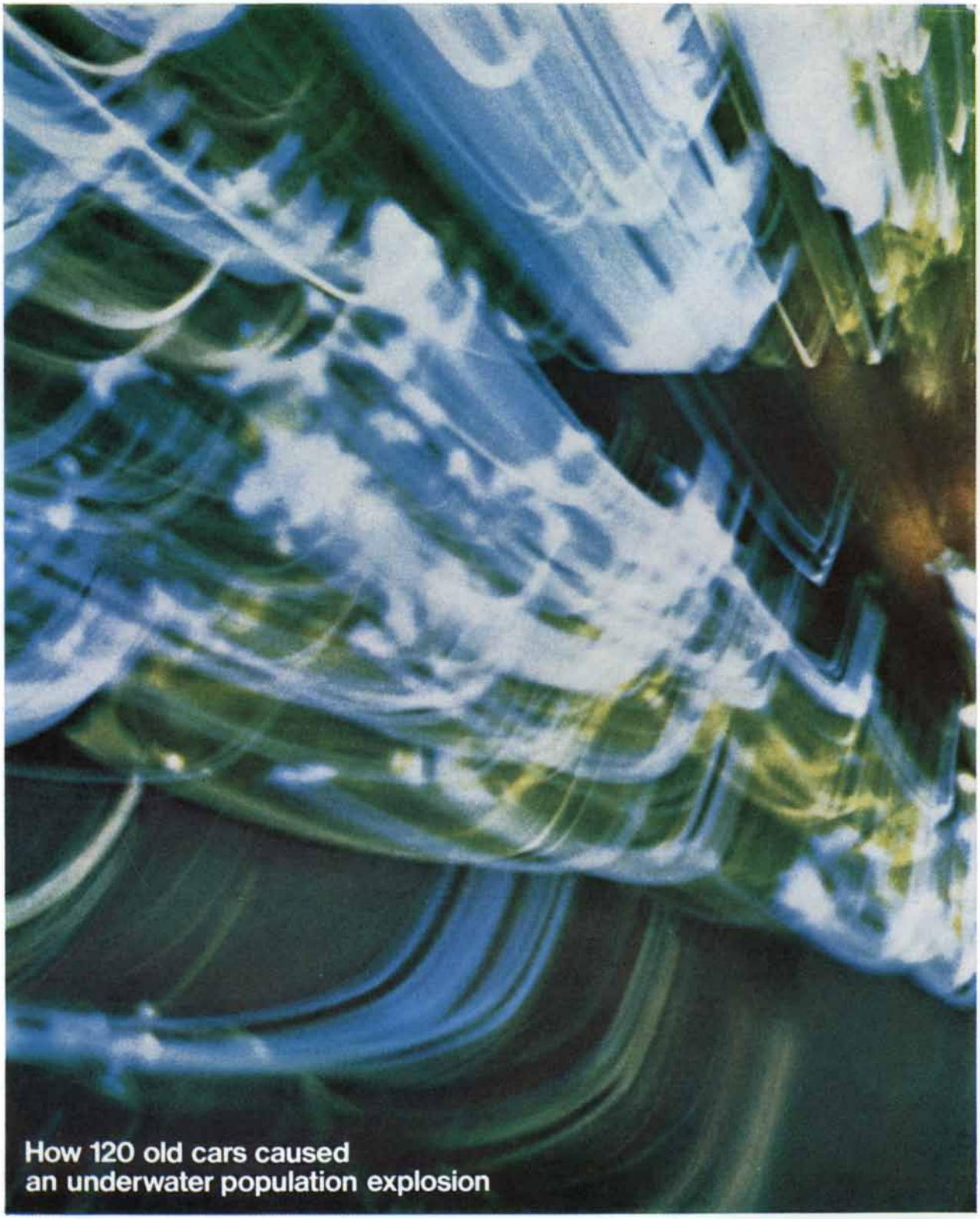

Off the coast of California, near our oil wells, there's an artificial reef built of discarded automobile bodies. One so compatible to local sports fish that it has become a veritable deep sea apartment house.

Atlantic Richfield created the reef as an experiment in improving the environment for fish colonies. Algae began to grow on the cars. As did kelp, mollusks and lots of other very tasty undersea delicacies. So the fish moved in, and reversed a dwindling birth-trend. It's the kind of population explosion we like to see. And just one of many steps ARCO is taking to make the world we live in just a little better than when we started.

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