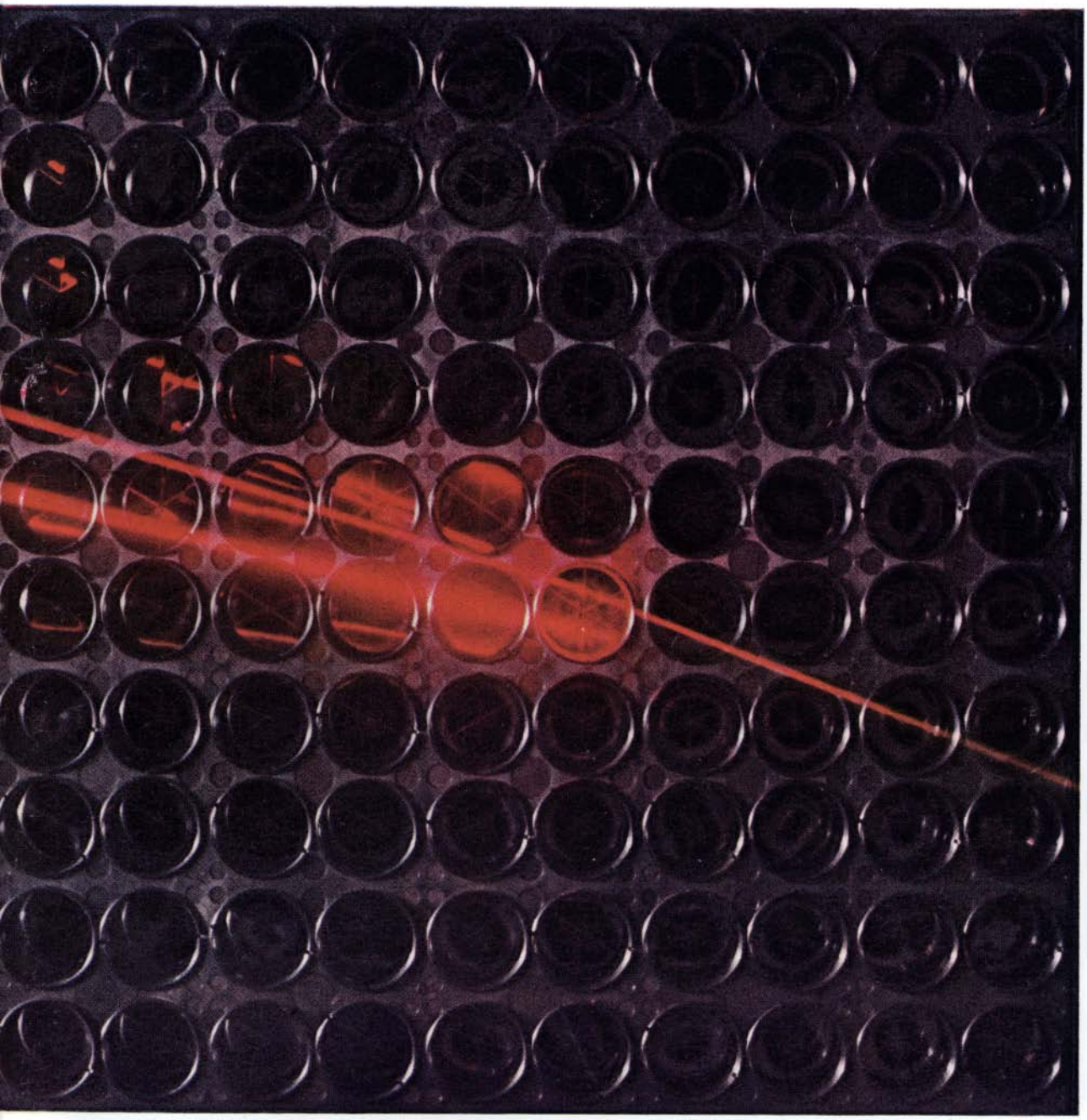
SCIENTIFIC AMERICAN



LUNAR LASER REFLECTOR

ONE DOLLAR

March 1970

In two years, she'll

tune in the world.

A folk festival from Malmö. An archeological discovery from Turkey. A soccer game from Ecuador.

All these and more. Televised live and in color from places with names hard to pronounce, even more difficult to spell.

She can see much of the world right now, because 25 countries are already linked by a satellite system operated by INTELSAT, the International Telecommunications Satellite Consortium. Still, there are parts of the globe blacked out for her.

In two years, there'll be so many new earth stations in so many more countries that INTELSAT will have put up a new generation of larger, more complex satellites to handle the heavier load.

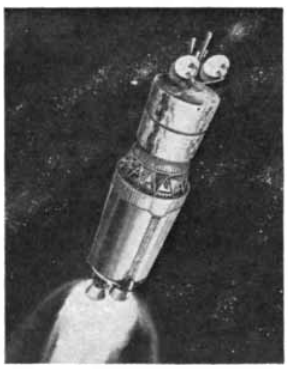
Then, live TV, and every other form of electronic communication, really goes worldwide.

General Dynamics builds the Atlas-Centaur rockets that will put those satellites in orbit. Why Atlas-Centaur?

INTELSAT, through its manager, COMSAT, has contracted with NASA for the Atlas-Centaur, having judged it to be reliable, economical and big enough to carry the extra load.

With good reason.

Atlas is the booster that fired John Glenn into orbit eight years ago, launched every U.S. planetary mission, and is still going strong after more than 370 launches. Its second-stage mate, Centaur, is the pioneer in hydrogen rocketry. As a team, they boosted seven Surveyors toward the moon, as well as both 1969 Mariner probes to Mars.

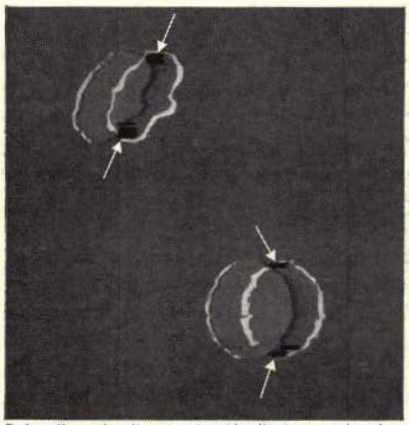


Sketch: satellite atop upper-stage Centaur.

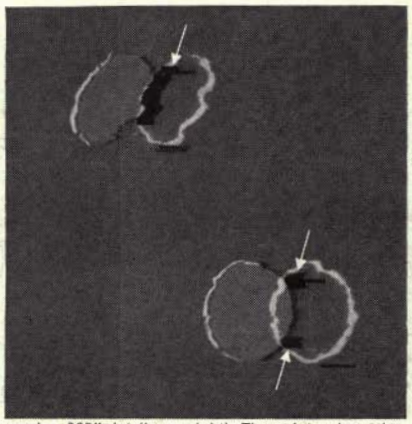
It's another example of what technology can accomplish when it's handed a problem. At General Dynamics, we put technology to work solving problems from the bottom of the sea to outer space...and a good bit in between.

GENERAL DYNAMICS

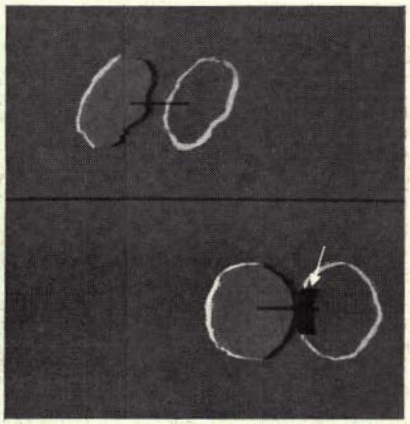
How Western Electric spots dots with TV.



Delay line circuitry creates duplicate, overlapping "ghost" images for pencil mark (upper left) and



regular .025" dot (lower right). The points where the images cross can be made to produce black areas



(marked by arrows). The ghosts are moved right or left, and the positions of the black areas tested

How would you use automation for drilling holes when every hole has to be in a precise spot, but every spot isn't exactly where you expect it to be?

That became a critical problem for Western Electric when we started using a polyethylene with very superior electrical properties as the base laminate in printed circuit boards. Unfortunately this material showed a tendency to shrink when the circuit pattern was etched in the copper on the board—not enough to affect its electrical properties, but enough to dislocate the dots which indicated where holes were to be drilled for placing components. The shrinkage was unpredictable but could move a dot by as much as $\frac{1}{32}$"—more than its own diameter.

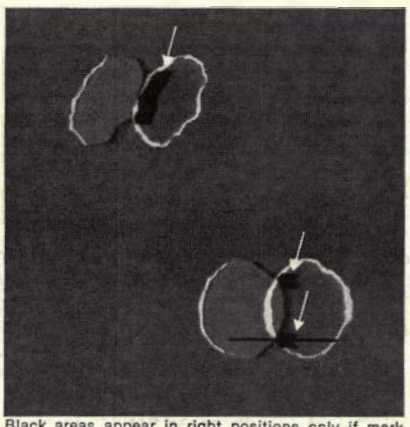
What that meant was that we could not use a conventional tape-controlled drilling machine, which put the drill in precisely the same spot every time. We needed a machine that could, in effect, "see" a dot, no matter where it was, tell it apart from an accidental marking of about the same size and shape, and put a drill right through it.

Engineers at our Greensboro, N.C., Works made such a machine. It consists of a TV camera hooked up to circuitry which removes the grays from the picture, turning it into a series of true on-or-off digital pulses; and logic circuitry which can respond to such pulses and activate a mechanism which moves the board around.

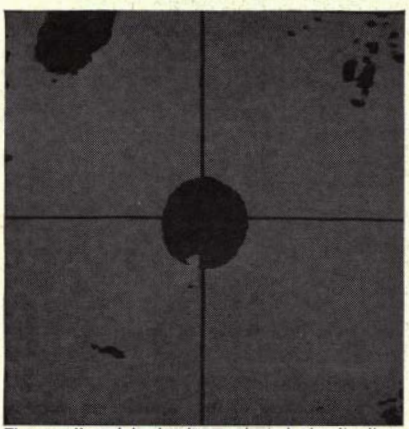
Once the dot has been roughly centered beneath the camera, delay line circuitry creates a second image which is first superimposed on the original, then moved by successive stages to the right. The points where the two images meet—i.e., where the two circles cross—will be in certain positions if and only if the original dot is a perfect circle of the proper size. Logic circuitry tests these positions, and if they are not exactly right, it won't drill and the circuitry sets itself to search for another dot. If they are, it lines the dot up, moves the camera aside, moves the drill into position, and there you are.

A simple, fast, economical, and very, very precise solution to a vexing problem. The kind of solution that helps us keep the quality of the equipment we make for the Bell System high, and the costs low.

Western Electric



Black areas appear in right positions only if marking is a circle of the proper size.



The pencil mark having been rejected, circuitry lines up acceptable dot for drilling.

Established 1845 **SCIENTIFIC AMERICAN** March 1970 Volume 222 Number 3

ARTICLES

DEPARTMENTS

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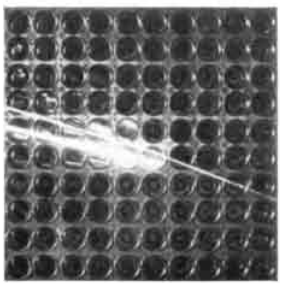

THE COVER

The photograph on the cover shows the beam from a helium-neon laser striking one of the corner reflectors in a duplicate of the retroreflector array placed on the moon last July 20 by the astronauts of *Apollo 11*. The array was designed to reflect intense laser pulses beamed from the earth so that the round-trip travel time of light signals could be measured (see "The Lunar Laser Reflector," page 38). The measurements have now established the earth-moon distance with a precision of six inches. In the photograph the laser beam is striking the sixth corner reflector from the left in the sixth row from the top. The incident beam, the broadest of three distinct beams, is traveling from left to right. After three internal reflections the principal exit beam is returning on a path precisely parallel to and above the incident beam. Although virtually as strong as the incident beam, the exit beam looks weaker because, from the viewpoint of the camera, it is striking the back of the dust particles used to make the beams visible. The sharp beam traveling off to the right is actually a weak secondary exit beam produced by complex internal reflections. The photograph was made with the kind assistance of Arthur D. Little, Inc., which designed the array.

THE ILLUSTRATIONS

Cover photograph by Sol Mednick

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We love 'em then we leave 'em.

After six months of loving attention, we change our fleet of new Plymouths for a fleet of brand-new Plymouths.

Not that we're heartless.

We're businessmen.

We figure we have to give you a better reason for renting from Avis than for going someplace else.

And what better reason than this: A new car drives better, feels better, even smells better than a not-so-new car.

If you think Avis tries harder, you ain't seen nothing yet.

LETTERS

Sirs:

The article "Acute Respiratory Failure," by Peter M. Winter and Edward Lowenstein [SCIENTIFIC AMERICAN, November, 1969], emphasized unintentionally, by what it did not say, the gap in communication between modern medical research and the people this research is intended to serve. The authors proudly describe the knowledge and the technique they apply in dragging half-dead people back to life. They never discuss how all this may look from the point of view of the patient. Their failure to mention the human problems that such methods of treatment create must increase the distrust felt by many of us toward modern medicine in general. The article tends to confirm our (no doubt quite unfair) picture of the modern-style intensive-care unit as an impersonal monster designed to rob the patient of any chance of a peaceful and dignified death.

I should like to give the authors of the article an opportunity to answer a few practical questions to set the record straight:

1. To what extent are patients given a free choice before they begin the treatment?

2. How large a fraction of the patients not only survive the treatment but also return to some more or less normal and useful life?

3. Does the doctor who makes the crucial decisions have any personal contact with the patient, and does he have time to get acquainted with him as an individual human being?

FREEMAN J. DYSON

Princeton, N.J.

Sirs:

The moral and philosophical problems of radical intervention in the care of the critically ill are an integral part of intensive care, and are of immediate concern to those who practice it. We are grateful to Dr. Dyson for raising these timely and important issues.

First let us clarify a basic misunderstanding between Dr. Dyson and us. The difference between prolonging life and prolonging death is indeed a critical one. His impression is that these radical therapeutic techniques are applied to patients in the terminal stages of chronic and irreversible disease. This impression is incorrect. All men die, and death in dignity and peace is one of the fundamental rights of the living. It is a right with which we attempt to deal rationally. Certain diseases are incurable. One may call them the natural processes of aging, if one likes. No one, however, dies of old age. Patients die of disease. We make the conscious effort to avoid radical intervention in the terminal stages of an irreversible process. The patients with whom we deal, however, almost never fall into that category. We are sorry that this did not emerge more clearly in our article, but if the reader will look at the table of disease entities common to respiratory intensive-care units, he will see that almost none of the patients had irreversible disease. Almost all were in the acute respiratory failure secondary to some other primary and reversible condition. Such patients can anticipate recovery if they can be tided over this life crisis by proper respiratory care. A typical example might be a young man brought into the hospital with multiple rib fractures and damaged lungs following an automobile accident. Not many years ago such a patient would have

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NAME

NEW ADDRESS

OLD ADDRESS

EAI datalinks

A Newsworthy Compendium of How EAI Hybrid, Digital and Analog, systems help make a complex world relatively simpler.

HOW ROUND IS ROUND?

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

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

GC PEAKS AND THE SOFTWARE DEMON

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

For a copy of the paper and a detailed booklet on PACE III write to Dept. 206H. And if you're at the Pittsburgh Conference, plan to attend our seminars and see PACE III in operation.

IMITATION POLLUTION CAN BE A SOLUTION

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

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

KINETIC DATA MEANINGFULLY SHAPED BY COMPUTER

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

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

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

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

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died of unrecognized respiratory failure. We now have the means to sustain life until healing allows him to maintain respiratory homeostasis without assistance. Thus the effort is very much to preserve life, not to prolong death, and we are acutely aware of the difference.

These differentiations sound simple. In reality they are not. Before going on to more complex issues, we shall respond to Dr. Dyson's specific questions.

1. Patients who voluntarily come to the hospital have, by that action, indicated that they are seeking medical treatment for an illness. To assume otherwise without direct evidence is unthinkable. They do not specify that they want to be treated only if their hospital course is uncomplicated. Consent implies *informed* consent, and truly informed consent at the height of a crisis is almost always impossible, even when the patient is a physician (or a physicist). To take the most extreme example: Does Dr. Dyson seriously suggest that if the patient is unconscious, the physician should take the family's word for the fact that the patient prefers not to live?

2. Specific figures cannot be quoted because they are based on the definition of normality, but the overwhelming majority of patients who have been in respiratory intensive-care units do return to a "normal and useful life."

3. In a good intensive-care unit the physician is probably closer to the physical and psychic problems of the patient than in any other form of hospital practice. In the respiratory intensive-care units of some academic hospitals the ratio of physicians to patients is nearly one to one. The physicians get to know their patients very well indeed.

Allow us now to indicate some of the nightmarish complexity of decision-making in an intensive-care unit. There are, in theory, at least three participants in the decision-making process in intensive care: the patient; the physician best able to estimate the chances for useful survival, and the society as a whole, which must ultimately bear the already staggering cost of medical care. (We do not wish to discuss the latter issue in depth, but it is an increasingly important one that may, at some time in the near future, become dominant.) Decision-making by the patient alone is almost always inadequately based. The majority are poorly equipped to make rational judgments about the probability of survival—they simply do not have the information. The physician and the patient should always have the closest and most meaningful dialogue possible. Courses of action should be by mutual agreement when possible, but to place on such a patient the *sole* responsibility for decision-making is neither humane nor useful. The physician has to strike a most delicate balance between the rights of the patient to self-determination and the nearly universal dependency needs that accompany illness.

To place this responsibility on the physician alone puts him in a remarkable position. Since he entered medical school, the fundamental principle he lived by was that it was his function to heal. That decision was made for him and was seldom questioned. The impact of technology, science and economics has now made this less clear in some circumstances. In those frequent instances in the intensive-care unit when there is grave doubt as to outcome, the physician must decide (knowing that the decision is always based on inadequate information and a number of unknown variables) whether or not he should subject the patient to enormous stress on the chance that the patient may be saved. Traditionally the medical profession has avoided this issue by pretending that it was none of its business. Avoidance is no longer tenable. The decision not to act is therefore the most radical course, both for the patient and for himself, that the physician can choose. Radical intervention—the attempt to preserve life at all costs—must now be a calculated decision, an agonizing, repetitive and inescapable one.

Intensive care is frequently unpleasant for the patient but is of unquestionable effectiveness in saving life. To describe it as a torture-chamber environment, as Dr. Dyson implies, is grossly inaccurate. For the physician it is one of the most stressful *forms* of medical practice. Yet we find it rewarding, in both humanitarian and scientific terms. The emotional needs and rights of the patient primarily and the physician secondarily are fundamental. We did not emphasize these aspects in our article, perhaps because we have lived with them for so long and have resolved the issues in our minds as best we can. Compassion, skill and knowledge need to be combined with carefully formulated philosophical attitudes and scientific criteria, both in and out of intensive-care units.

PETER M. WINTER, M.D.

Seattle, Wash.

EDWARD LOWENSTEIN, M.D.

Boston, Mass.

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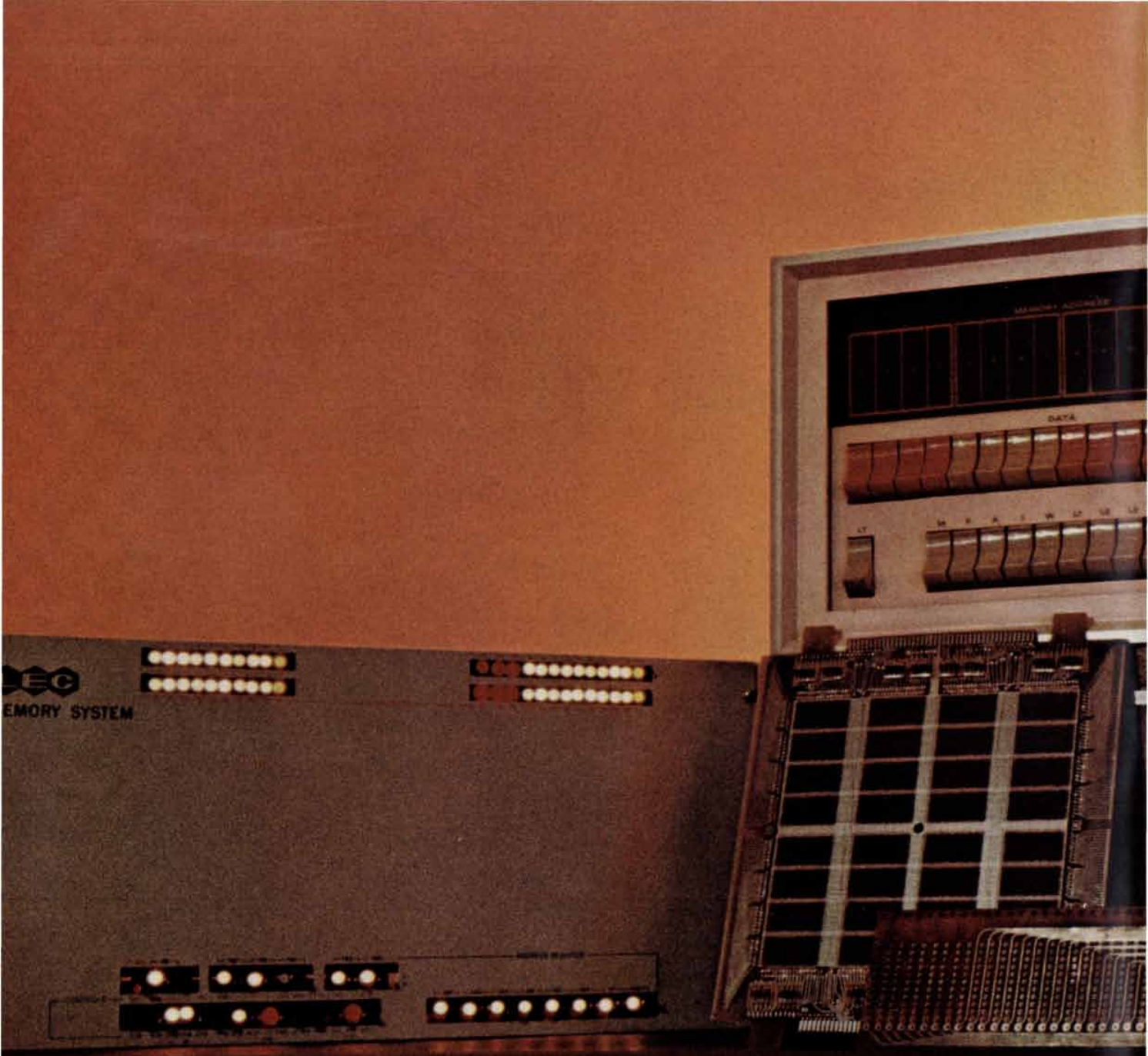

Funny, it doesn't look

Almost everyone knows our first name. Lockheed. The confusion starts when they get to the Electronics part.

Even though we've been in business for over ten years, some people can't get used to seeing the Lockheed name on memories, computers, and printed circuits.

Fortunately for us, a lot of people who buy electronics have gotten used to Lockheed Data Products. We've shipped more bits of high speed—one microsecond or faster—core memory than all other independent manufacturers combined.

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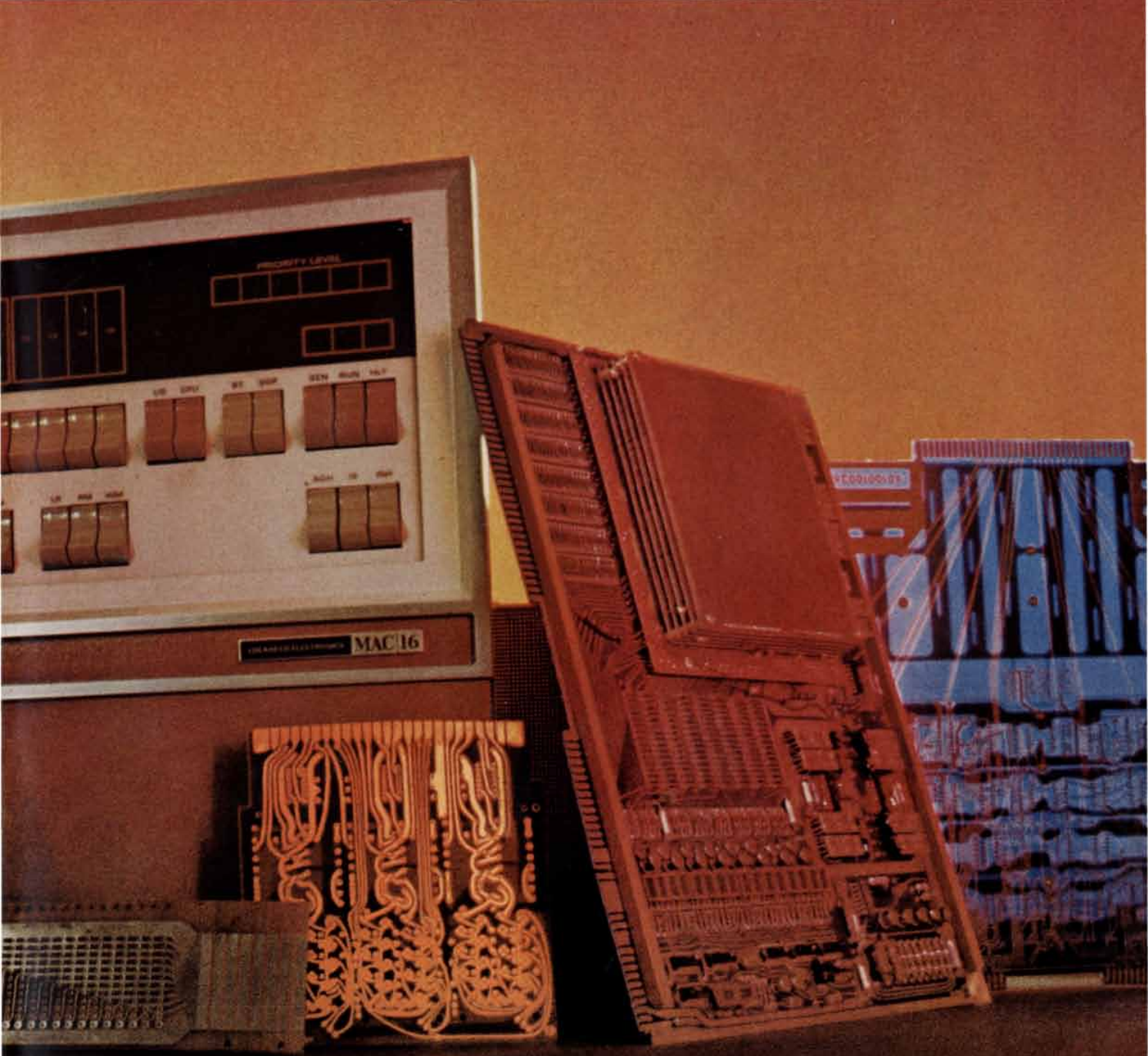

like a Lockheed.

parts, ourselves. There's not another manufacturer of mini computers who can say that.

We're producing plated wire memory systems and flexible circuits. We have a habit of being right there at the head of the line in new product breakthroughs.

Our products don't have wings. Or nosecones. So we may not look like a Lockheed to you. But we're flying high all the same.

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Lockheed Electronics

Data Products Division
A Division of Lockheed Aircraft Corporation
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Venture: Cook exhausts to clear the air.

The problem: minimize the part the internal combustion engine plays in air pollution.

The primary goal: reduce auto exhaust emissions dramatically through some simple, inexpensive but effective method.

The solution? Five years of research and development work by scientists, engineers and technicians at Du Pont have produced a non-catalytic emissions control device called the exhaust manifold reactor. It has achieved the best control of auto emissions by any system known to date.

Mounted in place of the conventional exhaust manifold, the reactor is an insulated outer shell with a tubular core. Exhaust gases, mixed with injected air, are held in the high-temperature zone of the inner core until they are almost completely oxidized.

The principle of finishing the combustion process in the exhaust system is not a new one. But what is new is the effectiveness of Du Pont's device.

In individual tests of up to 100,000 miles, emission levels have been below 30 ppm hydrocarbons and 0.6% carbon monoxide, compared with 1970 standards of 180 ppm hydrocarbons and 1.0% carbon monoxide. And reactors now being tested have further reduced carbon monoxide emissions to 0.26%.

The reactor system can be adapted to any gasoline-burning automobile engine. And soon metals research should develop the low-cost materials needed to make the reactor economical for all new cars.

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 engaged in.

DU PONT
REG. U.S. PAT. OFF.

Ventures for better living.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1920: "The results that have followed the researches made on and with the devices that have grown out of the improved De Forest audion indicate that in this instrument electrical engineers and scientists have a most potent tool for advancing the art not only in the communication field but also elsewhere. Although many new and important uses employing the principles involved in the audion have been developed, the limits to the extent of its applicability are not yet in sight. It is probable that at no time in the world's history have so many physicists been engaged in a single piece of work as are now involved in the study of thermionic problems."

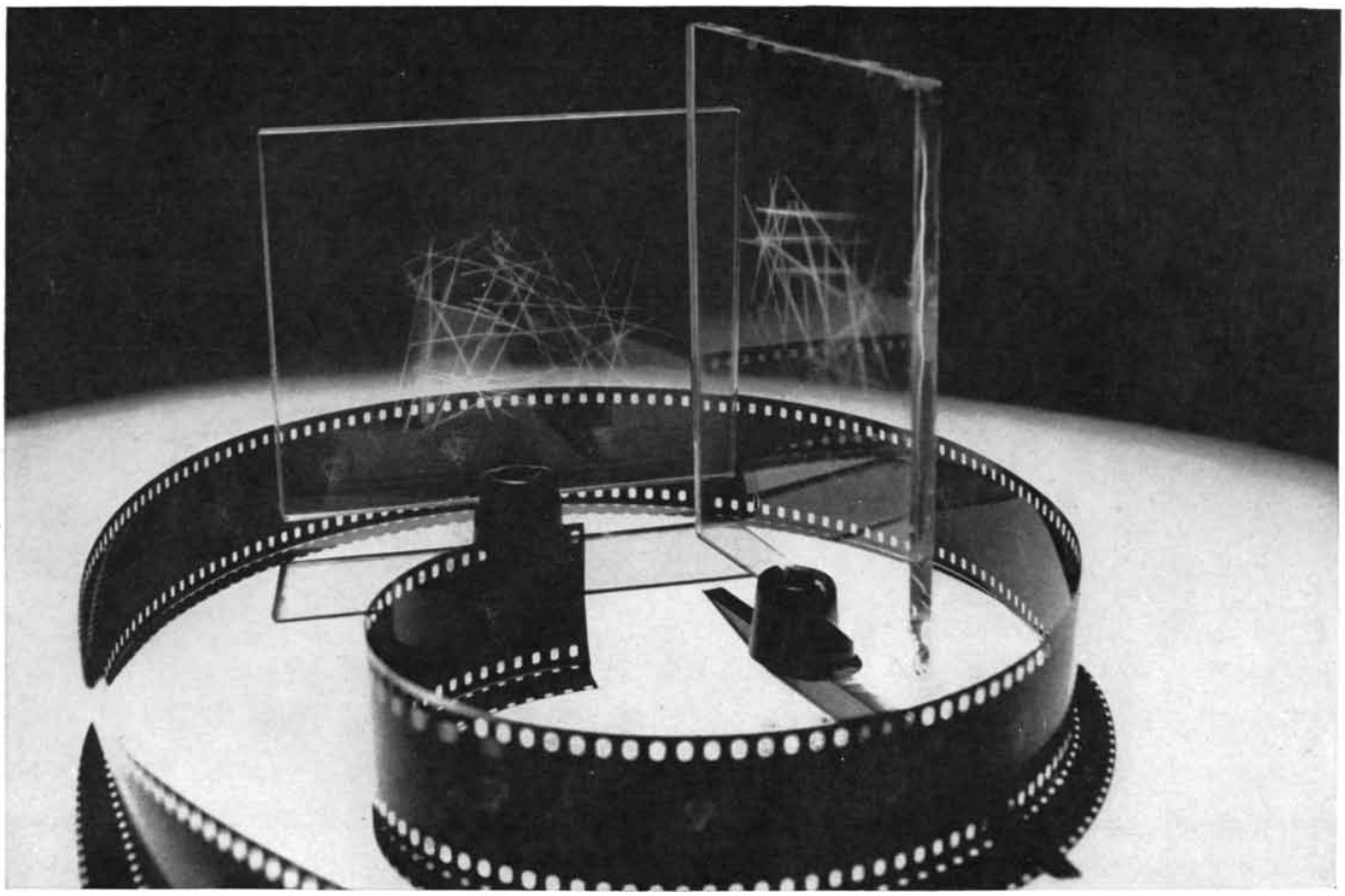
"The outstanding lesson taught by the Army long-distance flight across the American continent and back, which was held last summer, was the crying need for suitable landing fields; and as the fuller details of the recent 12,000-mile flight from England to Australia are made known, the same lesson is taught with even greater emphasis. If long-distance aviation is to become a commercial success, a large share of future appropriations, whether governmental or private, should be devoted to the provision not of extemporized but of thoroughly well built and completely equipped aerodromes, with all facilities for obtaining fuel supplies, stores and other indispensable necessities."

"In his recent testimony before the House Naval Committee, Rear Admiral Badger urged that our plans for naval construction should be so drawn as to give us by 1925 the largest navy in the world. This means that it will be necessary to increase our material in the way of ships, guns and general equipment fully 50 percent. To make such a fleet effective it would be necessary furthermore to acquire some score or so of naval stations all over the world. But do we require the largest navy in the world, and if so, when did it become necessary? Before the war, and even after it had been long under way, such patriotic advocates of a strong navy as the Navy League and the National Security League considered that it would be sufficient if our navy held an unchallenged position as the second naval power (after Great Britain). The taxpayers of the U.S. are asking what is the unexpected and seriously menacing new condition in international affairs that makes it necessary for an eminently pacific people like ourselves to go on adding to its fighting fleets on a far greater scale than the advocates of preparedness considered necessary even in the days when the German menace loomed large on the international horizon."

SCIENTIFIC AMERICAN

MARCH, 1870: "The proposition to sell a portion of the Yosemite valley to certain persons, as pre-emptors of the land, is again before Congress and has been reported upon favorably by the committee appointed to consider the subject. As this valley belongs to the people of the United States, the question appears to be between two squatters and all the rest of the inhabitants as to who shall finally obtain control of the grandest scenery on the face of the earth. It is a matter of so much importance that we think it proper to devote some attention to it, for the sake of entering an earnest protest against any sale or cession of the territory to private speculators. The original law of Congress granting the valley to the people of the United States as a pleasure ground for their use forever was one of the most enlightened acts of legislation on record, and it would be better to stand by the original bill. If the State of California is weary of the trust, then let Commissioners be appointed by Congress, to whom shall be confided the important responsibility; under no circumstances, and on no pretense, ought the property to pass into private hands."

"The notion of sudden 'catastrophes' at remote periods, by which mountain chains were upheaved or seas opened, is now generally abandoned. Sir Charles Lyell has succeeded in making the doctrine generally accepted that geological facts are to be explained by forces now at work; that the same power which now raises the coast of Scandinavia at the rate of a few inches in a century and depresses that of parts of New Jersey about as fast, if it has time enough to work in,



Holography—quickly—by computer

One of the most startling things about a hologram is that it produces images with parallax... that the appearance of the image varies according to the angle of view, just as in the real world. That's why we see the subject in 3-D, even though each eye, looking along its axis through a separate small area of the hologram, sees only two dimensions. Bell Labs scientists M. C. King, A. M. Noll, and D. H. Berry took advantage of this to generate holograms of nonexistent objects (such as 3-D mathematical graphs) with a few seconds of computer time.

Normally, a hologram is made by photographically recording wavefronts of laser light reflected from a real object. (Holograms have also been generated by calculating such wavefronts and recording their pattern on a photographic plate, but this takes many hours of computer time, even for simple subjects.)

A King-Noll-Berry hologram, however, is actually a series of holograms, each about 1mm wide and 100mm high, on a single holographic plate. These individual holograms are made, one by one, from a series of two-dimensional computer-generated pictures (film strip above), showing the hypothetical object from a range of viewing angles, in 0.3° steps. (Because of a hologram's high information capacity, each 1-mm vertical strip can contain—and project—a full-width picture.) And since each of the viewer's eyes looks through a different vertical strip, the viewer sees the object binocularly, in 3-D.

Like most holograms, these should be viewed with a laser; this limits their usefulness for many scientists, engineers, and students. But, because the "strip"-hologram images are two dimensional, placing a holographic plate with a special emulsion in the plane of the projected real image yields a copy hologram (glass plates above). Viewable under an ordinary incandescent bulb, this hologram can be studied wherever and whenever the user wishes.

This technique is the first way to make "hard copy" holograms of imaginary solid objects with little computer time... a fast and inexpensive way of converting abstract data into three-dimensional pictures and graphs. It opens another avenue of fluent communication between man and machine, for possible use in communications technology, science, finance, architecture, statistics, and other fields in which the computer has become necessary.

From the Research and Development Unit of the Bell System—

Bell Labs

Evaluating performance is Continental's business.

For their own needs they selected our real-time system.

Who should know how to evaluate performance better than someone in the business? Like Continental Testing Laboratories, Fern Park, Florida. For their own on-line computer system needs Continental looked at no less than nine different computer companies, large and small. And they finally chose our Real-Time Executive.

Continental tests some of the most sophisticated, state-of-the-art gear around. And they needed a system that would provide almost instant analysis of the kind of complex data that usually takes days, even weeks to handle. So performance played a major role in their decision. But with Continental, it's total performance that counts. That's why, in making their final choice, they looked for a supplier that was reponsive to the needs of their engineers. They chose Hewlett-Packard because, as one Continental executive put it, "HP is our kind of company."

This means Continental is receiving a fully operational, thoroughly de-bugged real-time system. And the kind of support that will provide them with a deep understanding of the system as well. Their people will go to HP operating seminars and service schools. They'll learn to program, maintain and repair their RTE.

They'll also learn how to modify it themselves, to meet the complex needs of rapidly changing test programs. And for backup they'll have the comfort of knowing that one of HP's 141 service centers (we've got them all over the world) is just a few miles away.

And, of course, our RTE system can more than hold its own in the product performance category. It handles background and foreground programs simultaneously. Permits you to control tests in real time. Develop new programs. Analyze data. And at the same time, handle everyday chores like batch processing. Ninety-nine priority levels allow your most important programs to claim immediate attention. And multiprogramming capability, with simultaneous I/O, helps you control almost any number of different operations at the same time.

HP's 2005A Real-Time Executive does all this and more, at prices starting at just $71,600. For more information about our RTE, and the company that is most responsive to your needs, call in your local HP computer systems team. Or write Hewlett-Packard, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

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DIGITAL COMPUTERS

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will suffice to make continents of all the oceans and to submerge every continent; that the earthquakes and eruptions which have built up some mountains and islands in our own time need nothing but more time to build innumerable others."

"By means of an 11-inch objective the distinguished astronomer Mr. Rutherfurd has obtained photographs of several groups of stars. One of these groups, comprising 43 stars in the constellation of Pleiades, some of them of the ninth magnitude, was obtained after an exposure of three or four minutes. By means of a very delicate micrometer Mr. Rutherfurd has been able to measure the arc of the angle which separates the stars of this constellation. The results have been compared by Dr. Gould with those formerly obtained by Bessel and confirm the remarkable accuracy of the latter's work. By means of photography Mr. Rutherfurd can obtain in one night results that cost the Prussian astronomer the labor of 10 years."

"M. Lesseps announces that the minimum depth of the Suez Canal is 19 feet, and that this is over the rock at Serapeum. The rock is to be removed shortly, and then the minimum depth will be at a spot near Suez. It will range from 23 feet to 27 feet."

"The doors of the Beach Pneumatic Transit Company (Mr. A. E. Beach of SCIENTIFIC AMERICAN, prop.) were thrown open to the public for the first time on the 26th ult., when an 'Under Broadway Reception' was given by special invitation to the State authorities, city officials and members of the press. The New York *Herald* says: 'It was virtually the opening day of the first underground railway in America.' The New York *Times* says: 'Certainly the most novel, if not the most successful, enterprise that New York has seen for many a day is the pneumatic tunnel under Broadway. A myth or a humbug it has hitherto been called by everybody who has been excluded from its interior; but hereafter the incredulous public can have the opportunity of examining the undertaking and judging of its merits. Yesterday the tunnel was thrown open to the inspection of visitors for the first time, and it must be said that every one of them came away surprised and gratified. Those who entered to pick out some scientific flaw in the project were silenced by the completeness of the machinery, the solidity of the work and the safety of the running apparatus.' "

First color-mated plastic bumper-backer.

The Marlex® Marketing Team helped create it.

A bumper-backer is the valance panel you see under the car bumper.

The problem the automotive manufacturers faced was to build one that wouldn't rust, chip or corrode. One that would accurately match the colors of their cars. So they called in their Marlex Sales Engineer.

He consulted with other members of the Marlex Marketing Team. People skilled in plastics . . . resin development, color compounding, mold design and more.

The result was the first color compounded polyolefin part ever used in exterior service on an American-made car.

That's the way it goes when the Marlex Sales Engineer gets involved in filling a customer's needs. And that's why, if you have any reason to work with plastics, you have every reason to work with Phillips . . . inventors of the leading process for producing high density polyethylene. The only producers of genuine Marlex, the resin that's worth more.

Get help from the Marlex Marketing Team. Call:

Robert F. Lynch, Fairfield, N.J. 201 227-6600.
Gerald Tucker, Southfield, Mich. 313 353-6666.
Ralph Porter, Villa Park, Ill. 312 834-6600.
Harry House, Memphis, Tenn. 901 682-8317.
David Day, Los Angeles, Calif. 213 685-6380.

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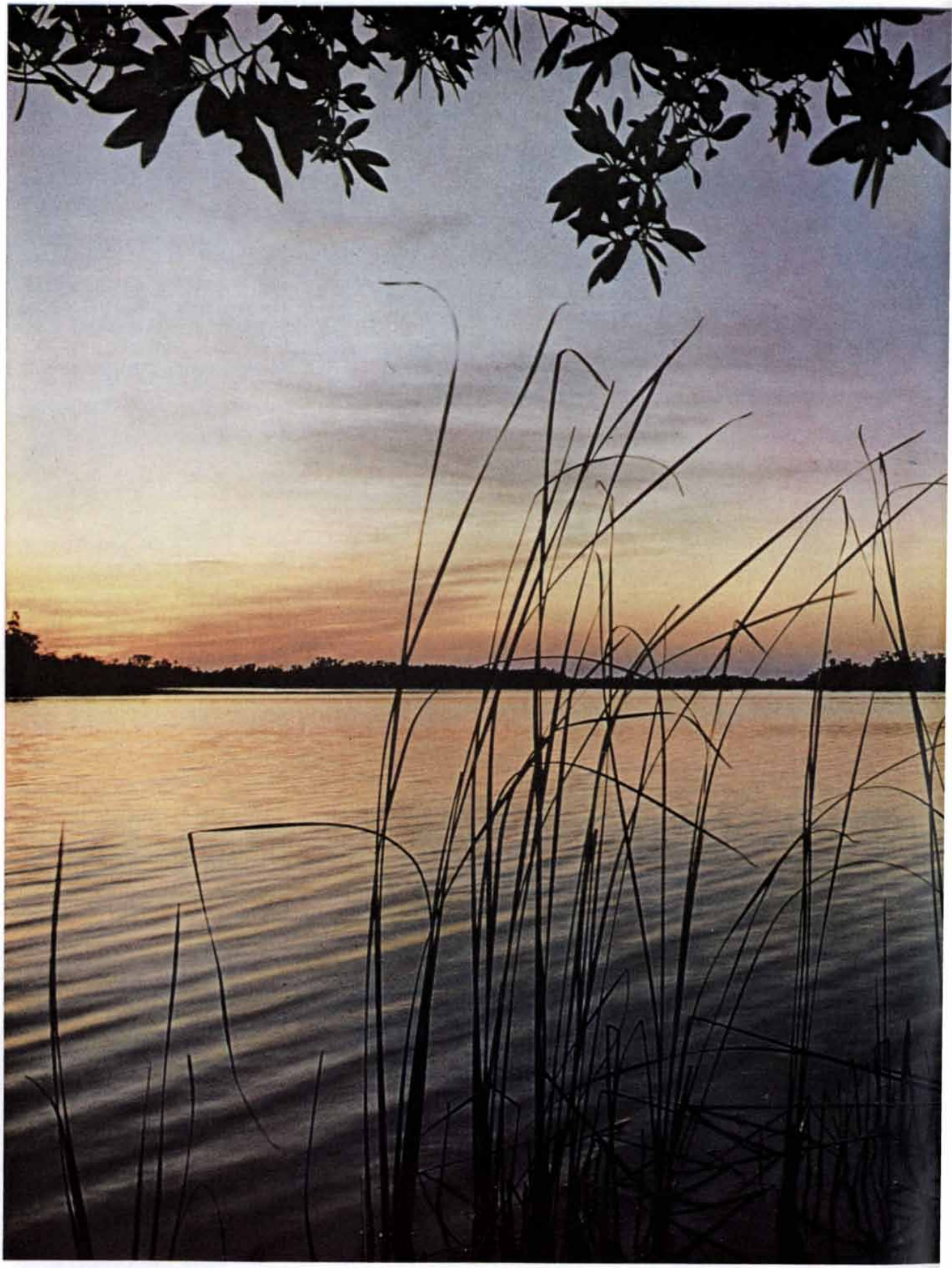
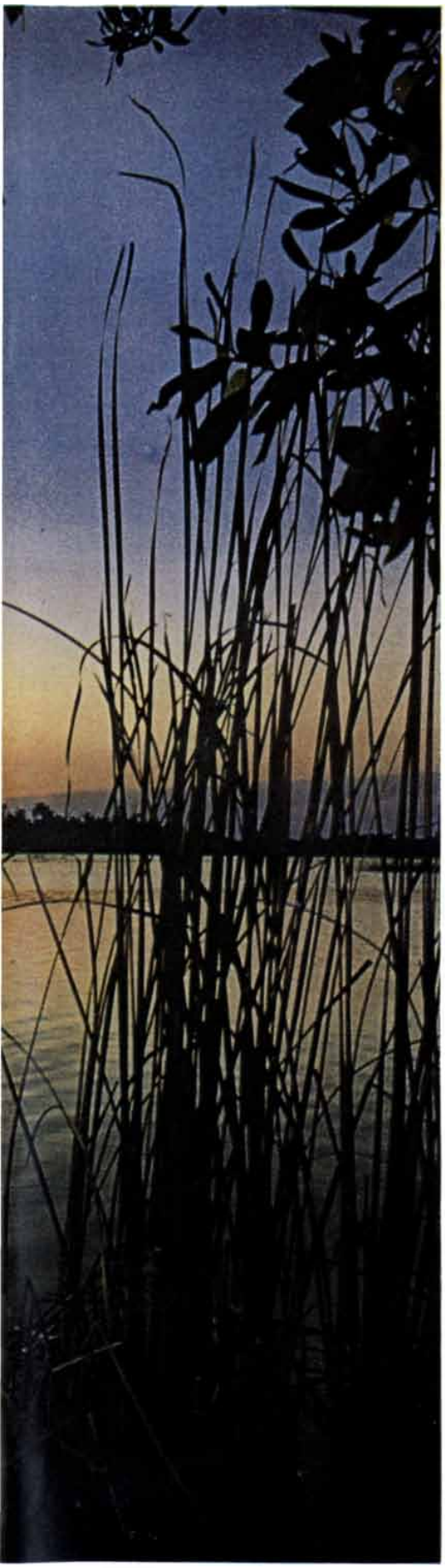




Bugs ate this lake clean.

In every lake or river or stream are tiny little microorganisms that eat pollution.

That's all they do. Eat and get fat and sink to the bottom. Where they won't bug you.

But sometimes the water gets too polluted. And the little bugs start starving for air. And stop reproducing and eating.

That's the problem Union Carbide's Linde Division took on.

We've just come up with a system that gives these little bugs a straight shot of pure oxygen. It makes them eat and eat and eat. And reproduce more rapidly. So even more little bugs start eating.

Already we've used this oxygen aeration idea to save a sick river in Louisiana. And we think it can revolutionize waste water treatment.

Hungry bugs isn't the only idea we've had to clean up water pollution. We've had a lot of good people working on detergents that chemically break down and don't spoil the water. And new instruments to constantly watch the water that goes into rivers and the like.

Back to bugs...

You should see the way they stuff themselves once you whet their appetites.

UNION CARBIDE

THE DISCOVERY COMPANY

The rubber

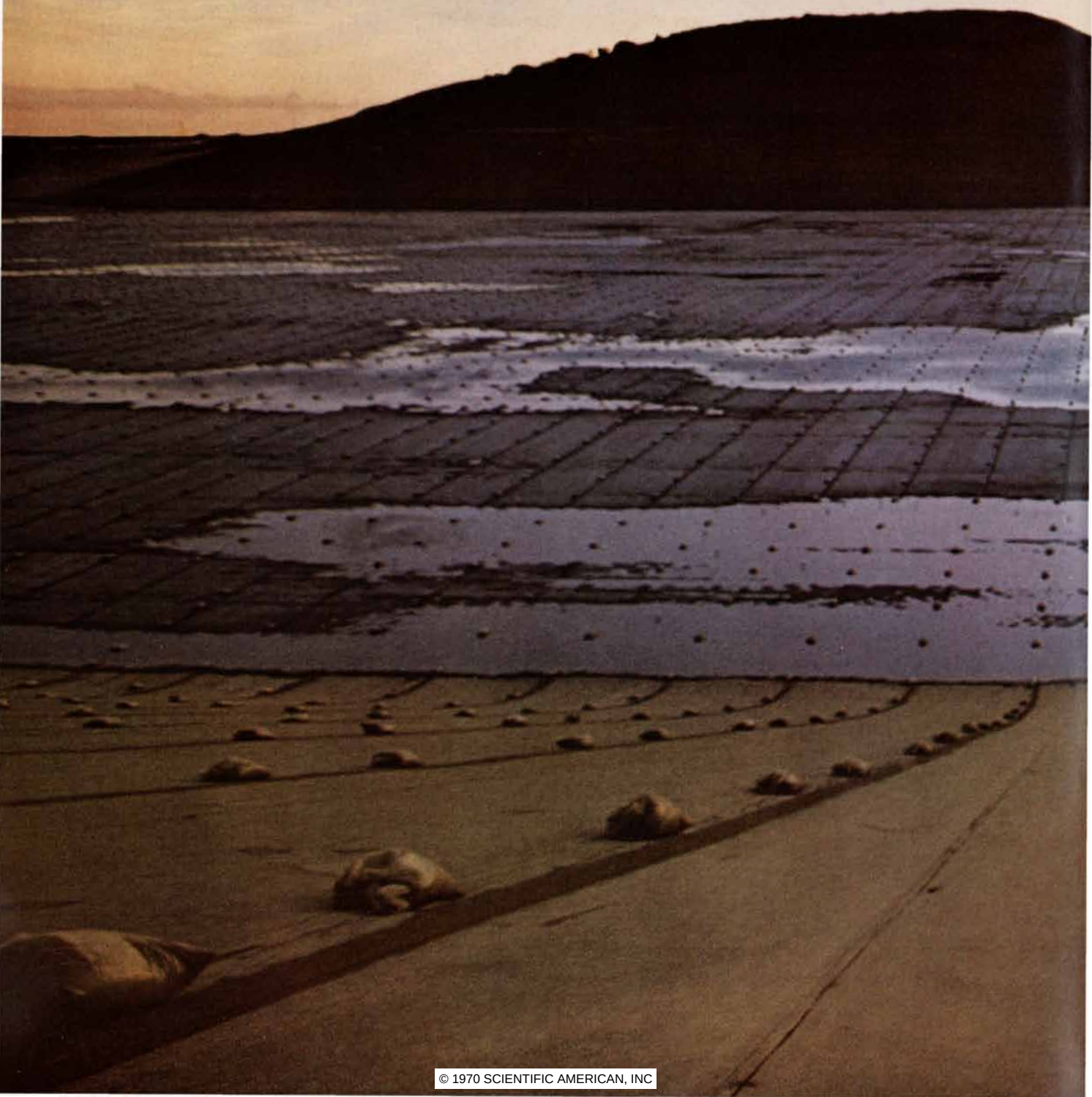
You are looking at more than five million square feet of Butyl rubber. Rubber made from oil by Enjay Chemical Company, a Jersey affiliate.

When Jersey's scientists invented Butyl rubber more than thirty years ago, they never dreamed their invention would be used to line a reservoir. But already several hundred reservoirs have been lined this way. This one happens to be the biggest in the world.

You'll find it on the Hawaiian island of Molokai, where they have a water problem. It rains in the mountains. But, down where the pineapples grow, it doesn't rain enough. So they have to pipe the rain from the mountains and store it. Hence this mighty hole.

To give you some idea of scale, the area covered by the nylon-reinforced Butyl could hold a hundred football fields.

Mr. David Wisdom, president of Wisdom Rubber Industries, the company that lined the



reservoir.

reservoir, said that Butyl rubber was chosen by the state of Hawaii for good reasons. Compared with concrete it is inexpensive. Roughly a tenth the cost. Yet, as a water barrier, there's nothing to beat it.

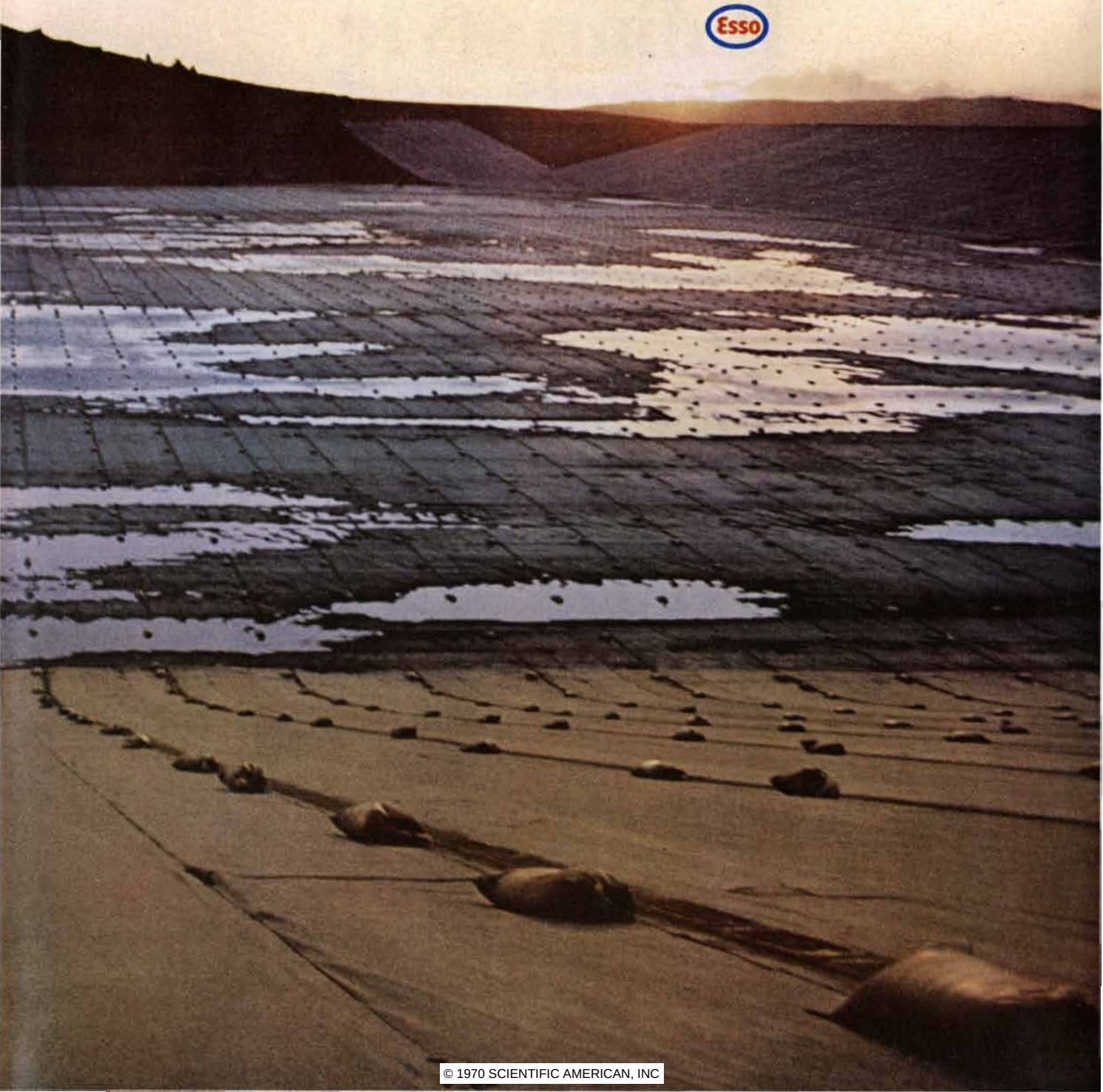
Installation is remarkably speedy. Seventy workers were trained in two weeks. They then lined the entire reservoir in seventy-four days. And Butyl is as tough as blazes. So tough that Mr. Wisdom has guaranteed his reservoir against deterioration for twenty years.

The effect of the reservoir on Molokai's economy will be considerable. It will irrigate some 18,000 acres of land, most of which will grow pineapples. But there is also a truck farming experiment in the area that may well turn Molokai into the breadbasket of the state.

Our scientists are proud that one of their inventions is being put to such good use.

Standard Oil Company (New Jersey)

Esso



Picture this.

Your four-door family sedan with a body designed by Pininfarina. With the same flair, the same sleek treatment of contours that mark the Ferrari and Lancia.

Result? The kind of car that gathers a curbside crowd wherever you park it. The unrivaled Italian sporty look you've so often stopped to admire yourself.

The interior, the "soul" of the car, is elegantly French. The fully reclining bucket seats, the thick wall-to-wall carpeting, the built-in adjustable headrests and foldaway armrests—each feature, each detail reflecting that centuries-old French love of luxury.

And the bright warmth of sunlight—how the French love that. A solid steel sliding sunroof lets you enjoy it, too!

All these opulent interior components are standard equipment.

Standard equipment, too, is every engineering advance that gives this car its "international muscle". Each of the four wheels has its own independent suspension, its own power disc brake. A newly designed engine gives you as much as 25 miles to the gallon; lets you cruise at 90 mph all day. The entire body is built of .9mm sheet steel—heavier, safer, longer-lasting than you've had before. It comes with Michelin radial tires. And four-speed synchromesh transmission. This is the car that's built to take any road, anywhere in the world.

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THE AUTHORS

JAMES C. ABEGGLEN ("The Economic Growth of Japan") is vice-president of the Boston Consulting Group, Inc., and is responsible for the firm's operations in London and Tokyo. "I have essentially pursued two careers," he says, "initially academic and subsequently business. There was of course overlapping between them, and a period of three years with the International Telephone and Telegraph Corporation in the Far East bridged the transition." Abegglen obtained both his bachelor's degree and his doctorate from the University of Chicago. He was instructor and research associate there from 1952 to 1955 and assistant professor at the Massachusetts Institute of Technology in 1956 and 1957. Since 1959 he has worked with consulting firms in Southeast Asia, Europe, Africa and Australia as well as Japan. Abegglen estimates that since 1955 he has spent about half of his time in Japan.

JAMES E. FALLER and E. JOSEPH WAMPLER ("The Lunar Laser Reflector") are respectively associate professor of physics at Wesleyan University and assistant astronomer at the Lick Observatory of the University of California. Faller was an undergraduate at Indiana University and received his master's degree and Ph.D. from Princeton University. He was at the Joint Institute for Laboratory Astrophysics until he went to Wesleyan in 1966. Faller writes that his research interests "center on experimental relativity and other fundamental experiments designed to look for possible invalidations of accepted physical laws in some extreme of magnitude." Wampler was graduated from the University of Virginia in 1958 and obtained his master's degree and Ph.D. from the University of Chicago. He has been at the Lick Observatory since 1963.

HALET ÇAMBEL and ROBERT J. BRAIDWOOD ("An Early Farming Village in Turkey") are at Istanbul University and the University of Chicago respectively. Miss Çambel, who was born in Berlin, was graduated from the American College for Girls in Istanbul in 1935, did graduate work at the Sorbonne in Paris and obtained her Ph.D. from Istanbul University in 1944. She has been professor of prehistory and head of the department of prehistory there since 1960. Braidwood is Oriental Institute professor of Old World prehistory and professor of anthropology at the University of Chicago, where he received his Ph.D. in 1942 after undergraduate work at the University of Michigan.

A. R. LURIA ("The Functional Organization of the Brain") is professor of psychology and head of the department of neuropsychology at the University of Moscow. He was graduated from the University of Kazan in 1921 and the First Moscow Medical School in 1936. His degrees include doctor of science (in psychology) and doctor of medicine. He is a member of the Academy of the Pedagogical Sciences of the U.S.S.R. and a foreign associate of the U.S. National Academy of Sciences and the American Academy of Arts and Sciences. A number of his books have been published in English as well as in Russian; among the more recent ones are *Human Brain and Psychological Processes, Higher Cortical Functions in Man* and *Traumatic Aphasia.*

CORNELIUS T. LEONDES ("Inertial Navigation for Aircraft") is professor of engineering at the University of California at Los Angeles. He received his bachelor's, master's and doctor's degrees from the University of Pennsylvania between 1949 and 1954, serving also on the university's research staff between 1950 and 1954. He went to U.C.L.A. in 1956 after a year with the International Business Machines Corporation. His main professional interests are computers, controls, aerospace systems and problems of large-scale systems. Apart from his work he likes to combine an enthusiasm for travel with a partiality for French gourmet cuisine; he says that last year he and his wife visited "every three-star restaurant in the Michelin guide."

T. G. TAYLOR ("How an Eggshell Is Made") is professor of applied nutrition at the University of Southampton. "My main scientific interest is in the physiology and biochemistry of nutrition," he writes, "although most of my research has been on various aspects of mineral metabolism in the fowl in relation to egg formation. I have also done a little work on vitamins and amino acids. My main interests outside the laboratory and the home are in gardening (particularly in the greenhouse, where I like to grow various tender flowering plants) and in breeding parakeets. I am particularly interested in the genetics of color in these

birds and in a queer disease from which they suffer known as French molt. My interest in growing and breeding things probably stems from my farming background; I lived on a farm for the first half of my life and all my close relatives are farmers." Taylor was graduated from the University of Cambridge in 1939 and obtained his Ph.D. from the University of Reading in 1955. He was a member of the faculty at Reading from 1947 to 1966, and from 1966 until he went to Southampton last fall he was head of the biochemistry department of the Agricultural Research Council's Poultry Research Centre in Edinburgh.

CHRISTOPHER WILLS ("Genetic Load") is assistant professor of biology at Wesleyan University. "I was born in London just before the war," he writes, "but avoided the blitz by going to Canada with my parents. I attended the University of British Columbia, then migrated south to the University of California at Berkeley, where I got married and obtained my Ph.D. in 1965. There I met and was inspired by many people with a long and passionate interest in the nature of genetic variability. I stayed for a year at Berkeley to learn some yeast genetics and apply it to this problem. We now live surrounded by five acres of trees, birds and assorted mammals just a few minutes from campus. We travel a good deal, and sometimes I can indulge in my passion for skin diving. My wife is certain I will be eaten by a shark one day."

KARL H. DREXHAGE ("Monomolecular Layers and Light") is with the research laboratories of the Eastman Kodak Company. Born and educated in Germany, he came to the U.S. in 1968 and spent a year at the research laboratory of the International Business Machines Corporation in San Jose, Calif., before beginning his present work. "At the age of 20," he writes, "I went to the University of Marburg, where I received the diploma in chemistry in 1960. For theoretical work on the light absorption of a compound named cyclotetracosadodecaene and experiments on energy transfer I was awarded a Ph.D. there in 1964." He notes that he finds "the whole of nature intriguing" and doubts "all ideologies." He adds: "My outside activities include soccer playing, jogging and now snow shoveling." Drexhage wishes to thank a number of associates in the work described in his article: M. Fleck, H. Forster, H. Kuhn, F. P. Shäfer, J. Sondermann and W. Sperling.

Honeywell Radiation Center
Lexington, Mass.

Pointing and Tracking by Eye Control

A new device which measures the direction of vision should make eye control of systems feasible in environments ranging from aviation to production.

For centuries man's ability to point tools, weapons and machinery has been limited by his manual dexterity. The hand is both slower and less accurate than the eye; in the stressful conditions of a space capsule, an air traffic control center, or a reconnaissance plane, this disparity increases significantly. In an attempt to free the operator's hands and to harness the remarkable tracking ability of the human visual apparatus, Honeywell is developing a new method of measuring eye direction.

Eye control is possible because of the concentration of the sensory capacity of the retina on an extremely small central portion, the fovea. For maximum resolution, the eye must be physically pointed at the target with an accuracy of .25 inch at 5 feet in order to center the object on the fovea. By measuring the direction of the operator's eye as he looks at a target, precise target bearing coordinates can be obtained without manual action.

One laboratory method of measuring eye direction uses electrodes implanted in the skin around the eye to measure the basic potential between the front and back of the eye. However, this eye direction measurement is made relative to the head and does not provide an absolute indication of the bearing of the target detail. A more accurate method was provided by optical tracking. In these systems, electro-optical equipment tracks the displacement of some visible portion of the eye (such as the iris-white boundary) and from this measurement, the direction of vision can be determined. Although optical tracking itself is not difficult, most systems in use require an absolutely immobile subject, since they extrapolate vision direction from measurements of the position of eye detail within the skull. The tracking device is usually clamped to the skull by a dental "bite plate" to limit head movements to a thousandth of an inch. Obviously these are prohibitively restrictive for pilots or astronauts; they are also unsatisfactory in many psychological experiments because of the unnatural restraint of head movement.

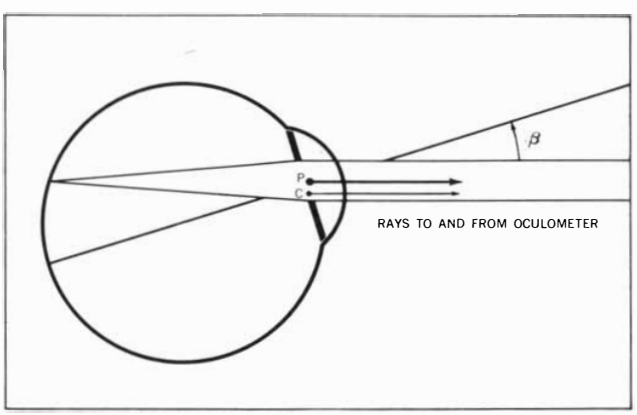
Believing that an eye control system which would not confine the subject could make a whole new field of automation possible, Honeywell scientists began work over five years ago on a device to track and record eye movements. The instrument developed, the Oculometer, shines a beam of infrared radiation on the eye, and from the reflections off the retina and cornea, an electro-optic sensor records the actual movements of the eye.

The Oculometer works in the following manner: If an infrared beam is directed on the eye, a reflection of that light off the cornea is produced approximately in the plane of the pupil. The direction of the illuminating radiation, which is along the optical axis of the Oculometer, is the reference direction. The direction of the eye relative to this reference is proportional to the displacement of the corneal reflection from the center of the pupil. Because the Oculometer determines the location of the reflection *within* the pupil itself, head movements do not affect the measurement.

The Oculometer images the pupil and corneal reflection on an electro-optical sensor. Using a raster scan, the Oculometer quickly locates the pupil and tracks its perimeter. It then scans the corneal reflection. The amount of additional electrical input needed to move from the pupillary center to the corneal scan gives the coordinates of the corneal reflection. Mathematically the displacement of the corneal reflection from the center is K sin β, where β is the angle between the geometric axis of the eye and the direction of the illuminating radiation. K is a dimensional constant of the eye. After completing the corneal scan, the image dissector repeats the pupillary scan, continually changing its diameter with changes in the pupil's diameter. The period of the repetitive scan is 2ms, fast enough to follow the fastest eye motion.

If the Oculometer output is connected to servo driven equipment, it could be used for many control applications normally done by hand. For example, the student's response in a teaching machine could be determined instantly by analyzing his eye movements.

The Oculometer could be used as part of an automated vision tester system measuring not only central but peripheral vision, speed and acceleration of the eye, and astigmatism and accommodation. Data on the changing diameters of the pupillary scan yield valuable information for both physiologists and psychologists, since pupil size may be correlated to the subject's interest in what he is looking at.



Apparent Displacement of Corneal Reflection C From Pupil Center P is Proportional to Eye Direction β

If you are working in the area of optical tracking of the eye, and want to know more about Honeywell's investigations, please contact John Merchant, Honeywell Radiation Center, 2 Forbes Rd., Lexington, Mass. 02173. If you are interested in applications for the Honeywell Oculometer, contact Peter Albertini, at this same address. If you have an advanced degree and are interested in a career in research at Honeywell, contact Dr. John Dempsey, Vice President Science and Engineering, Honeywell Inc., 2701 Fourth Ave. So., Minneapolis, Minn. 55408.

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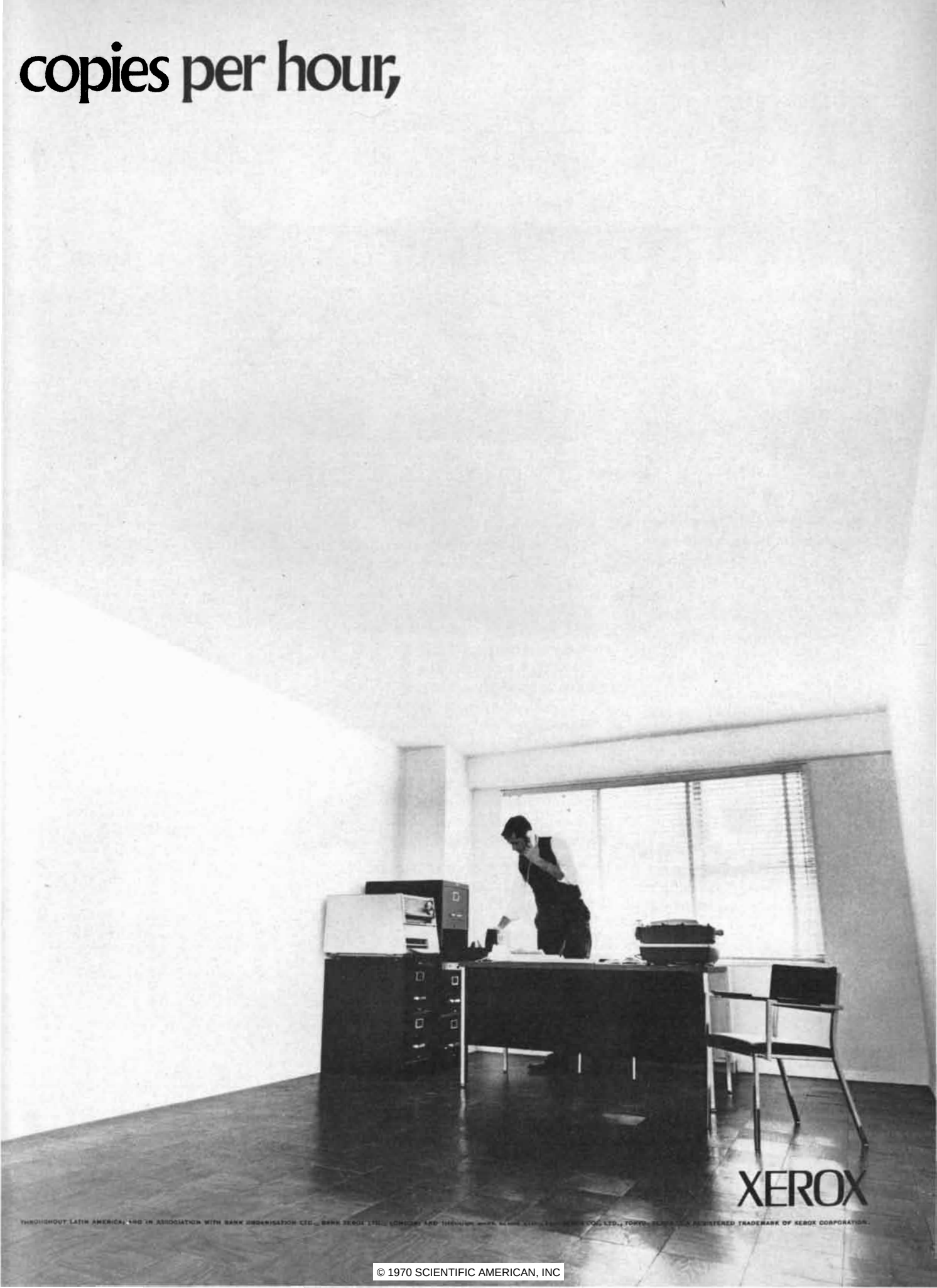
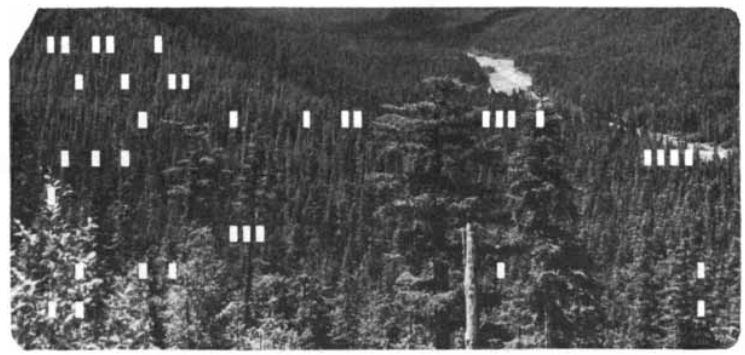




How to program a forest.

Washington is known as "The Evergreen State." And with good reason. More than half the State consists of great stands of Douglas fir, Western cedar, pine and spruce. Washington leads the nation in the production of wood pulp, is second in plywood and third in lumber. Today, with the use of modern reforestation techniques and the aid of the computer, it seems clear that Washington will *always* be known as The Evergreen State.

Despite the immense size and economic importance of Washington's diversified timber industry, it has not enjoyed a serene history. In the 1930s, the supply of privately-owned trees in the State was running out. At the urging of Washington's civic groups and lumber interests, congressional action brought into being the Sustained Yield Act of 1944—now recognized as a landmark in conservation. It also opened the door to a unique experiment in forestry.

In 1946, the Forest Service signed a contract with Simpson Timber Company, a privately owned firm in the State. This contract, a pace-setting example of the new approach to Washington's forests, called for combined management, sustained-yield harvesting of both Simpson-owned land and certain government-owned land. In all, some 350,000 acres.

Under the new program, Simpson began applying scientific forestry practices and modernizing its manufacturing plants to get more and more wood from each tree. Growing, harvesting and re-growing continuous crops of timber became the rule of the day. As the only natural resource capable of renewing itself, timber can do pretty well on its own. But with man's help, the renewal process has been greatly improved.

Under Simpson's program, yearly forest inventories are taken. A vast amount of data on species and subclasses, rapid growth or deficit growth patterns, presence of disease and so forth—is recorded and fed into computers.

From these computerized inventories, it is possible to gauge the effects of such things as tree grafts, fertilization, aerial seeding, thinning and many other factors. Desirable adjustments in the reforestation program can then be made. In effect, to plan tomorrow's forest crop from today's EDP findings.

Appropriately, the inventory data is all neatly recorded on computer cards produced from paper that was once part of a timber harvest itself. And likely as not, analysis is carried out by a new breed of forester—college trained and technically oriented. A far cry from the days of the snoose-stained logger who "cruised" through the forest estimating timber volume by guess and by gosh.

The State of Washington is a fertile field for exciting breakthroughs in industry. In forestry, aerospace, oceanography, agriculture, bio-engineering, nuclear energy and many other areas, the smart money is betting on the State of Washington.

Daniel J. Evans
Governor

STATE OF WASHINGTON

For business location information, write: Daniel B. Ward, Director, Department of Commerce and Economic Development, Olympia, Washington 98501

Established 1845 SCIENTIFIC AMERICAN March 1970 Volume 222 Number 3

The Economic Growth of Japan

The Japanese economy is now the third largest, and its growth rate approaches 15 percent per year. If present trends continue, Japan will be the world's most affluent nation by the end of the century

by James C. Abegglen

The remarkable growth of the Japanese economy is a major fact of the 20th century. Japan's economic advance has taken place over a period of two decades and has therefore not had the dramatic impact of events such as the Russian or the Chinese revolution, and yet its consequences may be as far-reaching. The Japanese economy is now the third-largest in the world, after those of the U.S. and the U.S.S.R. Its growth rate is without precedent or parallel: 9 percent per year (in real terms) in the 1950's, more than 10 percent in the 1960's and 13 or 14 percent in the past few years. Japan is the nation most likely to equal or surpass the U.S. in standard of living and industrial productivity in this century; the 21st century may be Japan's. It is important to examine what is happening in Japan and why it is happening.

First it is necessary to clear away some misconceptions. Japan's achievement raises questions about why other nations have not done as well, and it is sometimes written off as being temporary or explained away with myths. The fact is that the rate of economic growth has increased quite steadily throughout Japan's industrialization, since late in the 19th century. There is nothing temporary about an economy half again as large as Britain's, growing substantially faster than any other and showing few signs of faltering.

One persistent myth is that the growth is based primarily on "cheap labor." It is not. Many parts of Asia have lower labor costs (as well as more raw materials) and have not achieved significant economic development. To be sure, Japan's labor rates are generally lower than those in many Western countries, but in sophisticated sectors such as steel and machinery, which are growing the most rapidly and are the most competitive worldwide, direct labor rates are at European levels.

Another myth has it that Japan's growth is the result of exports. Actually Japan exports less of its production than most industrialized countries: 10 to 12 percent of its total output, about half as much as West Germany and Britain. Indeed, the success of Japanese companies in the export market grows out of high domestic demand. In manufactures from umbrella frames to motorcycles the initial growth has taken place to supply a rapidly expanding domestic market, with the export thrust following three to five years later.

A third myth is the long-standing view of the Japanese as copiers unable to conceive original products or technology. Every country moving toward industrialization begins by copying; the process by definition involves the adoption of existing technologies, and Japan's reputation for copying was earned largely during its industrialization in the 1930's. Things are different today. Japan now invests as much of its national product in research and development as West Germany or France does, and more than Italy does. The investment apparently buys more than it does in most countries: the proportion of personnel in research and development is higher than it is in any other country except the U.S. Since government investment in this area is lower than it is in Europe or the U.S., investment by private companies is relatively high, so that there is emphasis on nonmilitary products and specifically on development. The results are beginning to show in terms of licenses from Japanese firms to foreign ones and in new Japanese products ranging from synthetic fibers and microwave devices to supertankers.

Japan's success, then, is not a temporary phenomenon and is not the result of cheap labor or exports or copying. It can be attributed to the efficient functioning of a very special system, all of whose parts interact to stimulate growth. It is important to keep in mind that Japan is the only non-Western country that has become industrialized. It has not become Western in the process, and Japan's business system and practices are quite different from those of any Western economy. The differences have tended to obscure understanding in the West of the nearly ideal conditions Japan has created for economic growth. There are three key elements that determine the Japanese system: unusual methods of financing growth, a unique relation of government and business and special ways of using labor resources.

The first requirement for growth is

MASS PRODUCTION of products with a high labor content and increasingly advanced technology has characterized Japanese industry. Television sets are being wired on this production line at the Ibaragi plant of the Matsushita Electric Industrial Company.

LIFETIME EMPLOYMENT POLICY in Japanese industry tends to establish a close tie between the worker and his employer. At Matsushita Electric plants workers begin the day by singing the company song. Every January thousands of the company's executives, foremen, senior workers and union representatives attend a meeting such as this one, where policies for the year are announced.

capital. A large part of the capital requirement of Japanese companies is supplied by bank loans—a practice that would be extremely dangerous and indeed unthinkable in most countries. In Japan it works, and it is a source of much strength. A massive debt goes into the capital structure of Japanese corporations, nearly 85 percent of whose capital is obtained by this means. The "net worth ratio" of Japanese corporations is therefore extremely low compared with European and U.S. companies in all industries. For example, the leading domestically owned petroleum company, Idemitsu, has a debt-to-equity ratio of about 11 to one. Debt ratios on this order mean that Japanese companies need not finance their growth out of retained earnings. Once they earn enough to cover the interest on their debt there is little financial constraint on growth.

How can Japanese business assume the level of risk associated with such heavy debt? The main reason is that the government stands behind the debt position of major Japanese companies. In so doing it not only makes possible the financing of growth through debt; it also ensures for itself a central role in determining the pace and direction of that growth.

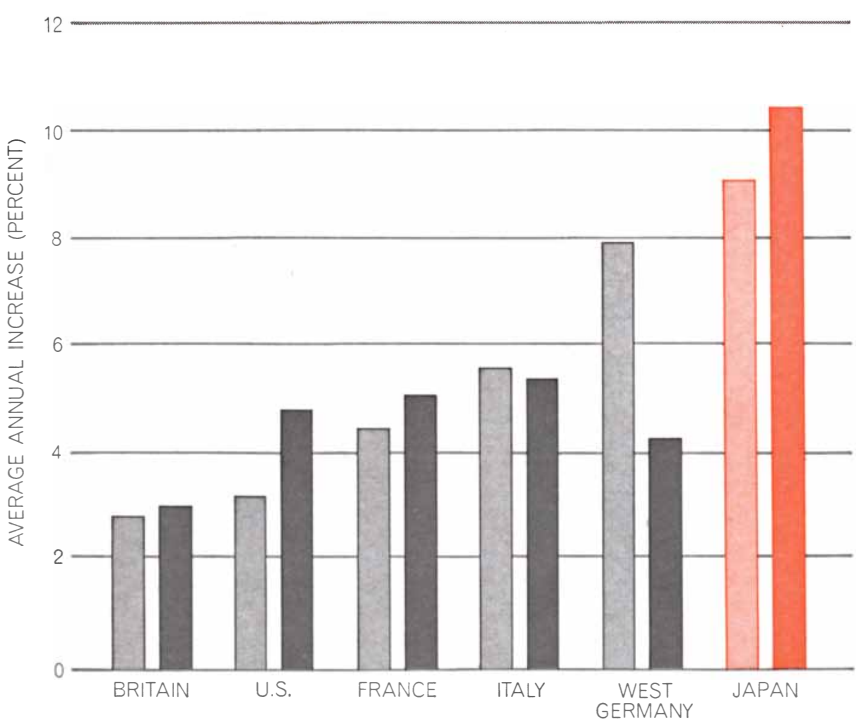
The commercial banks are aggressive lenders, with almost 100 percent of their deposits out on loan. This makes them in turn extremely dependent for funds on the central bank (the Bank of Japan). In addition to bringing to bear the usual monetary tools (discount rates, open-market operations and reserve requirements) the Bank of Japan determines the availability of funds for commercial-bank loans by imposing penalty rates on borrowings from it by individual banks in excess of certain limits. The central bank in effect stands as guarantor to the commercial banks and thus ultimately to the borrowing corporations. By channeling funds through the commercial banks to specific companies on specific conditions, the Bank of Japan can save companies that are in trouble or can put them out of business. No major company's loan is ever likely to be called unless the central bank wants it called.

This system of debt guarantee works to the advantage of the larger companies, which tend to be freer from financial risk. Two aspects of Japanese corporate structure create this tendency. One is the existence of the *zaibatsu*, industrial groups composed usually of a variety of large, noncompeting companies under the fiscal management of a major financial institution. A *zaibatsu* is similar to a U.S. conglomerate, which is also a group of unrelated companies under sophisticated financial management. Since the earnings of member companies in different industries are not likely to fluctuate together, grouping makes the companies less risky and gives them a higher debt capacity.

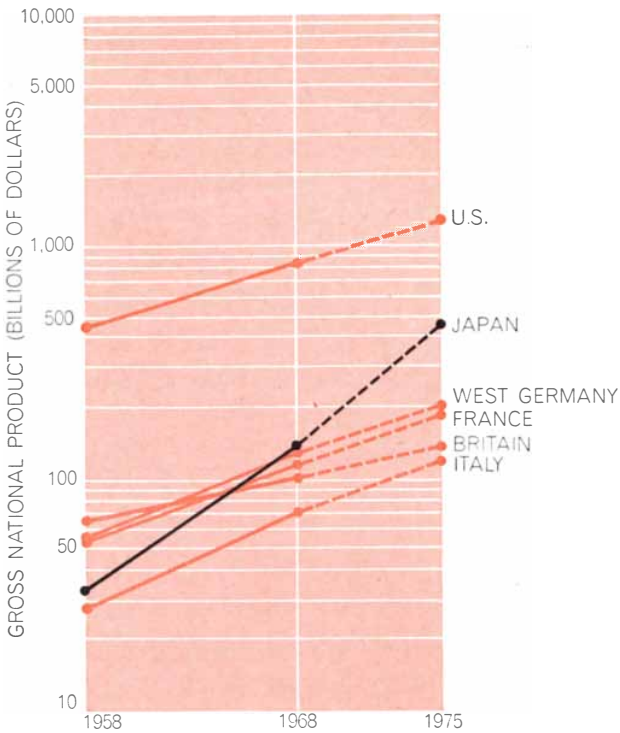
The other peculiar aspect of Japanese corporate structure that makes big companies financially more stable is their use of small suppliers as a buffer against business fluctuations. For example, they subcontract much of their production, buying the entire output of small companies, in order to reduce fixed costs and take advantage of the lower labor costs of small manufacturers. When the economy goes down, the big corporation simply reduces its purchases or lowers its purchasing prices and the small concerns absorb most of the effects of the recession. Financial institutions exaggerate the discrimination against small companies in their loan policies. It also seems clear that the government utilizes this discriminatory structure as a means of weeding out small and inefficient firms.

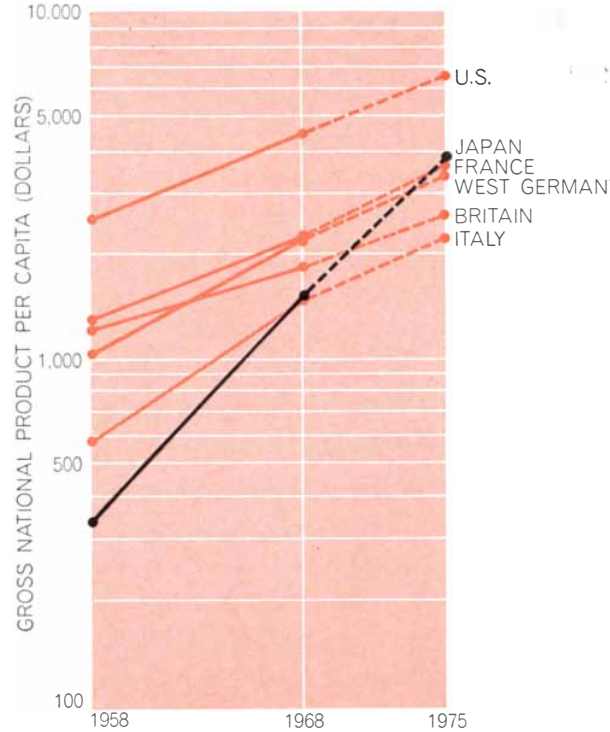
The relations between the Japanese government and business are difficult to describe in Western terms. The relations are close. Government and business work in partnership toward goals that are for the most part mutually agreed on; it is often difficult to say where government action ends and business action begins. As *The Economist* put it recently, "the ultimate responsibility for industrial planning, for deciding in which new directions Japan's burgeoning industrial effort should try to go, and for fostering and protecting business as it moves in those directions, lies with the government." Yet the relation is not that of a socialist economy, with the state in control. Nor is it analogous to the U.S. system late in the 19th century, with government essentially an instrument of big business. Perhaps "Japan, Inc.," the label a Japanese businessman recently applied to his country's economy, best indicates how the system functions. In this analogy the Japanese government corresponds to corporate headquarters, responsible for planning and coordination, long-term policy formation and major investment decisions. The country's large corporations are thus analogous to corporate divisions: they have a good deal of autonomy within an overall policy framework, are free to compete with one another and are charged with operating responsibility.

Direct intervention by the government in business activities is not extensive. It is probably less than in the U.S., if one



RAPID GROWTH of Japanese output has continued for two decades. Here the annual real growth (increase in constant-dollar gross national product, discounting the effects of inflation) between 1950 and 1960 (*light bars*) and between 1960 and 1967 (*dark bars*) is given.





JAPANESE OUTPUT (*left*) has passed the outputs of the western European countries and is expected to increase at an even greater rate between now and 1975. The per capita product (*right*), which is a rough indication of standard of living, is changing more rapidly still as the birthrate is brought under control. Japan expects to be first in per capita income by 1988, ahead of the U.S.

takes into account the U.S. postal service, such agencies as the Atomic Energy Commission and the Tennessee Valley Authority and the enormous U.S. military establishment. Through public corporations the Japanese government does operate most railroads, telecommunications, postal services and the cigarette and salt monopolies, and it controls the major airline. What is significant, however, is not this direct intervention but a complex apparatus involving government ministries and institutions such as the Bank of Japan on the one hand and business associations on the other. Through these institutions the government bureaucracy and the business leadership are able to interact closely and continuously.

For the government, long-range plans are put forward by the Economic Planning Agency. These plans carry no legal sanctions for their enforcement; they are advisory, intended to indicate in what directions the economy can most efficiently move. Actual policies are worked out in the ministries, notably the Ministry of International Trade and Industry and the Ministry of Finance, and specifically through the work of some 300 consultative committees of businessmen and officials. Quite apart from formal committee meetings, there is constant

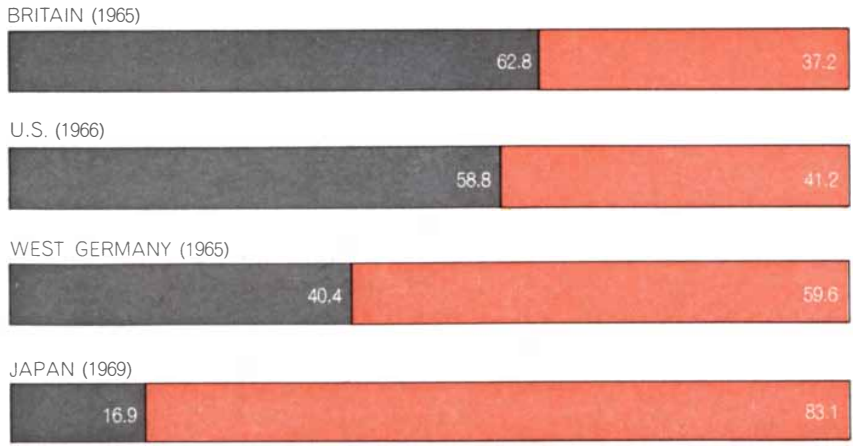
INVESTMENT in new capital construction (including housing) and equipment accounts for a significant portion of Japan's output (*left*). This high level of investment is possible, in turn, because of a high rate of saving (*middle*) and low defense spending (*right*).

interaction between business and government personnel, giving industry representatives an opportunity to learn how officials react to their investment proposals and plans and also to negotiate informally for assistance and favors.

Virtually all sectors of Japanese business are organized into trade associations that represent an industry before government agencies and in the community. The associations, in turn, make up a federation of economic organizations, Keidanren, which speaks for industry as a whole in major policy matters and in relations with counterpart groups in other countries. Keidanren cannot be compared to the Chamber of Commerce or National Association of Manufacturers; its prestige and real power are far greater. Similar business representation is accomplished with regard to trade union matters by a federation of employers' associations, Nikkeiren, which speaks for management in national policy decisions on labor and in confrontations with nationally organized trade unions.

Neither Japanese government nor Japanese business is monolithic. The ministries vary in their approaches, and different sectors of industry have different needs and objectives. Policies tend to represent compromises among various special interests. In general any substantial shift in product, investment, pricing or distribution policy of a major company is at least informally reviewed by one or more government officials. Similarly, government decisions on new laws or regulations affecting business are preceded by detailed discussions with the businessmen likely to be affected. As implied by the phrase "Japan, Inc.," there is a basic assumption that the objectives of government and business are the same: the maintenance of Japan's economic health and the promotion of the nation's interests. Whereas a real corporation's head office can ultimately issue orders to its divisions, however, the Japanese government does not. To a remarkable extent the entire system operates by consensus.

There are several peculiarly Japanese reasons why this is so. One is the long history of government leadership in business, beginning with the Meiji era's drive toward industrialization and continuing with the drive toward military supremacy in the 1930's. Second, there is the strong sense of national identity that pervades Japan, derived in part from island geography, the long exclusion of foreigners, the single language, the homogeneous culture and the sense of ethnic identity. Finally, there is the common background in education and training of leaders in government and in the large corporations, most of whom go to the same universities and have similar early career experiences.



GROWTH of Japanese companies is financed largely by borrowing. Their capital structure therefore includes more debt (*colored area of bars*) and less equity (*gray*) than in the West.

The upshot of all these factors—corporate structure, business practices and historical and sociological influences—is a national economy that behaves as one huge corporation. Moreover, "Japan, Inc." is a special kind of corporation: a conglomerate, in U.S. terms. A conglomerate can channel cash flows from low-growth to high-growth areas and apply the debt capacity of safe, mature businesses to capitalize rapidly growing but unstable ventures. It can move into a dynamic new industry and bring to it financial power that no existing competitor can match. It can increase capacity quickly. The result is that the conglomerate is in a position to dominate a new industry by setting prices so low that existing competitors cannot finance adequate growth. Its costs are so low, compared with the competition's, that it can sell at the going price and earn large profits. In all these senses "Japan, Inc." is indeed a conglomerate, a *zaibatsu* of *zaibatsu*. The Bank of Japan is the financial center, and with the bank's help each rapidly growing industry can incur more debt than it could on its own; the borrowing power of the entire portfolio—Japan itself—is available to each industry. Hence the economy as a whole funds new enterprises, holds prices down, competes successfully in the world market and earns large profits.

The employment pattern in a large Japanese concern is strikingly different from the Western pattern. The Japanese factory worker, technician, clerk or manager is employed for life, or at least for as long as the company survives. His salary is set not by his job or his productivity but almost entirely by his age, education and length of service. In effect he is a member of the corporate family throughout his career; he and the company have the mutual obligations, covenants and privileges that such a relationship implies. To a Western businessman, accustomed to depending on immediate and direct compensation to provide motivation, a salary system based on seniority may seem stultifying. The inability to hire and fire in order to vary the work force with fluctuations in the business cycle or to get rid of inefficient workers appears highly uneconomic. Yet these labor practices, which appear so restrictive, have great strength in the context of the Japanese culture and particularly under conditions of rapid growth. The employment system of Japan is, in fact, a key element in the total system that accounts for the Japanese success.

Permanence of employment and the seniority-based wage conspire to divert labor resources into sectors that are growing most rapidly and to increase pressure on the less efficient and less dynamic sectors. Since pay is related to age, a fast-growing firm or industry, continuing to recruit directly out of schools and colleges, maintains low labor costs. The skill level of its employees tends to remain high. Moreover, since it is difficult to recruit from outside a company, growth causes management responsibility to be delegated to younger and presumably more aggressive people. The slow-growing firm, in contrast, hires few young graduates. Its labor costs rise with age, its employees' technological com-

SUPERTANKERS are among the products of Japanese industry that are large in scale as well as advanced in technology. The *Idemitsu Maru*, capacity 210,000 tons, was the world's largest when it was built in 1966, and since then larger ships have been launched.

petence decreases and its management becomes older and presumably less aggressive. At the same time the lifelong employment policy provides a strong incentive for the able and ambitious young person to seek out growth industries and individual growth companies when he makes his crucial first career choice.

The employment system also has important effects on job performance and labor unrest. The worker identifies himself closely with his company and its interests. Although the industrial labor force is about as unionized as it is in the West, and although its leadership is aggressive and often left-wing, strikes tend to be token ones, labor unrest is at a low level and production is not often disrupted by work stoppages. (The reciprocal of this effect is that management, having such a close relationship with its employees, accepts an obligation to provide housing and other benefits.)

A surprising effect of the Japanese employment policy is a high degree of flexibility in the utilization of labor. Although there is little mobility among companies, there is greater internal mobility within a Japanese business organization or factory than there is in the West. Since status and salary do not depend on job assignment, union contracts do not define jobs or procedures and personnel can be assigned as desired. Rigid work rules and "featherbedding" are almost unknown. This goes far to explain the rapidity with which a Japanese company can step up investment per worker, adopting the latest production methods and laborsaving devices.

The employment system leads indirectly to Japan's "full capacity" policy because labor must be viewed as a fixed cost. The same is true of the carrying charges associated with heavy debt. The only remaining variable of any consequence is the cost of raw materials, and so there is extreme pressure on a Japanese company to operate at capacity as long as revenues can cover raw-material costs. This pressure can make export prices that are quite low seem attractive to the producer. The tendency to operate at capacity is reinforced by the experience and expectation of growth; in an expanding economy it is of overriding importance that a company maintain its share of the market, even if that means a temporary drop in current profits. Japanese companies therefore typically add capacity in anticipation of an expansion in their market. The high break-even point set by fixed labor costs and debt costs means that new facilities are operated at capacity and products are moved into world markets. This helps to explain the tendency of Japanese exports to increase sharply and quickly when domestic demand slackens.

The factors I have cited as being conducive to growth—debt financing, the government-business partnership and the employment system—can function favorably only in a stable economy. The Japanese government does much to keep the economy stable. Some of the policies it pursues are not explicitly stated, but they can be inferred from the government's application of direct and indirect controls. The government apparently seeks to do four things: to provide a flow of capital adequate for maximum growth but not so large as to permit overactivity leading to inflation and shortages of goods; to stabilize the rate at which labor is displaced from older industries at a level that can be fully absorbed by the new high-growth,

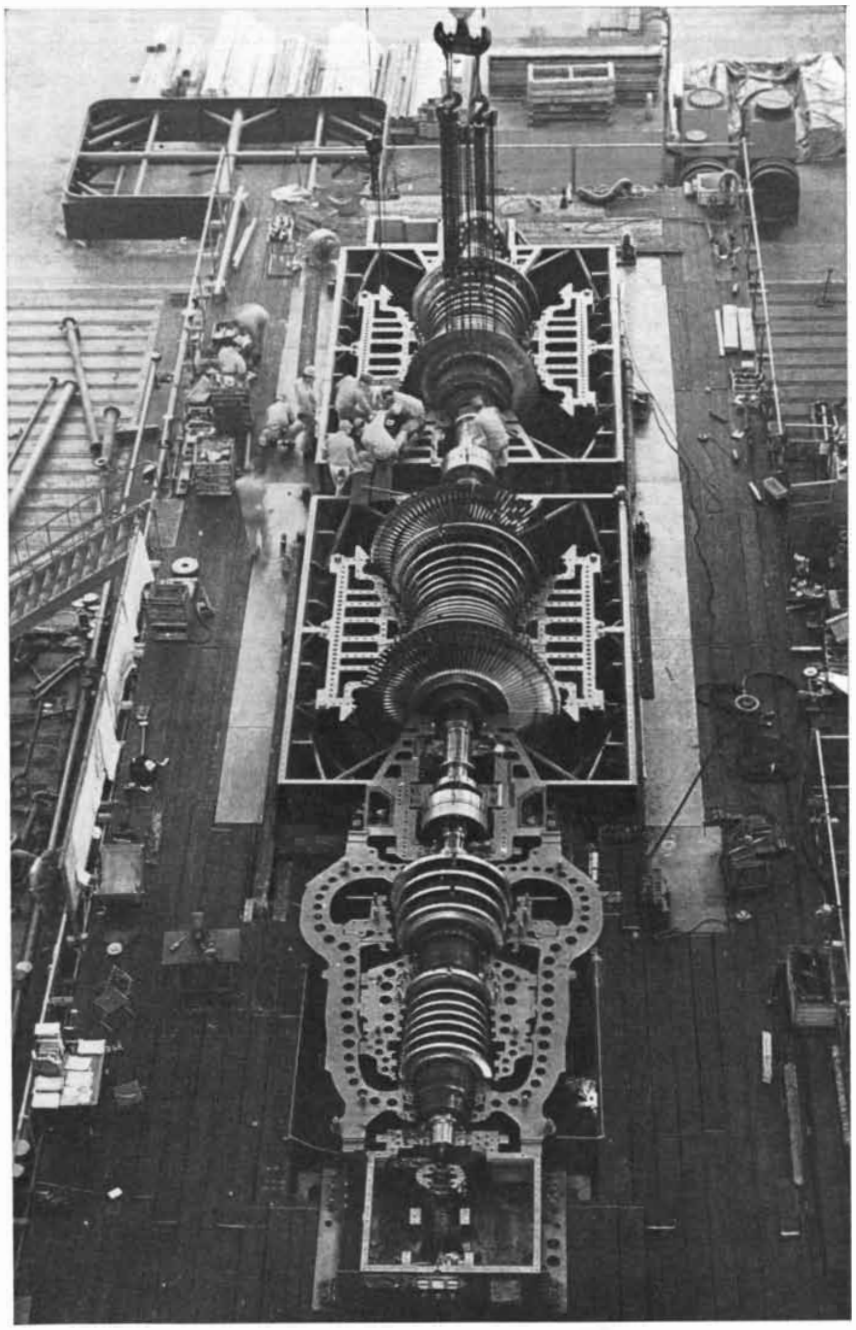
high-capital industries; to concentrate investment in the industries in which Japan can best compete worldwide (which once meant products with high labor content but is now coming to mean products dependent on advanced technology and heavy capital investment); to protect domestic industry until it has the technological maturity and size to be self-sufficient.

How long can Japan keep it up? Much of the economy's growth is based on the rapid formation and investment of capital. That is made possible, in turn, by deferring consumption—by saving. The future growth of Japan depends primarily on how much capital can be created by deferring consumption and on how great a rate of return can be generated on that capital. The Japanese consumer is now deferring about a third of his potential consumption, and consumption can increase annually along with the growth rate without reducing the rate of new capital formation. Maintaining the rate of capital formation will be a continuing problem of public policy, however. It is essentially a political issue, since saving can be forced by taxation or can be voluntary.

A return on investment that is high enough to induce voluntary saving can be generated only by an efficient capital market mechanism and by good investment opportunities. In Japan the banking-government-industry mechanism is effective and should become even more so, and favorable opportunities to invest are implicit in the growth rate. The current rate of investment in new capital of some 34 percent of the gross national product is producing Japan's current 10 to 14 percent growth rate, indicating a broad trend of roughly a 33 percent return on investment. Such a high return depends on transfers of manpower from low-capital to high-capital activities. Such transfers become increasingly difficult as an economy reaches a technological plateau. To maintain a high growth rate, therefore, new investment opportunities will have to be created by new technology.

There are no fundamental reasons why Japan's unequaled growth rate cannot remain very high for some time. Yet some formidable challenges will have to be met. Business will have to learn how to manage ever larger and more diversified enterprises. Increased funds for research and development will have to be made available at the risk of short-term reductions in profit. The government will have difficulty making wise decisions on the allocation of capital, particularly if the economy is disturbed by inflation, depression, labor stoppages, defense demands or balance-of-payment problems. Efforts to maintain the rate of personal savings may be frustrated by a demand on the part of labor for higher direct compensation or by the still largely unmet needs of the low-income population. Finally, increased adult education and retraining will be required to enable displaced workers to take jobs in new industries.

None of these challenges is insurmountable. Japan's economic system would appear to be the most efficient in the world for generating high productivity. Neither state socialism with its bureaucratic rigidity nor Western capitalism with its own rigidities in labor utilization and capital formation seems as well suited to the needs of a high-growth, high-output economy. This being the case, Japan's economy should continue to grow, and the country to change. Within a generation it may well be the world's most affluent society.



HEAVY ELECTRIC MACHINERY is produced in Japan. A compound steam turbine for generating power is assembled at the turbine works of Tokyo Shibaura Electric Company.

THE LUNAR LASER REFLECTOR

A reflector array placed on the moon by its first visitors returns pulses of light emitted by lasers on the earth. The round-trip travel time yields the distance to the moon with an accuracy of six inches

by James E. Faller and E. Joseph Wampler

In July of last year the astronauts of *Apollo 11* placed on the surface of the moon an array of prismlike reflectors that has made it possible to measure the distance between the earth and the moon with an accuracy approaching six inches. The distance is determined by aiming the intense light beam from a laser at the reflecting array and measuring the time required for a brief pulse of light to travel to the moon and back.

The important quantity, however, is not the absolute distance between the earth and the moon at some particular instant but the variations in distance measured with six-inch precision or better over a period of months and years. Such variations can be studied to answer a number of important scientific questions. These include the determination of how the mass inside the moon is distributed, the rate at which the continents on the earth are drifting toward (or away from) one another and changes in the location of the earth's North Pole (which shifts in response to unknown forces). A more fundamental question than any of these, which may be answered by long-term observations of the earth-moon distance, is whether the gravitational constant is indeed constant or whether it may slowly be weakening with the passage of time.

For more than 2,000 years the moon has been a testing ground for man's theories of the universe. In the third century B.C. Aristarchus of Samos inferred from lunar eclipses that the distance to the moon is roughly 10 times the diameter of the earth. He based his estimate on the observation that the diameter of the earth's shadow on the moon during an eclipse is about two and a half times the diameter of the moon. If the sun were a point source of light at infinity, the earth's shadow would be exactly as wide as the earth itself. In that case the diameter of the moon would be 40 percent of the diameter of the earth. Aristarchus realized, however, that cone-shaped shadows cast by the sun taper down with an angle of about half a degree. Allowing for this, and estimating (incorrectly) the apparent diameter of the moon's disk, he arrived at his value for the distance.

Aristarchus' estimate would have been much better if he had not badly misjudged the apparent size of the moon. His estimate was two degrees of arc, or four times the actual value, with the result that he thought the moon was much closer than it actually is. A century later Hipparchus used a more accurate value for the apparent diameter and computed the distance of the moon as being 59 earth radii. (The true mean distance is 60.3 earth radii, or some 239,000 miles.) Hipparchus also discovered the eccentricity of the moon's orbit, the inclination of the moon's orbit to the plane of the earth's orbit, the motion of the nodes (the points where the moon's orbit intersects the plane of the earth's orbit) and the motion of the apsides (the moon's minimum and maximum distance from the earth).

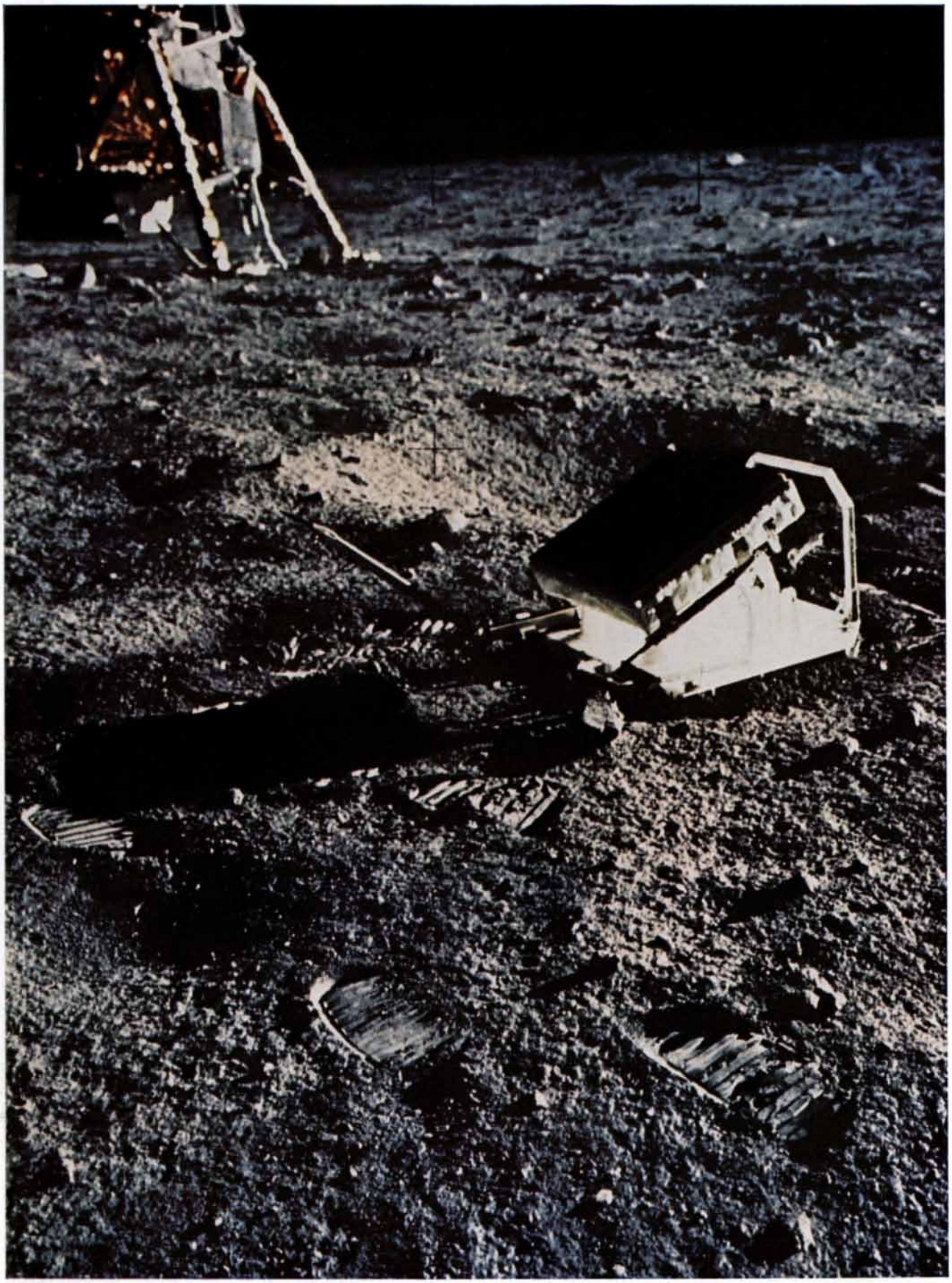
Except for minor improvements in some of the measurements there was no fundamental advance in knowledge of the lunar motion until the revolution that swept astronomy in the 16th and 17th centuries. The climactic achievement of this period was Newton's theory of gravitation, in which the moon figured prominently. "[I] compared," Newton wrote, "the force requisite to keep the moon in her orb with the force of gravity at the surface of the earth, and found them answer pretty nearly."

In the next two and a half centuries astronomers used measurements of optical parallax and simultaneous observations of stellar occultations to reduce the uncertainty in the earth-moon distance to ± 2 miles. Since 1957 conventional radar techniques have also been used to study the moon. In addition to determining the moon's distance to $\pm .7$ mile, radar studies have provided information concerning the small-scale roughness of the moon's surface and even some electrical properties of the surface material.

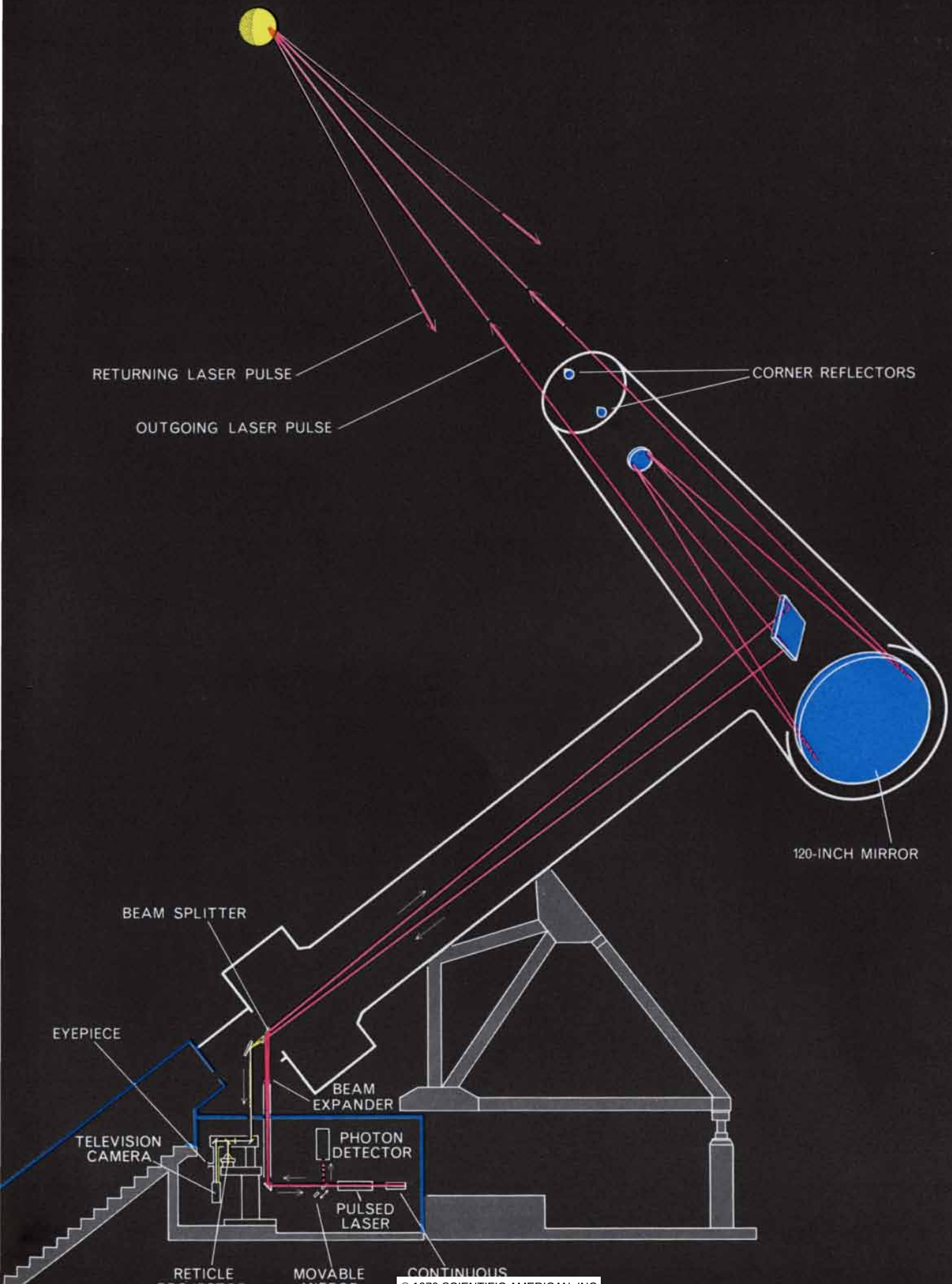
More recently light from ruby lasers has been directed at the moon and the weak signal reflected back has been detected. The first detection of ruby laser

Editor's Note

The Lunar Laser Ranging Experiment is the responsibility of the LURE group, which consists of Carroll O. Alley, Jr., University of Maryland; Peter L. Bender, National Bureau of Standards; D. G. Currie, University of Maryland; R. H. Dicke, Princeton University; James E. Faller, Wesleyan University; Henry H. Plotkin, Goddard Space Flight Center; David T. Wilkinson, Princeton University; J. D. Mulholland, Jet Propulsion Laboratory; William M. Kaula, University of California at Los Angeles, and Gordon J. F. MacDonald, University of California at Santa Barbara. The success of the experiment owes much to a number of other workers at these member institutions as well as to the scientific staffs of both the Lick and the McDonald observatories.



RETROREFLECTOR ARRAY was placed on the lunar surface last July 20 by Neil A. Armstrong and Edwin E. Aldrin, Jr., the first men to walk on the moon. The array contains 100 corner reflectors, prismlike devices that will reflect a beam of light back to its source. The individual reflector sockets are not visible because the face of the array is in deep shadow. The device is tilted so that its face is perpendicular to light rays originating from the earth. *Eagle*, the landing module of *Apollo 11*, can be seen in the background.



light reflected from the lunar surface was accomplished eight years ago by a group at the Massachusetts Institute of Technology. Laser pulses of one-millisecond duration were transmitted through a 12-inch telescope. With a 48-inch telescope as the receiver, many shots were required to define a detectable return signal. A similar reflection experiment was carried out in 1964 by Russian astronomers, who used a 104-inch telescope for both transmitting and receiving.

The first experiment with enough accuracy to be of scientific value was conducted by the same Russian group in the fall of 1965, when they used the 104-inch telescope to transmit and detect pulses of 50-nanosecond duration produced by a "Q-switched" (short-pulse) ruby laser. The experiment established the earth-moon distance to an accuracy of about 600 feet. A fundamental limitation on the precision that can be obtained by bouncing a light beam directly off the lunar surface arises from the curvature and the irregularity of the surface, which spread out the arrival time of the returning signal.

Eight months ago, some 2,000 years after the first measurement, the method of determining the earth-moon distance was dramatically changed. During their brief sojourn on the moon Edwin E. Aldrin, Jr., and Neil A. Armstrong set up an array of "retroreflectors" that can return a laser signal with an intensity between 10 and 100 times greater than that produced by reflection from the natural surface. Equally important, the array eliminates the stretching out in time that results from light pulses' being reflected back from different parts of the lunar surface.

The laser-ranging experiment had its origin some 10 years earlier at Princeton University in a gravitational research group headed by R. H. Dicke. In 1959 three members of that group wrote a paper reviewing the problem of making precise optical position measurements of artificial satellites. The paper discussed three methods of illuminating a satellite to obtain range information: direct sunlight, a pulsing light aboard the satellite or an optical "corner" reflector, or retroreflector, aboard the satellite to return pulsed beams from an earth-based searchlight. The paper led to early experiments by Henry H. Plotkin and his satellite-tracking group at the Goddard Space Flight Center.

In 1962, the year the M.I.T. workers reported the first laser reflection from the moon, the suggestion was made in the Princeton group of placing a corner reflector on the moon to enhance the strength of the returned signal and to sharpen its definition in time. Although initially motivated by a problem posed by the Brans-Dicke scalar-tensor theory of gravitation, the laser-ranging experiment in addition has great importance for a number of areas in geophysics and astrophysics. Following the publication in 1965 of a paper titled "Optical Radar Using a Corner Reflector on the Moon" the LURE (Lunar Ranging Experiment) group was formed. The membership of the group reflects the many areas of science on which the experiment bears and the broad base of knowledge required for the experiment's successful execution. Coordination of the group's efforts has been the responsibility of Carroll O. Alley, Jr., of the University of Maryland.

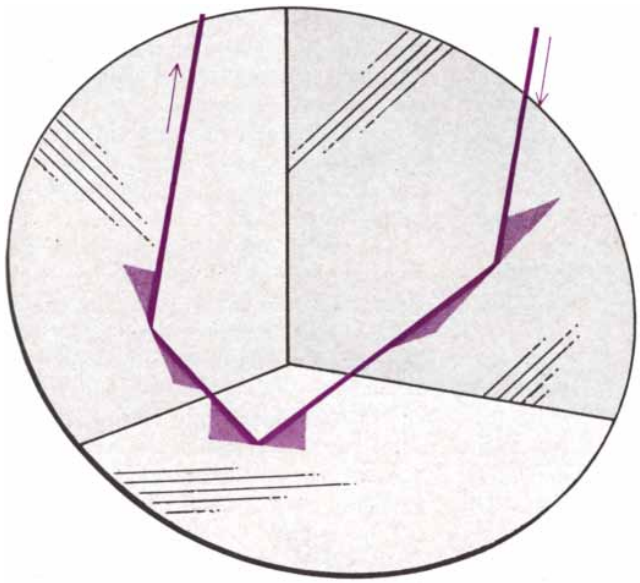
The retroreflector package that was placed on the moon last July consists of 100 "corner cubes" arranged in an 18-inch-square array [*see illustrations on next page and on the cover of this issue*]. Each of the 100 corner cubes is in effect an ultraprecise version of the reflectors used on bicycles and in traffic stop signs: it is designed to direct a beam of light back to its source regardless of the direction from which it arrives. Each cube does for the three-dimensional world of light what the corner of a billiard table does for the two-dimensional world of billiards. A billiard ball sent (without spin) into the corner of the table will, after two bounces, return along a path parallel to its incident direction. In the case of light three reflecting surfaces, all at right angles to one another, form a corner with the same retroreflective property.

The preliminary design for the array was suggested by one of us (Faller) after considering the many (and sometimes conflicting) requirements the array had to satisfy simultaneously in the lunar environment. Workers at the University of Maryland accurately calculated the spreading of the reflected beam from a corner cube, and they verified the performance of a cube of the suggested size (1½ inches in diameter) under lunar surface conditions with a solar simulator at the Goddard Space Flight Center. The final design, fabrication and testing of the array package, based on a detailed thermal analysis, was done by Arthur D. Little, Inc., in cooperation with members of the LURE team. The Perkin-Elmer Corporation and Boxton-Beel, Inc., produced the extremely precise corner cubes. The Aerospace Systems Division of the Bendix Corporation carried the overall engineering responsibility for the array's inclusion in the Early Apollo Scientific Experiments Package.

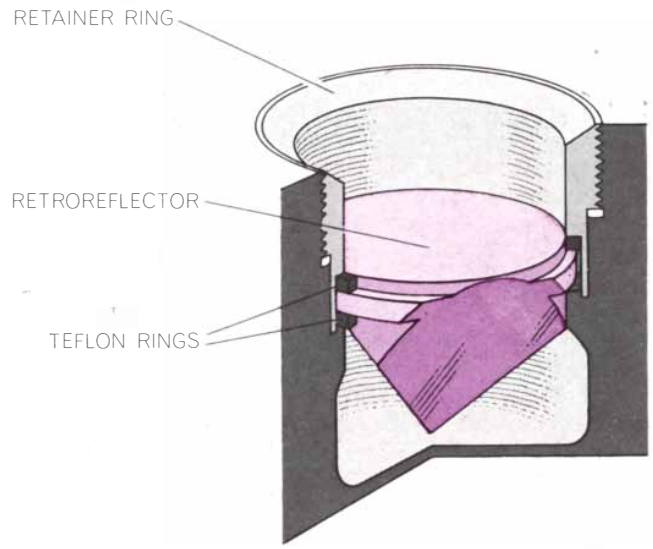
In theory the optimum size of corner reflector for lunar ranging can readily be determined. The returned light intensity is maximized by using a single diffraction-limited (optically perfect) retroreflector as large as weight restrictions will allow. In practice, however, the design must take account of two problems. The first is the fact that the returning laser beam will be displaced sideways because of the relative motion between the moon and the laser transmitter (velocity aberration); the second is the thermally induced optical distortion that occurs as a result of direct solar heating and the wide variation in temperature on the lunar surface (from −170 to +130 degrees Celsius).

The effect of the velocity aberration is to displace the center of the returned beam about a mile from the point of origin of the outgoing beam. Because of this shift the use of corner cubes five inches or more in diameter on the moon would require that the receiving telescope be spatially separated from the transmitting instrument in order to intercept a portion of the returning beam. For cubes less than about five inches in diameter, however, the diffraction pattern is wide enough so that the transmitting telescope will still be somewhat illuminated by part of the returned

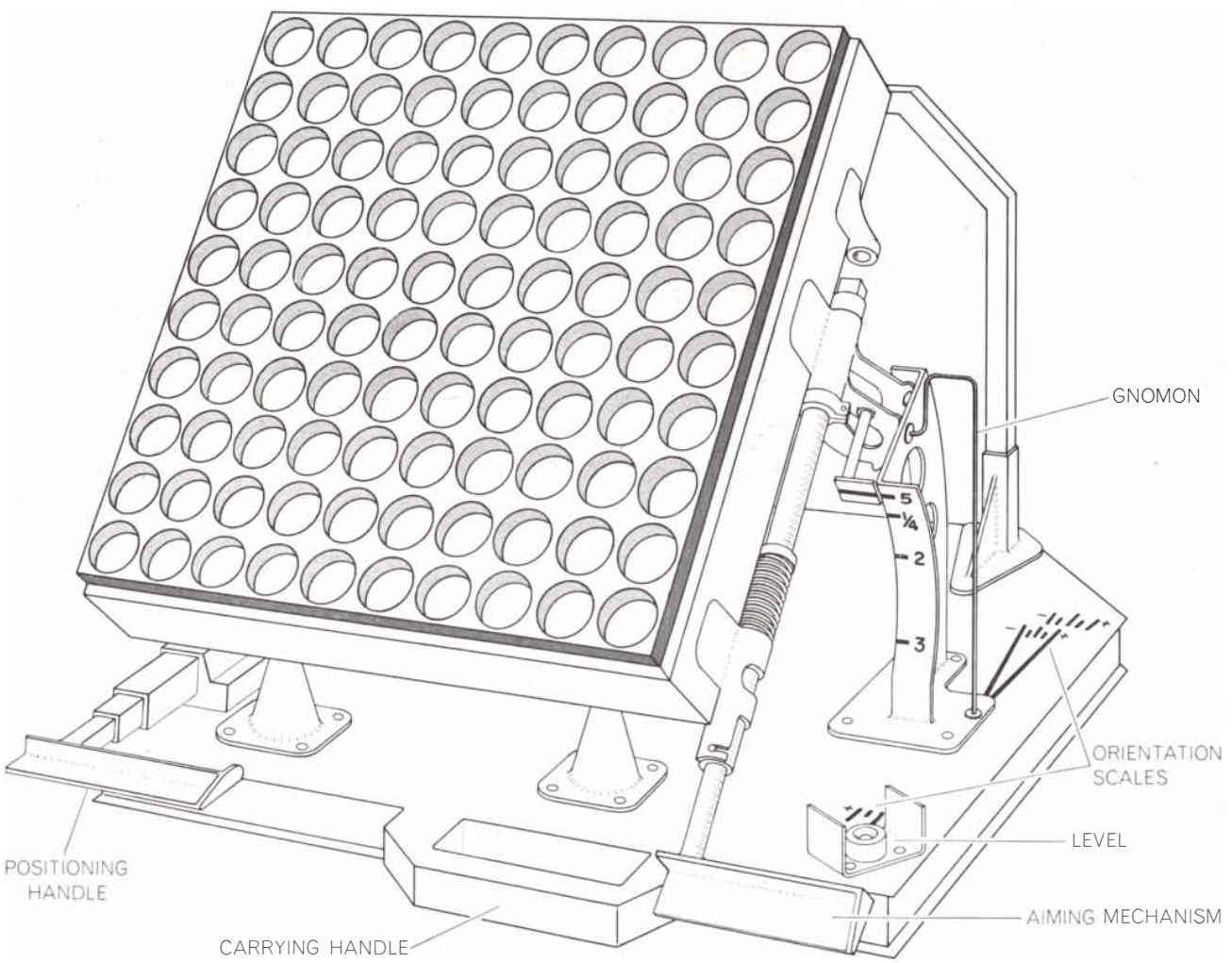
LUNAR-RANGING EXPERIMENT at the Lick Observatory, depicted on the opposite page, involved sending an intense pulse of laser light through the 120-inch telescope and detecting the pulse returned by the retroreflector array placed on the moon by the *Apollo 11* astronauts. The telescope optics limit the spread of the laser beam to a circle a little more than a mile in diameter on the moon. The portion of the returning laser light that enters the telescope is reflected by a movable mirror into a sensitive photon (light particle) detector. The outgoing pulse contains some 10^{20} photons, of which 25 or so return to the telescope 2½ seconds later. A low-power continuous laser, bore-sighted through the high-intensity pulsed laser, provides a continuous internal reference beam for aiming the telescope in conjunction with the television camera and reticle system shown at the lower left. Corner reflectors mounted near the front of the telescope intercept part of the laser light and send it back down the optical system, where it is superposed on an image of the moon in the aiming system. Two separate laser systems were available and were used by the group at Lick.



CORNER REFLECTOR, or corner cube, has the property of returning a ray of light (*color*) on a path exactly parallel to that of the incident ray. At each internal surface the angle of reflection equals the angle of incidence, as indicated by the colored triangles. The corner reflectors that were used in the array placed on the moon were cut from accurately polished cubes of fused silica.



MOUNTING FOR CORNER CUBE was designed by Arthur D. Little, Inc., to withstand the vibration and acceleration of an Apollo lift-off and, once on the moon, to minimize thermal gradients that would affect the optical performance of the reflectors. Each corner reflector is recessed by about half its 1½-inch diameter and is held by Teflon rings in a housing machined from aluminum.



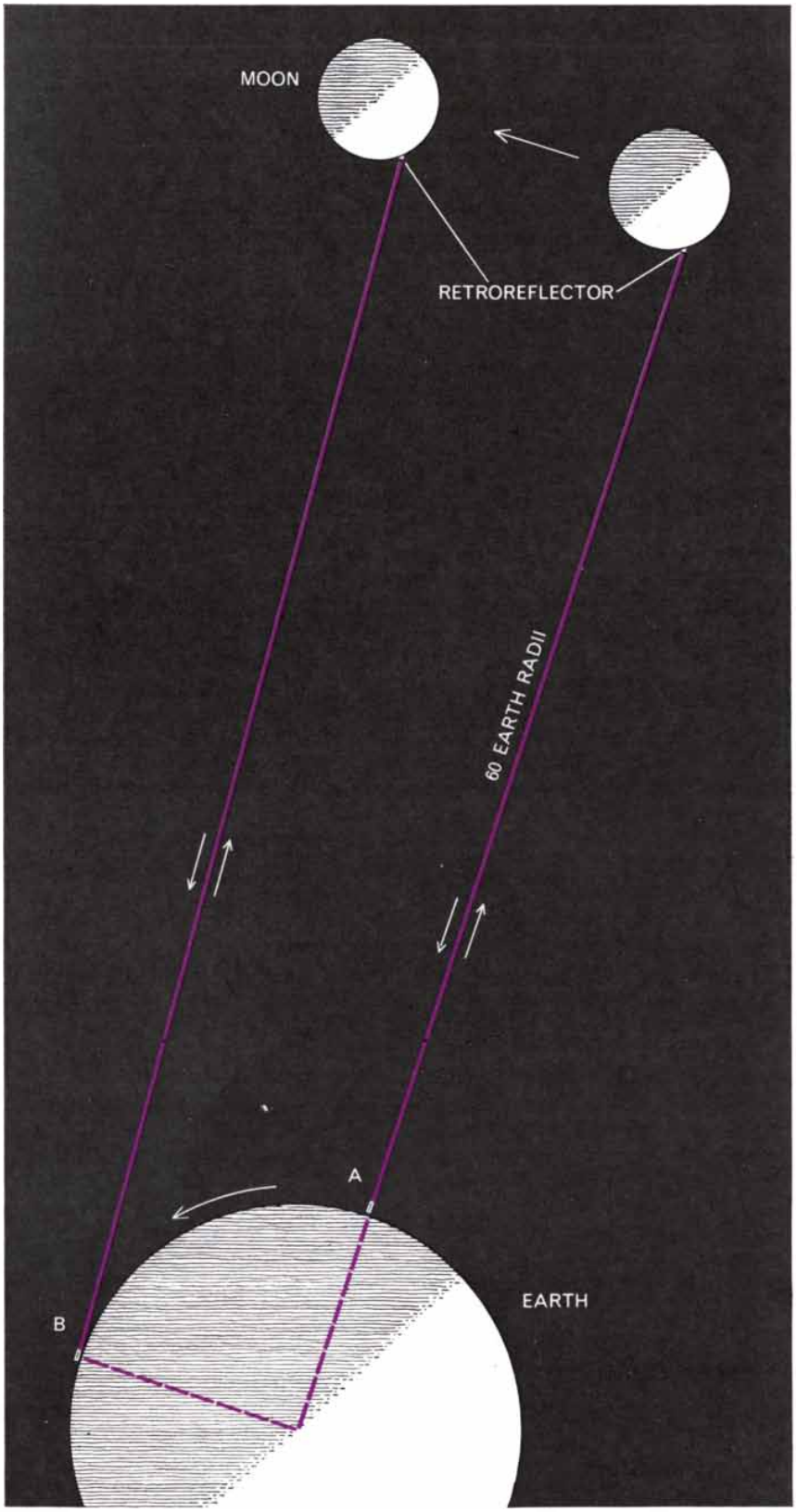
LUNAR LASER RETROREFLECTOR, 18 inches square, contains 100 corner cubes and can be adjusted to different angles to accommodate to different locations on the moon. Since it was actually placed close to the lunar equator at a point 23 degrees to the east of the subearth point, it was tilted up 23 degrees. Here the tilt is greater. The shadow of the gnomon provides east-west orientation.

beam. It turns out after some analysis that there is a wide range of corner sizes (from about 1½ to five inches in diameter) for which the ranging efficiency for a single transmitting and receiving site is almost independent of corner diameter and depends only on the total mass of corners used.

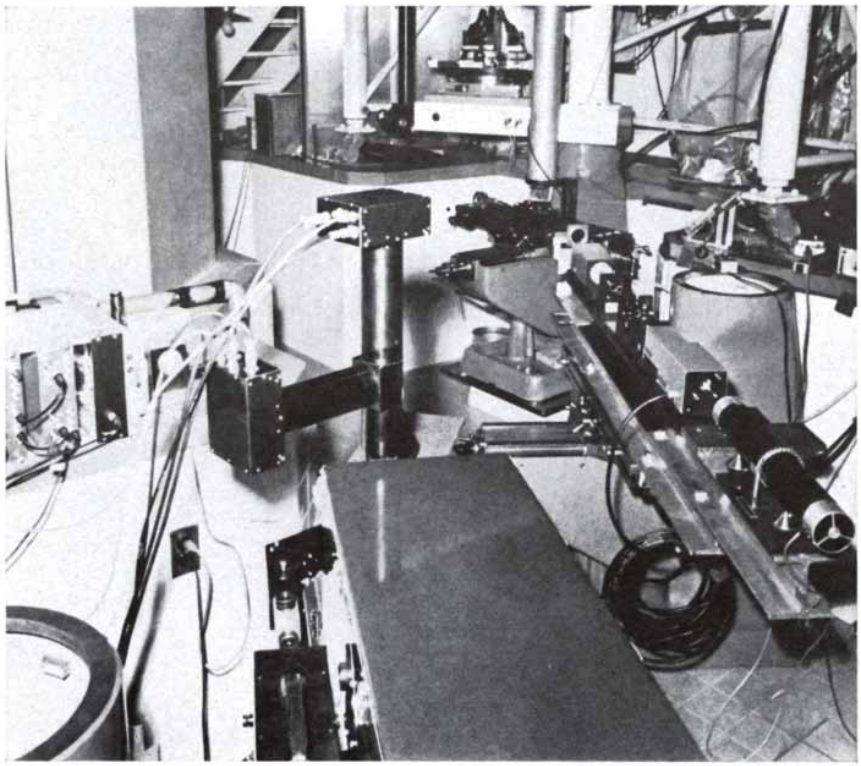
In order to minimize the thermal gradients that would distort the diffraction pattern of the returning beam, we therefore sent to the moon the smallest efficient size (1½ inches), simply using enough corner cubes to produce a reflected signal of reasonable strength. The temperature gradient is further minimized by recessing each reflector by half its diameter in a circular socket. Each reflector is tab-mounted between Teflon rings, which afford as much thermal insulation as possible. The mounting structure provides passive thermal control by means of its surface properties as well as by cavity geometry and insulation. In order to increase the lifetime of the array and to avoid added thermal distortion, we accepted about a two-thirds reduction in signal strength by relying on total internal reflection rather than aluminizing the back surfaces of the individual retroreflectors. Corners smaller than the 1½-inch ones that were sent to the moon would spread the returned light too thinly with the result that less would be collected by a given receiver area. As it is, the light reflected by one of the corners spreads because of diffraction to almost 10 miles in diameter in traveling the 240,000 miles back to the earth.

As the array was being developed our group was not certain which Apollo flight would carry it to the moon. To our delight, a little more than a year ago the National Aeronautics and Space Administration told us that our laser reflector was to be taken on the first flight, the flight of *Apollo 11*. On July 20 millions watched on television as Aldrin removed the unit from the bay of the *Eagle*, carried it out about 60 feet from the craft and set the array on the lunar surface. At that point Armstrong, using both the array-tilting handle and the deployment handle, tilted the unit so that the face of the array was approximately perpendicular to an imaginary line from the landing site to the earth. Finally he aligned the array to within a degree or two of an east-west orientation by using a shadow cast by a gnomon positioned on the base pallet [*see bottom illustration on opposite page*]. The entire task took about five minutes.

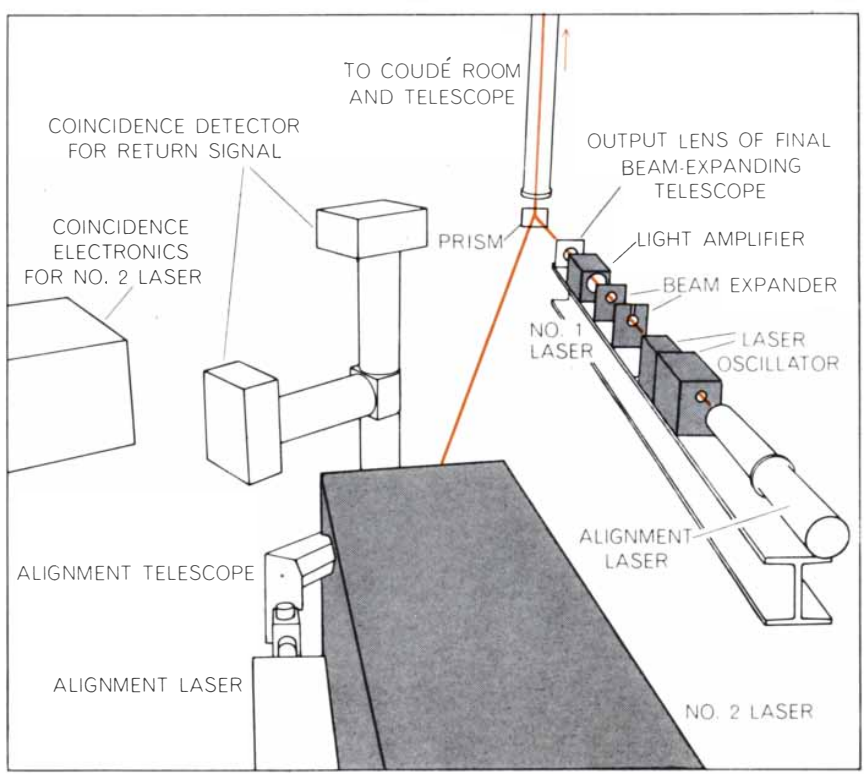
At the time of the *Apollo 11* landing



LUNAR-RANGING EXPERIMENT, in its simplest form, might involve measuring the distance to the moon at two instants six hours apart. The first measurement (*A*) is made when the observing station crosses an imaginary line connecting the center of the earth and the retroreflector on the moon. The second measurement (*B*) is made when the earth has rotated exactly 90 degrees. Account must be taken, of course, of the moon's motion: in six hours it travels about three degrees in its orbit. When corrections are made, the difference between the two values gives the station's distance from the axis of the earth's rotation.



EXPERIMENTAL AREA in a basement room below the 120-inch Lick telescope contained two laser systems, the guidance system for pointing the laser beam at the landing site on the moon and the equipment for detecting the weak return pulse (*see diagram below*).



EXPERIMENTAL APPARATUS for the lunar-ranging experiment at the Lick Observatory included two high-intensity ruby lasers. One (*right*) could fire twice a minute with a pulse duration of 10 nanoseconds; the other (*center foreground*) could fire 20 times a minute with a pulse duration of about 60 nanoseconds. The output of each of the lasers approached eight joules per pulse. With these lasers the authors and their colleagues obtained the first reflections from the retroreflector array on the moon on August 1 and August 3, 1969.

several observatories in the U.S. were standing by, ready to send laser pulses to the array and to try to detect the reflected light. At present two sites are still active. One utilizes the 107-inch telescope at the McDonald Observatory in Fort Davis, Tex., where observations are being carried out by the observatory staff in cooperation with the LURE group. The other, run by the Air Force Cambridge Research Laboratories, employs a 60-inch metal-mirror telescope located in the Catalina Mountains outside Tucson, Ariz. The first returns from the retroreflector array were recorded by a third station involving workers from Wesleyan University, the Goddard Space Flight Center and the University of California at Santa Cruz. It utilized the 120-inch telescope of the Lick Observatory on Mount Hamilton in California, which was specifically instrumented and made available for the purpose of cooperation in the initial attempts to detect reflected light signals from the array left on the moon.

Although the experiment was designed so that telescopes of moderate size could receive the reflected signals, NASA asked the Lick Observatory, with its excellent facilities, to cooperate in the initial attempts to detect the retroreflector. By using the 120-inch Lick telescope, the nation's second-largest, NASA hoped to maximize the chances of early detection of the return signals from the retroreflector on the moon. It is probably obvious that the larger the aperture of the telescope, the larger the amount of the weak return signal that is collected. What may be less obvious is that up to a certain size the larger the telescope, the greater the intensity of laser light that can be concentrated on the reflector package on the moon so that it can be reflected back.

Without any telescope at all the intrinsic beam divergence of the laser would spread the pulse of light to a diameter of about 300 miles by the time it reached the moon. Just as a telescope normally operates by taking light from an object subtending a small angle and making it appear to subtend a large angle, it can be operated in reverse to decrease the beam divergence of light sent through it. The amount by which beam divergence is reduced by a telescope is simply the ratio of the telescope aperture to the diameter of the laser. Although in principle the size of the laser spot on the moon continues to decrease as the telescope aperture is increased, in practice the turbulence in the earth's atmosphere sets a lower limit of a little

more than a mile in diameter. Even for the highest-quality high-power ruby lasers a telescope with an aperture of 100 inches or so is needed to reduce the divergence of the laser beam to match this limit set by the atmosphere under good seeing conditions.

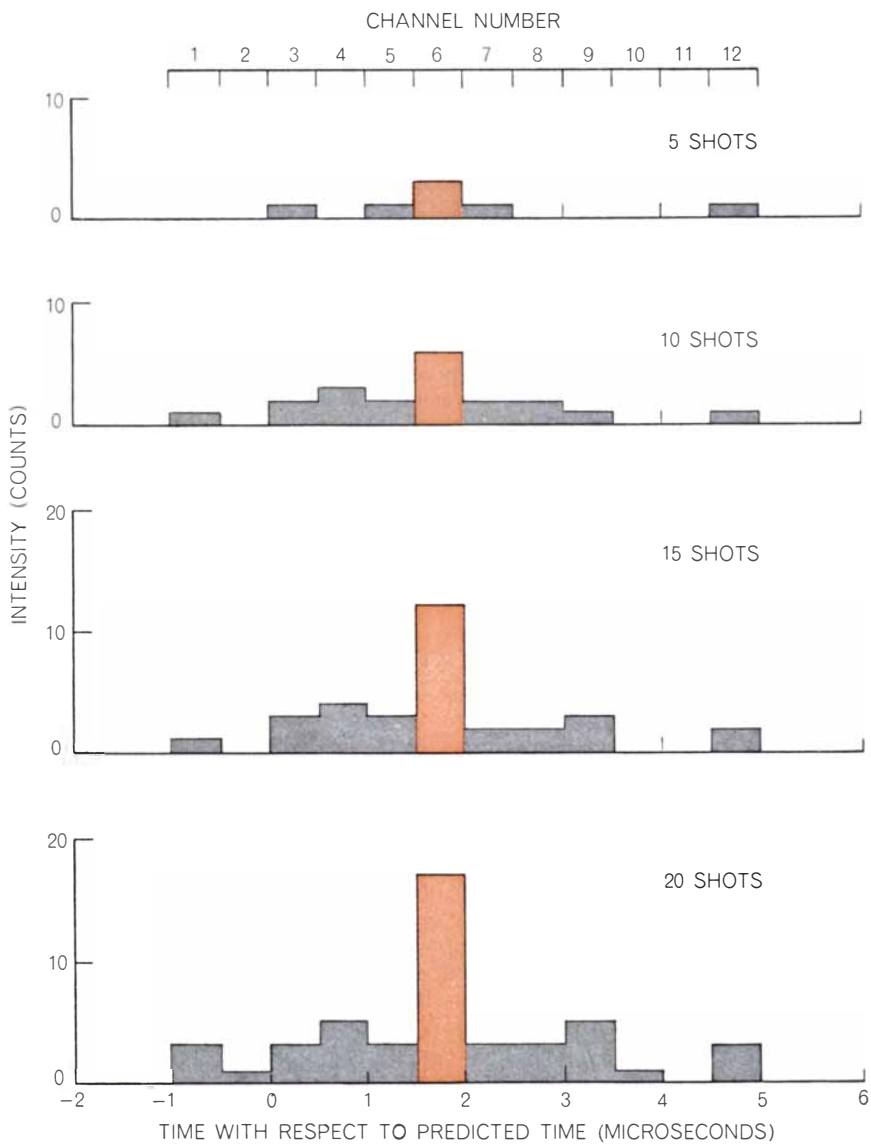
Two separate ranging systems were used at Lick. Each had its own high-power ruby laser and detection electronics. One of the laser systems could fire 20 times a minute. The other could fire only twice a minute but had a somewhat lower beam divergence. A small Galilean telescope was coupled to the output of each laser and served to increase the beam diameter from about three-quarters of an inch to two inches. The two-inch laser beam could be handled with ordinary optics without the severe risk of damage to the elements that would be caused by the more intense beam of smaller diameter.

After leaving the two-inch Galilean telescope mounted in front of the laser, the beam was bent upward by means of a prism toward a beam splitter [*see illustration on page 40*]. The prism served the dual purpose of sending the light to the beam splitter and acting as a switch between the two laser systems. Before reaching the beam splitter this parallel two-inch beam was caused to diverge by means of a negative lens chosen to make the laser light just fill the aperture of the 120-inch telescope. On leaving the telescope the beam was 10 feet in diameter and was diverging by only about one foot in 50 miles. The beam splitter was made to be 99 percent reflective for light at the wavelength of the laser and to be transparent to light of shorter wavelengths. As a result ordinary blue and green light from the moon could pass freely through the beam splitter and be reflected by a mirror into a field-viewing system that was used to set and guide the telescope.

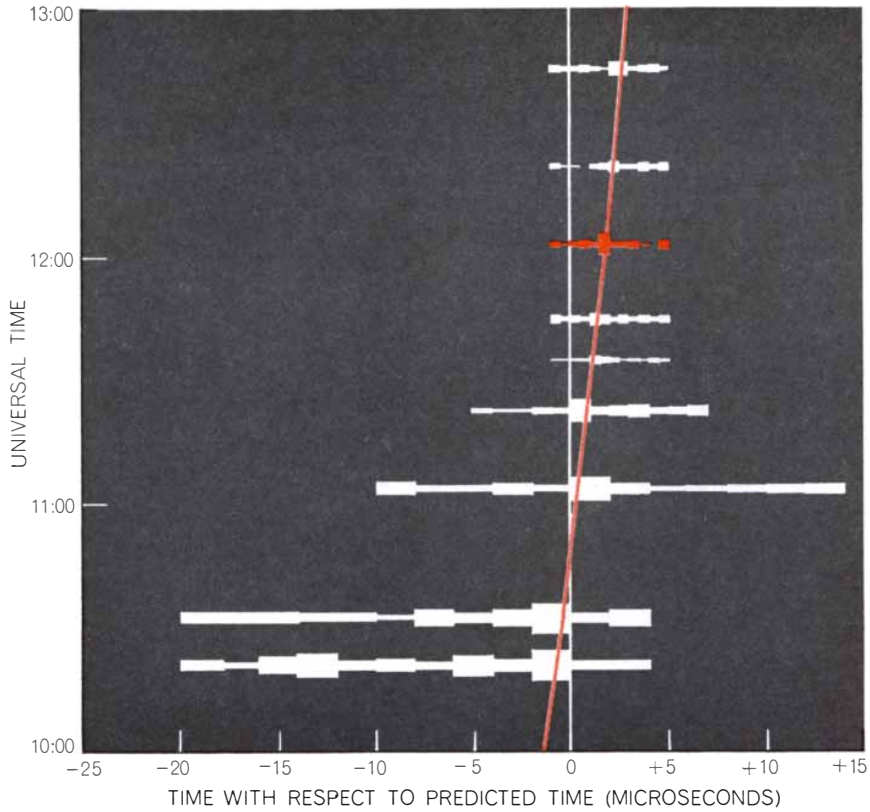
The return signal from the retroreflector followed in reverse the path taken by the transmitted laser pulse, eventually passing through the output lens of the two-inch Galilean telescope. Behind this lens was mounted a small mirror that could be flipped into position after the laser fired, thereby deflecting the return signal into the detector. The detector was located behind a pinhole that reduced the amount of background light reflected from regions well away from the landing site. In addition the detector was covered by a filter that prevented light other than that at the laser wavelength from reaching it.

The guidance system used blue-green moonlight that passed through the beam splitter to provide a view needed to aim the telescope at the landing site. The image of the moon was mixed with light from three projection reticles and then focused onto a viewing television camera. By setting the positions of the reticles to those of known lunar craters and then moving the telescope so that the images of the craters are superposed on the image of the reticles, the telescope could be accurately pointed to the landing site, which was on a flat and nearly featureless region of the moon [*see illustration on page 47*].

Several small corner cubes were mounted in front of the 120-inch mirror so as to intercept a part of the beam as it left the telescope and return it along a path exactly parallel to the outgoing pencil of light. When the laser was fired, somewhat less than 1 percent of the returned light passed through the beam splitter and entered the guidance system. This small sample of the outgoing light produced a momentary bright spot on the television monitor and showed accurately the point on the moon at which the telescope was aimed when the laser was fired. By holding the reticle images on the preselected craters and then monitoring the location of the flashes returned from the corner cubes



IDENTIFICATION OF REFLECTED LASER SIGNAL was done by dividing the output of the photon detector into 12 time channels embracing the predicted time of arrival, and observing whether or not one of the channels filled up faster than the others. The width of each channel could be varied from .25 microsecond to four microseconds. On the run shown here, made on August 1, 1969, at the Lick Observatory, the width of each channel was .5 microsecond. One channel, No. 6, filled more rapidly than the others, confirming that the returning photons were indeed coming from the retroreflector array on the moon.



DEPARTURE FROM PREDICTED ARRIVAL TIME presented a puzzle during the lunar-ranging runs made on August 1, the night return pulses from the retroreflector were first detected. Each horizontal bar represents a separate run; the thickness of each segment indicates the number of counts in each of 12 counting channels. The run illustrated on the preceding page, made at 12:03 Universal Time, is shown in color. The colored line drawn through the channels with the most counts indicates that the actual time of arrival of return pulses was at first earlier than the predicted time (*vertical white line*) and then fell behind by more than two microseconds. It was discovered that the 120-inch Lick telescope is actually some distance (about 1,800 feet) from the position used for calculating the range predictions. When the correct location is used, the predicted and actual arrival times agree.

mounted on the telescope it was possible to point the telescope with an error of less than a mile on the moon. The use of a television viewing system, which ensured that there was no danger from backscattered laser light to the eyes of the person correcting the motions of the telescope in order to hold the landing site in the field of the transmitted beam, also served to increase lunar contrast. During the daytime features were discernible on the television monitor that could not be seen by viewing the lunar image directly with the eye.

A number of problems were encountered and had to be solved before the experiment operated successfully. A particular concern was that the normal landing pattern for aircraft arriving at airports in the San Francisco Bay area takes them over the Lick Observatory. As a safety precaution the Federal Aviation Administration diverted aircraft from this normal pattern during laser operations. The first night we were allowed to fire at the moon was on the night of the lunar landing itself, July 20. Unfortunately the original range and position data were not known with sufficient accuracy. Moreover, the moon was so low on the horizon that we had only about an hour to conduct a somewhat random search for the retroreflector before the moon disappeared. The search failed.

The following days were equally frustrating. The moon was drifting south in its orbit, so that it appeared lower in the sky each night; as a consequence turbulence in the atmosphere produced an increasingly poor image. The moon was also waxing, and this resulted in an increase in the background moonlight picked up by the detectors. Finally, the lasers themselves, which were being operated near the threshold of damage to their materials, demanded constant attention.

Four days after the landing, having detected no return signals and with the moon now unfavorably low in the sky, we decided not to range for the next five days and to use the time to work on the equipment and recheck every detail. On August 1 ranging was resumed from Lick with a new set of coordinates for the landing site from the NASA Space Flight Center in Houston. The first returns from the array were recorded at about 2:00 A.M. on August 1. Pulses fired repeatedly through the rest of the night (one every 30 seconds with an output energy of between seven and eight joules and a pulse length of approximately 10 nanoseconds) produced return signals that could only have come from the retroreflector sitting on the Sea of Tranquillity.

The method of counting the return pulses can be described briefly as follows. A photon, traveling at 186,000 miles per second, requires about 2½ seconds to make the 480,000-mile round trip to the moon and back. Accordingly 2½ seconds after a laser pulse is fired at the moon (the exact time delay being set for each shot according to range predictions provided by J. D. Mulholland of the Jet Propulsion Laboratory) 12 counters are activated sequentially to count any pulses that may be produced by the photodetector. The total time each counter is active can be adjusted from .25 microsecond to two microseconds. Therefore the total time available for detecting reflected photons could be varied from three to 24 microseconds. In 24 microseconds light will travel five miles; in three microseconds it will travel only 900 meters. Thus to be sure that we record the return signal we need to know the round-trip distance to the moon at any given time to an accuracy at least between these limits. The counting sequence can then be centered on the expected time of arrival. Sunlight scattered from the lunar surface produces a background that slowly fills the 12 counter channels in a random fashion. If, however, the laser beam is properly aimed at the retroreflector, and if the timing is correct, one of the channels will gradually fill more rapidly than the rest [*see illustration on preceding page*].

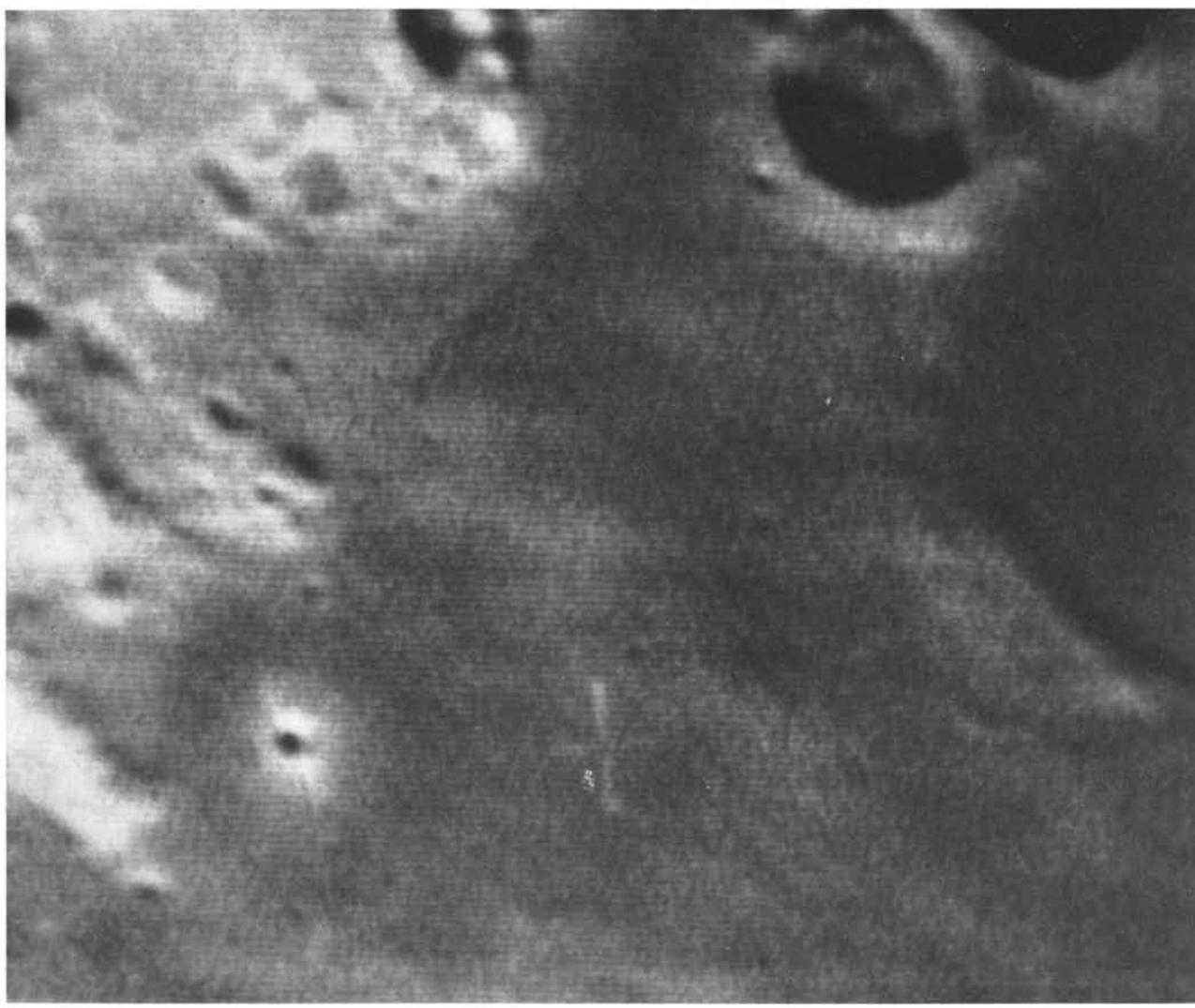
On August 1, the night of our initial success, the laser was fired 162 times in nine runs before the first returns were recognized. A final series of 120 shots, after various adjustments had been made, yielded 100 returns that exceeded the background level. Thus more than 80 percent of the shots produced a detectable return. On two of the runs we achieved a timing precision of .1 micro-

second, which meant we had established the distance to the moon with an accuracy of ±25 feet. We were puzzled, however, by an apparent drift away from the predicted time of return [*see illustration on opposite page*]. Later the mystery was solved when we realized that the 120-inch telescope is located some distance from the spot given for the Lick Observatory in *The American Ephemeris and Nautical Almanac*. The significance of the laser experiment for geophysical measurements was thus evident the first night.

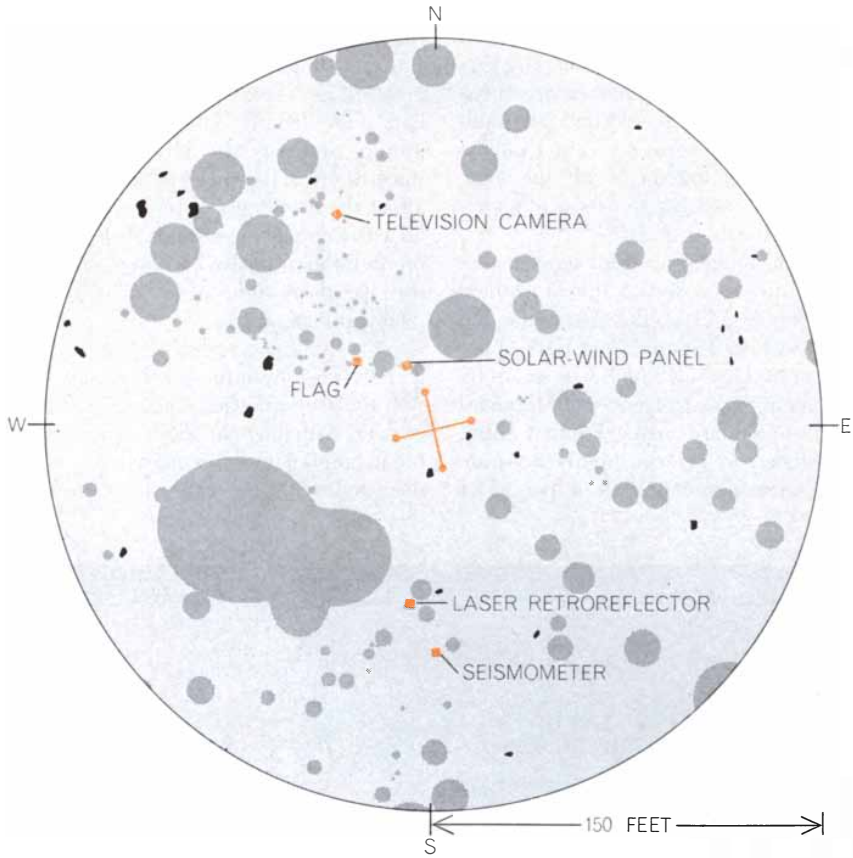
On August 3 the second laser system was operated successfully for nearly two hours. The data obtained in this run established the earth-moon distance with an error of only ±20 feet. The Lick results showed that the array had not been harmed by the *Eagle*'s blast-off, and that its operation in the lunar environment was as expected. In addition, the confirmation of the array's location on the lunar surface, together with the measured range, assisted the acquisition activities at the other stations.

Within the month return signals were successfully recorded at the McDonald Observatory and at the Air Force observatory near Tucson. The LURE apparatus at McDonald, which was set up by workers from the University of Maryland and the Goddard Space Flight Center, is designed to achieve highly accurate range measurements over a period of several years. The group there has recently been able to time the returning signal with an accuracy of two nanoseconds using a laser with a four-nanosecond pulse length. This corresponds to a range accuracy of one foot. The slight uncertainty in the speed of light does not affect the usefulness of the results, since all astronomical measurements are based on an internationally accepted value for the speed of light of 299,792.5 kilometers per second.

Let us now examine more closely the kinds of question one can hope to answer with an extended sequence of lunar-ranging measurements. An obvious result will be to define more precise-



INVISIBLE TARGET of the lunar-ranging experiment was the retroreflector array at the *Apollo 11* landing site in the Sea of Tranquillity. The guidance system that aimed a laser beam at the target through the Lick telescope incorporated a television camera, and this is a television view obtained while the astronauts were still on the moon. The landing site was located with respect to known craters. When the telescope was pointed so that a reticle fell on one of these craters, Moltke (*bottom left*), the target reticle was over the presumed position of the landing site (*bottom center*) some 25 miles away. (When this picture was taped, the data were not yet refined and so the target reticle is slightly misplaced.) In order to confirm the aim, a small portion of the laser light was returned to the television camera by retroreflectors in the telescope, so that a bright spot was superposed on the target reticle every time the laser fired.



TRANQUILLITY BASE, where *Eagle* landed, was mapped by NASA on the basis of photographs made from the landed module (*left half*) and of photographs made on an Orbiter mission and by the astronauts on the surface (*right half*). The map locates the module (*center*) as well as craters (*dark gray*), large rocks (*black*) and equipment left on the moon.

ly the motion of the moon in its orbit. The associated theoretical aspect, namely the attempt to adequately describe the motion of the moon, is among the oldest of scientific enterprises. Another experimental result will be a measurement of the lunar librations: the irregular rotations of the moon about its center that enable us to view some 59 percent of the lunar surface. Most of the apparent librations are caused by the lunar orbit's being elliptical, but residual motions are present because the mass of the moon is not evenly distributed. The retroreflector should lead to a large improvement in measuring these librations and provide the data for better calculations of the lunar mass distribution. From this knowledge it may be possible to infer something of the moon's history.

Another major objective is to learn more about the earth. Current theories suggest that the surface of the earth is subdivided into a number of large "plates" that move with respect to one another. These movements are believed to explain the drift of continents. For example, the Pacific plate is thought to be moving toward Japan at a rate of about four inches per year. After observing stations are established in Hawaii and Japan, the lunar-distance measurements will give the longitudes of these stations with such high accuracy that the expected motion should be observable within two or three years.

The data obtained from the lunar-distance measurements will also determine the position of the North Pole with an accuracy of about six inches, which is five or 10 times more accurately than it is now known. The position of the pole moves around on the surface of the earth in a rather complicated way, and it may travel nearly 200 feet along a roughly elliptical path during a year. The excitation mechanism for this polar wobble is still much in debate: it cannot be conclusively stated whether the mechanism is atmospheric mass shifts, variations in the coupling of the core and the mantle or mass shifts in the crust. The last hypothesis has been suggested by a correlation of pole shifts with major earthquakes, and hence better measurements may lead to a more complete understanding of earthquakes. The lunar-distance measurements will also allow more accurate determinations of the earth's rotation rate than have previously been possible.

Finally, the sensitivity afforded by the presence of the array on the lunar surface will make it possible to use the moon again, as it was used by Newton, as a testing ground for gravitational theories. We are interested in seeing whether or not the Newtonian gravitational constant is slowly decreasing with time due to the expansion of the universe, as has been conjectured by a number of physicists. A definitive test of these hypotheses may be obtained by monitoring the motion of the moon. In addition, there is the possibility of seeing some very small but important effects in the moon's motion that are predicted by the general theory of relativity.

In principle the method of extracting scientific results by measuring the precise distance to the moon is straightforward, but in practice many subtle factors must be taken into account. In the simplest case one wants to measure the change in distance from a given observing station during a six-hour period [*see illustration on page 43*]. After various corrections have been made in the relative motion of the earth and the moon during this period, one ends up with the distance of the station from the axis of the earth's rotation. To do this in practice many readings are taken with the moon high in the sky, and the distance from the axis is computed from the amplitude of the 24-hour component. Other information about the station location can be obtained in a similar fashion.

The major complexity that arises is that the moon's motion is not accurately known to begin with. A precise analytic theory of the lunar motion has been developed over the past 90 years by G. W. Hill, E. W. Brown and W. J. Eckert. The planetary perturbations have never been calculated with sufficient accuracy, however, to give the six-inch precision necessary to match the anticipated accuracy of laser ranging. Hence it is better to take advantage of modern electronic computers by calculating the entire lunar motion by direct numerical integration of the equations of motion for the entire solar system.

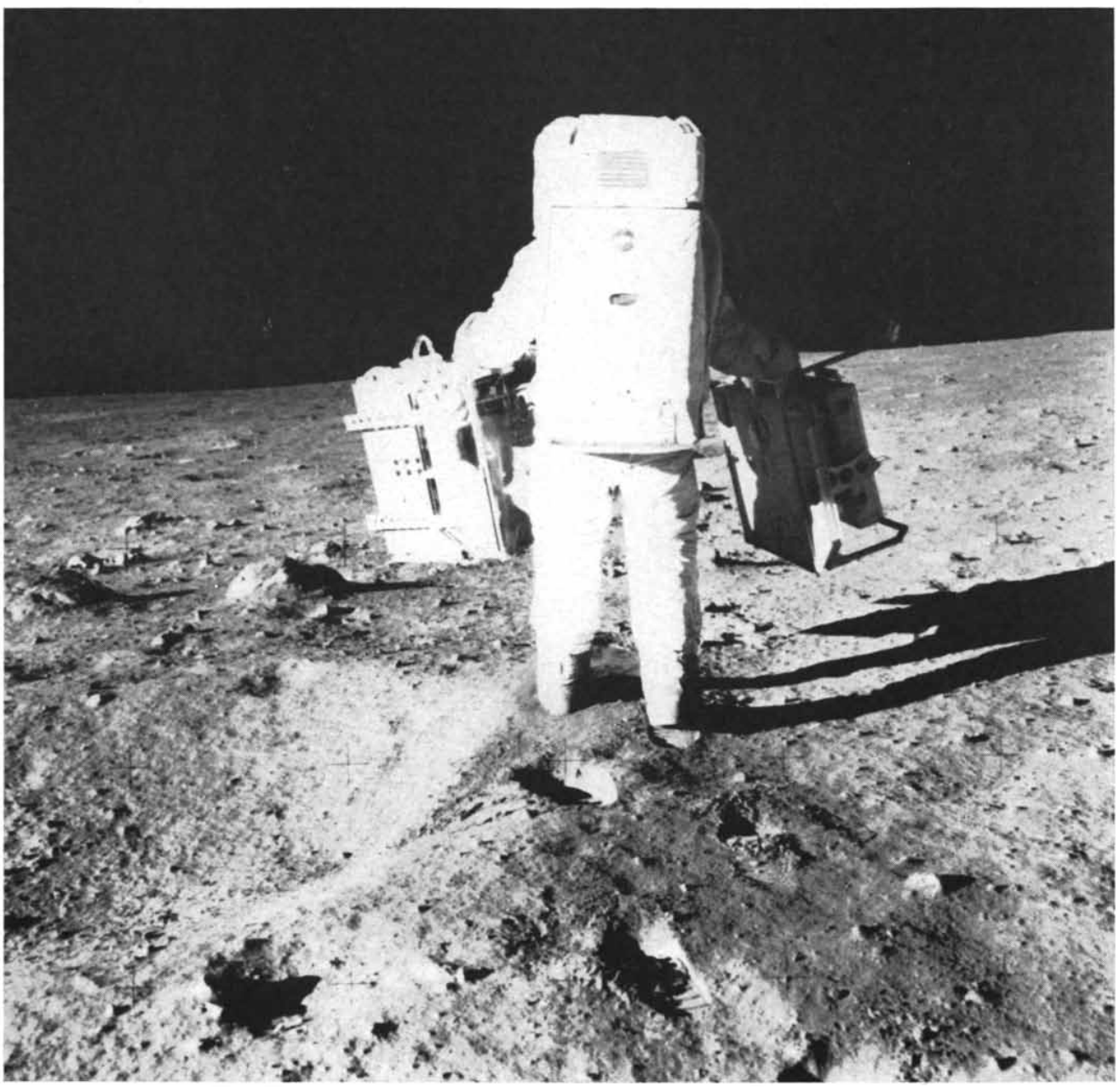
Once this has been done, the calculated lunar range as a function of time is compared with the range observed by bouncing the laser beam off the retroreflector. Improvements are then introduced to make the calculated result

agree more and more closely with the observed one. If the basic theory of motion in a gravitational field is correct, the results should converge.

It is not obvious, however, how in this procedure one can separate information about the moon from information about the earth. One can imagine, for example, that some unexpected wobble in the earth's rotation (or a movement of one of the surface plates) might be interpreted as a perturbation in the moon's motion. This is not the place to explore how such possibilities can be disentangled. Suffice it to say that good methods for separating lunar from geophysical effects are believed to exist. With data from four or more observing stations at well-chosen locations, one can also separate local aberrations such as continental drift from motions of the earth as a whole.

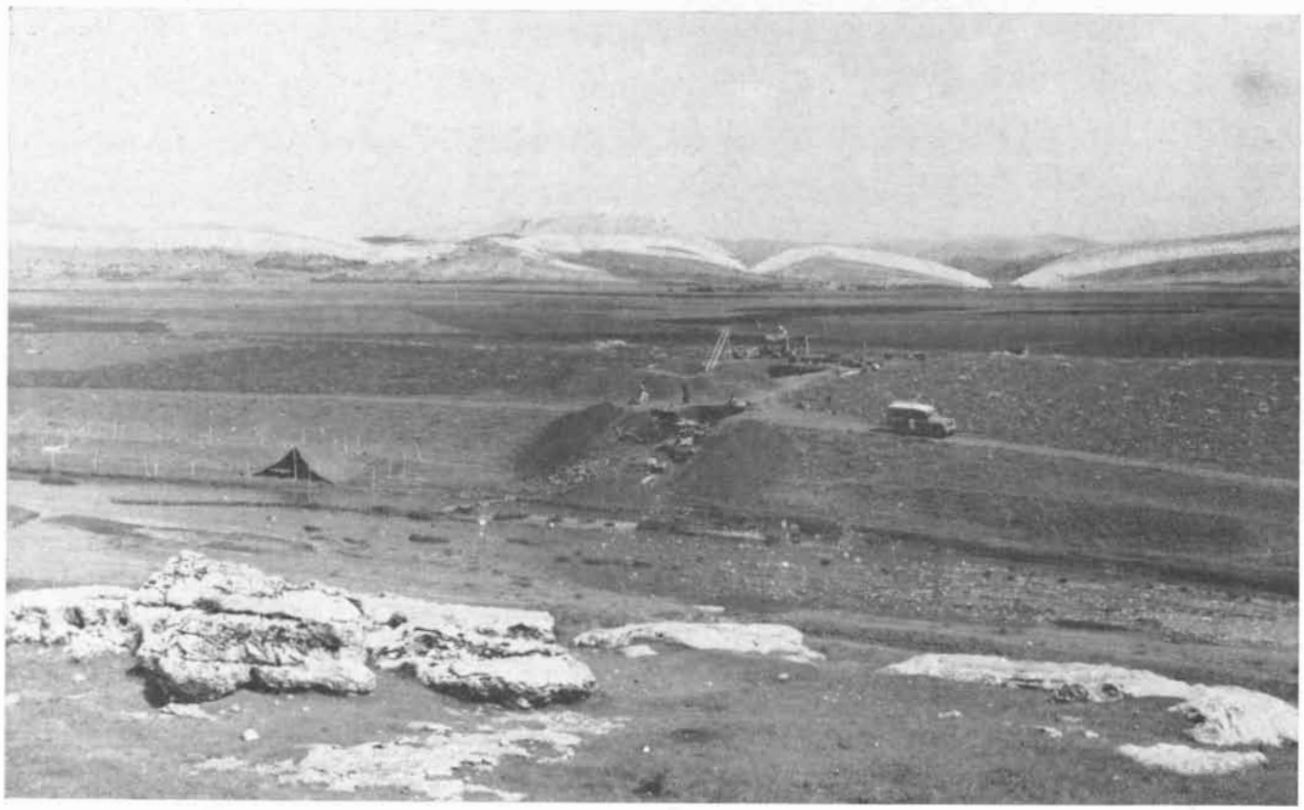
Clearly if the lunar array is to be put to optimum scientific use, a number of observing stations around the world are needed. International cooperation is not only desirable but also essential to the full exploitation of this new astronomical tool. We are delighted to learn that colleagues in France, the U.S.S.R., Czechoslovakia and Japan are preparing to make lunar-range measurements.

The placing of the retroreflector array on the moon last July by the *Apollo 11* astronauts has resulted in a dramatic change in man's ability to measure the earth-moon distance. Since the array has now survived several lunar nights and days without apparent harm, we have reason to hope that it will continue to function as intended, providing a primary bench mark in space for many years to come.



LUNAR PORTER, Edwin Aldrin, was photographed by Neil Armstrong, commander of *Apollo 11*, as he walked away from the *Eagle*, carrying the laser retroreflector array in his right hand and the passive seismic experiments package in his left. Later Armstrong carefully positioned the retroreflector array on the lunar surface, about 65 feet from the landing module, as shown on page 39. There had been some concern that the blast of *Eagle*'s ascent-stage rocket might cover the array with dust, but the concern proved unfounded.

AIR VIEW of Çayönü Tepesi, on the bank of a tributary of the Tigris River in southwestern Turkey, shows the work done by the authors in 1964. Near the river (*right*) digging uncovered stone walls and a floor of flagstones. On the crest of the village mound (*left*) six successive levels of occupation have been exposed; the next-to-lowest level contained objects made from copper.



GROUND VIEW of Çayönü Tepesi, from a rise on the south side of the river, shows a stretch of the broad Ergani plain beyond the site. On the northern horizon are the first ranges of the Taurus Mountains, here distinctively marked by light-colored bands of rock.

An Early Farming Village in Turkey

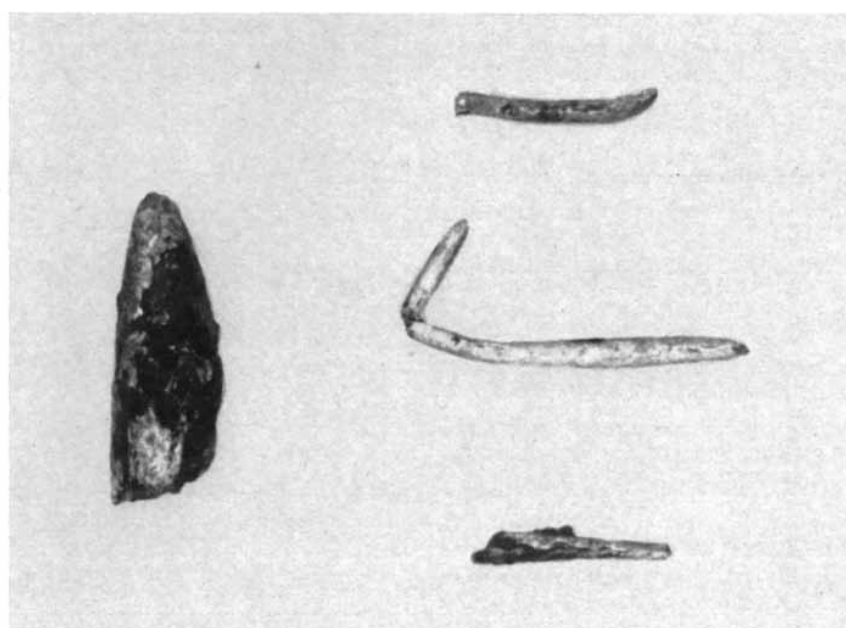
Çayönü Tepesi, a site in a little-studied part of Asia Minor, adds to the growing record of man's agricultural origins. Also revealed there is the earliest evidence of man's use of metal

by Halet Çambel and Robert J. Braidwood

When and where did men first turn to farming and animal husbandry as a way of life? This question has increasingly come to occupy the attention of archaeologists in recent years. The first direct attempt to discover just when in human prehistory farming villages appeared was made in the Near East a little more than 20 years ago when a party from the Oriental Institute of the University of Chicago began digging at Jarmo in the foothills of the Zagros Mountains in northeastern Iraq. Today scores of such investigations are in progress in several parts of the Old World and the New World. In the Near East alone the area of interest has grown until it stretches from Turkestan and the Indus valley on the east to the Aegean and the Balkans on the west. This article concerns one Near Eastern investigation that has opened up a new area and has by chance brought to light the earliest evidence of man's use of metal.

Field results in the years since Jarmo allow a few broad generalizations about the dawn of cultivation and animal husbandry. We now know that somewhat earlier than 7500 B.C. people in some parts of the Near East had reached a level of cultural development marked by the production, as opposed to the mere collection, of plant and animal foodstuffs and by a pattern of residence in farming villages. It is not clear, however, when this level of development became characteristic of the region as a whole. Nor do we yet have a good understanding of conditions in the period immediately preceding. The reason is largely that few sites of this earlier period have yet been excavated, and that during the earliest phases of their manipulation the wild plants and animals would not yet possess features indicating that they were on the way to domestication. Moreover, even the most painstaking excavation may fail to turn up materials that constitute *primary* evidence for domestication, that is, the physical remains of the plants and animals in question. Fragments of plant material and bone—the objects that could tell us exactly which of a number of possible organisms were then in the process of domestication—are often completely missing from village sites.

What should be said of villages that yield plant and animal material that we cannot positively identify as being the remains of domesticated forms? Until recently we tended to believe that if such sites had every appearance of being permanently settled, and if their inventory of artifacts included flint "sickle" blades, querns (milling stones), storage pits and similar features, then they probably represented the next-earliest level of cultural development; we called it the level of incipient cultivation and animal husbandry. Over the years, however, it has become increasingly probable that early village-like communities of a somewhat different kind may also have existed in the Near East. At these sites the food supply tends at first to include plant and animal forms that were not subsequently domesticated. In other words, even though such items as flint sickles,



EVIDENCE OF METALWORKING at Çayönü Tepesi includes four objects, shown here twice actual size. At left is the point of a reamer, formed from a lump of native copper by hammering. Beside it are two copper pin fragments and a whole pin that has been bent. The pinpoints have been formed by abrasion. A source of native copper lies quite near the site.

querns and the like appear in their inventories, and the architectural traces of their settlement suggest some degree of permanence, it looks as if we are dealing here with villagers living on a level of intensive collection of wild foods alone. Our older notion that villages had to mean farmers has gone by the board.

A prime example of such a non-food-producing community is the village-like site of Mallaha, in northern Israel. The excavator of Mallaha, Jean Perrot of the French Archaeological Mission in Israel, was the first to suggest that when other sites of a similar nature were unearthed, they too might lack any evidence of food production. Mallaha was inhabited about 9000 B.C. The village site of Mureybet, on the middle reaches of the Euphrates in Syria, is somewhat later, say about 8250 B.C. Mureybet, which was excavated by Maurits N. van Loon for the Oriental Institute in 1964 and 1965, also shows no trace of food production. An even later example is the "hunters' village" of Suberde in Turkey, excavated by Jacques Bordaz of the University of Montreal in 1964 and 1965 [see "A Hunters' Village in Neolithic Turkey," by Dexter Perkins, Jr., and Patricia Daly; SCIENTIFIC AMERICAN, November, 1968]. As late as 6500 B.C. the people of Suberde fed themselves mainly by killing large numbers of wild sheep and wild cattle.

In very rough outline the available evidence now suggests that both the level of incipient cultivation and animal domestication and the level of intensified food-collecting were reached in the Near East about 9000 B.C. In contrast to the moderately intensive food-collecting characteristic of the preceding level of development (the level of the late Upper Paleolithic period), what allowed this second kind of community to flourish was collecting of a most intensive kind. We believe such communities can be regarded as being incipiently food-producing, in the sense that their inhabitants were doubtless already manipulating both plants and animals to some extent. It seems to us that in much of the Near East this interval of incipient food production was just before or at the same time as what in Europe is called the Mesolithic period: a phase of cultural readaption, still on a food-collecting level, to the sequence of postglacial forested environments that formed in Europe about 11,000 years ago. (Food production proper did not reach most of Europe until sometime after 5000 B.C.)

The inventory of artifacts known as the Natufian assemblage, after the valley in Palestine where it was first discovered, provides examples, found both in caves and in village-like sites, of communities without food production. The artifacts uncovered at Mallaha, for instance, fit the Natufian classification. A different but contemporary inventory, found east of the Euphrates and Tigris rivers, is named the Karim Shahirian assemblage, after Karim Shahir, a site on the flanks of the Zagros Mountains. The artifacts from Zawi Chemi, another early site in Iraq, are of this second kind, and Zawi Chemi appears to have the earliest evidence for domesticated sheep (about 9000 B.C.). A somewhat later site in neighboring Iran—Ganj Dareh, near Kermanshah—contains an assemblage that, although it is similar, is somewhat more developed than the basic Karim Shahirian. It is not yet clear, however, either along the Mediterranean littoral or in the regions east of the Euphrates, through how many successive phases the incipient food producer—hunters' village level may have passed before the next developmental step took place.

The early phase of that next step—the level of effective village-farming communities—is now known from sites throughout the Near East. Representative early-phase villages have been unearthed in most of the region's grassy uplands, in some middle reaches of its major river valleys, along the Mediterranean and even beyond the Near East in Cyprus, Crete and Greece. Originally one of us (Braidwood) believed the most ancient evidence of this early phase

● SITES WITH ESTABLISHED FOOD PRODUCTION.

○ SITES WITH SEVERAL PERIODS OF OCCUPATION, SOME FOOD-PRODUCING.

◆ SITES WITH EVIDENCE OF "INCIPIENT" FOOD PRODUCTION.

◇ SITES WITH INSUFFICIENT EVIDENCE OR NO EVIDENCE OF FOOD PRODUCTION.

? SITES KNOWN FROM BRIEF TESTS OR SURFACE COLLECTIONS; NO EVIDENCE OF FOOD PRODUCTION.

SOUTHWESTERN ASIA, from beyond the Caspian (*right*) to the Mediterranean shore (*left*), contains many of mankind's earliest farming settlements, most of them in or near the hilly regions flanking the Fertile Crescent of Mesopotamia. The region also contains a number of village-like sites whose inhabitants were only incipient food producers or won a living by means of intensified hunting and gathering (*see key above*).

would be found only within a geographically restricted area, which was defined as the hilly flanks of the Fertile Crescent [*see illustration below*]. Moreover, even within this area the expectation was that the evidence would be confined to the zone naturally occupied today by certain wild but potentially domesticable plants and animals. One consequence of this view was that for a time the search for early sites was restricted to the "hilly flank" area, with the result that a large proportion of the early village sites now known are either in that area or immediately adjacent to it.

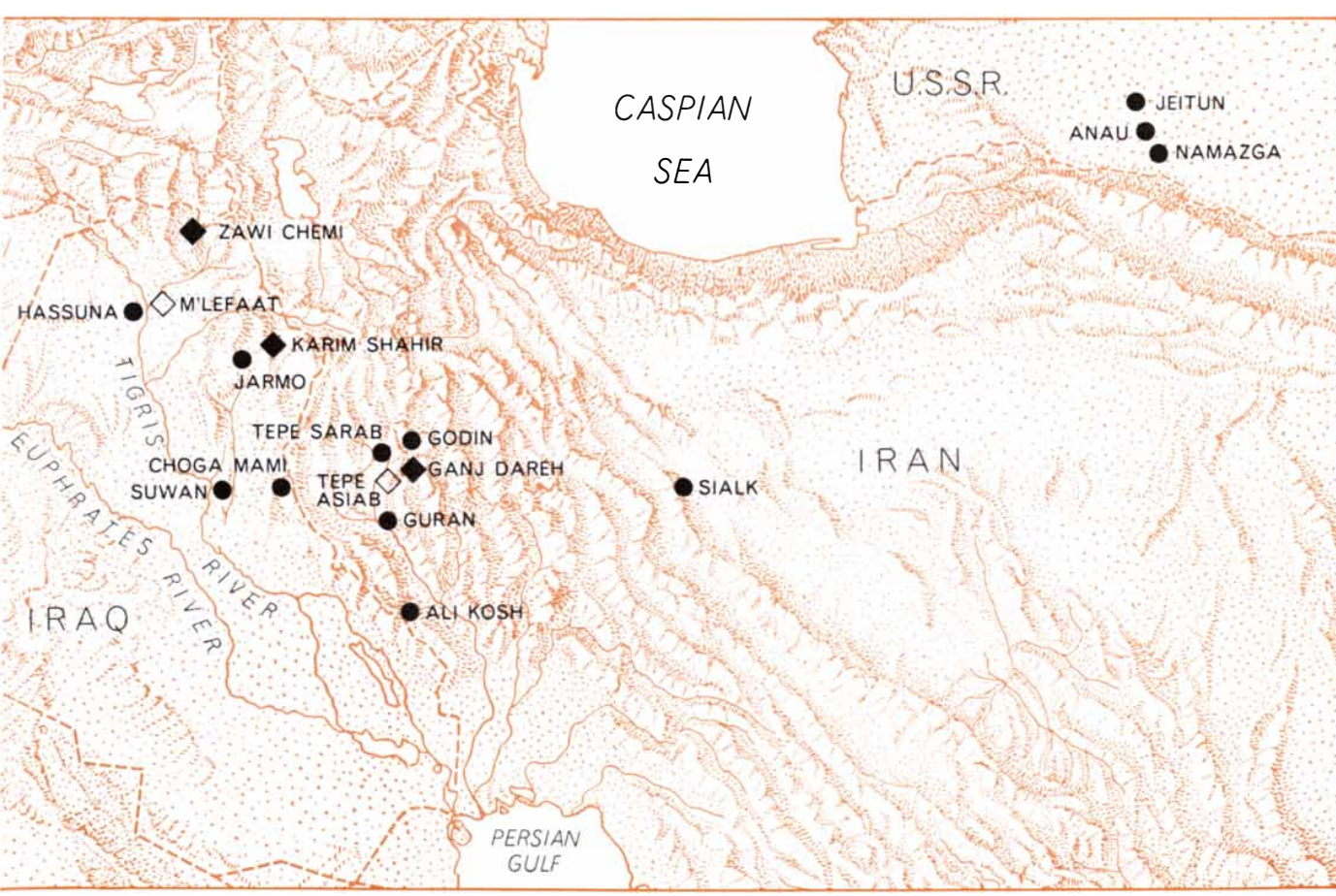
Recently it has become apparent that in past millenniums the natural range of the potentially domesticable forms of what may be called the "wheat-barley/sheep-goat-cattle-pig complex" extended well beyond the hilly flanks of the Fertile Crescent. For example, while extending earlier investigations by the Oriental Institute in Iran, Herbert E. Wright, Jr., of the University of Minnesota and Willem van Zeist of the University of Groningen have collected samples from the beds of lakes and ponds for analysis of their pollen content. Wright and van Zeist find that since about 17,000 years ago the vegetation and climate along the flanks of the Zagros Mountains have changed much more than had been supposed. At the same time test excavations by an Oriental Institute group at Koum, in the dry steppe country west of the Euphrates in Syria, have added another site to the growing list of early non-food-producing settlements. Koum, like Mureybet, lies well south of the hilly-flanks zone, just as Suberde in Asia Minor lies well north of it. We have yet to learn precisely how wide the natural range of the domesticable plants and animals constituting this Near Eastern complex was in early times. The question will be answered only with the continued help of our colleagues in the natural sciences.

In the 1950's there was a substantial increase of archaeological activity in the Near East, but not until the 1960's did it become possible to investigate one untouched area that formed a virtual keystone in the arch. This was the southern slopes and the piedmont of the Taurus Mountains in southeastern Turkey, an area that includes the entire northern watershed in the upper reaches of the Tigris and the Euphrates. We reasoned that, however extensive the ancient range of domesticable plants and animals may have been, the upper basin of the Tigris and the Euphrates must have been somewhere near the center of the zone.

Much of this unexplored territory lay within three Turkish border provinces (Urfa, Diyarbakir and Siirt), which for reasons of national security are normally out-of-bounds to foreign visitors. It seemed to us that if the area was to be reconnoitered, a joint Turkish-American venture was in order. In late 1962 the Oriental Institute joined forces with the department of prehistory of Istanbul University to establish a joint Prehistoric Project, and the authors of this article were made its codirectors. The project received the support of the National Science Foundation and the Wenner-Gren Foundation for Anthropological Research.

We proposed that a surface survey of the three provinces be made in the fall of 1963 and that exploratory digging be undertaken in the spring of 1964. We presently received the necessary approvals, which in this border region meant not only the cooperation of the Directorate of Antiquities of the Turkish Republic but also the active support of the Prime Minister, of many high civil and military authorities and of the governors of the three provinces and their staffs.

Thanks to the interest of all concerned, we were able to begin our sur-



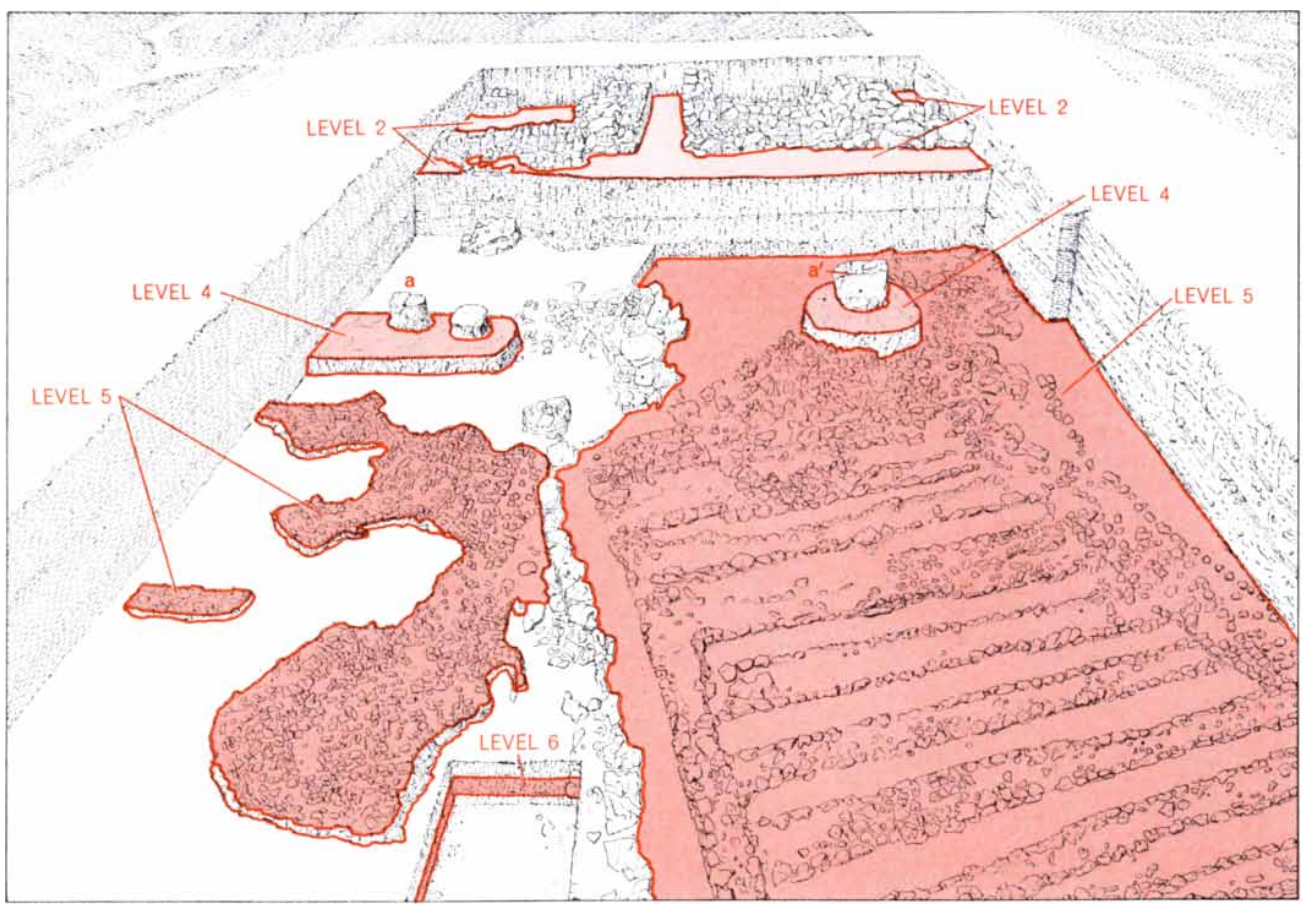
face survey in the province of Siirt early in October of 1963. We moved on to Diyarbakir in mid-November and ended the season with a five-day survey in Urfa in mid-December. Since the three provinces cover a total of more than 46,000 square kilometers, the reconnaissance could scarcely be an intensive one. The most detailed work was done in two valley regions: the plains of Kurtalan in Siirt and the Ergani plain in Diyarbakir. We found a total of 134 archaeological sites, plotted their location and roughly classified the materials we could collect on the surface at the main sites.

Our survey showed that this part of Turkey had been continuously occupied by men at least from the time (between 100,000 and 200,000 years ago) when stone tools of the Acheulean type were commonplace. So far as our particular interests were concerned, sites that looked as though they might be the remains of early farming villages were located in both the Kurtalan and the Ergani valleys. Still other sites in these valleys evidently represented more fully evolved village-farming communities. Some of the sites belonged to the developed village-farming phase termed Halafian (after Tell Halaf in northern Syria).

So far as settlements that might have belonged to the initial level of incipient food production are concerned, the most we can say at the moment is that our survey turned up no artifacts that, even in general terms, could be called representative of either the Natufian or the Karim Shahirian assemblages. Although it is probable that an unrelated third cultural tradition at the general level of incipient food production existed in this part of Turkey, we have yet to identify its traces.

In late April of 1964 we returned to the area of our survey prepared to undertake a number of test excavations. Bruce Howe of Harvard University, who had joined the project with the support of the American Schools of Oriental Research, tackled two small open sites in the area northwest of the provincial capital of Urfa. Named Biris Mezarligi and Sögüt Tarlasi, the sites contained numerous specialized stone tools produced from blades of flint. The inventory seems to represent some end phase of the Paleolithic period in the region. The sites did not yield samples adequate for carbon-14 dating, so that the age of this blade industry is a matter of conjecture; our guess is that the tools were made around 10000 B.C. or perhaps a little later. At Sögüt Tarlasi, but not at Biris Mezarligi, the blade-tool horizon was overlain by material of a time somewhat before 3000 B.C., contemporary with the Uruk phase of Sumerian culture in neighboring Mesopotamia.

While Howe worked in Urfa, the majority of the workers on the project moved on to Diyarbakir in order to investigate a promising mound some five kilometers southwest of the town of Ergani. Known as Çayönü Tepesi, the mound is about 200 meters in diameter;

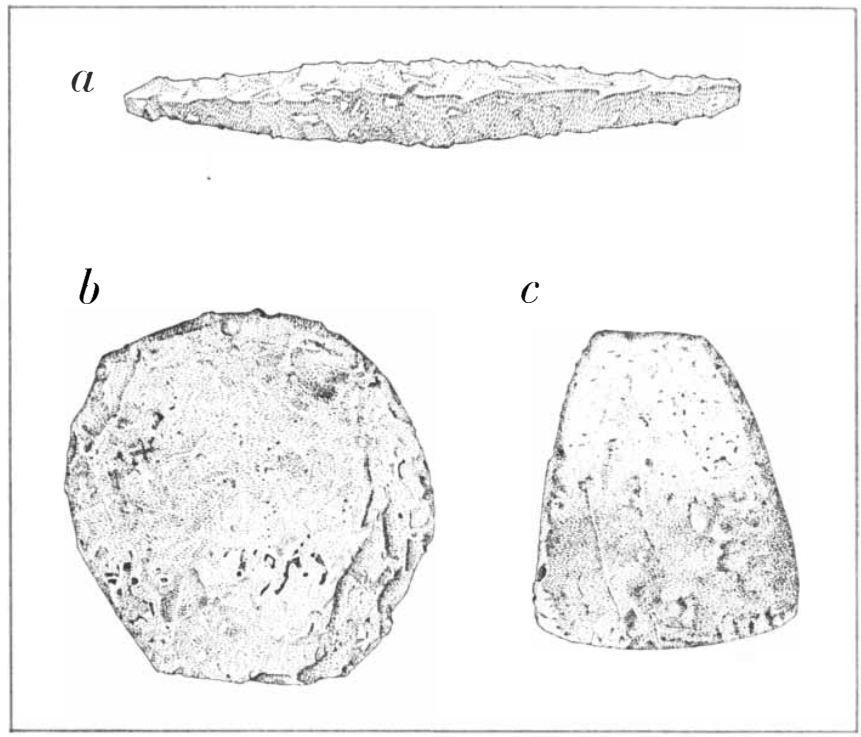


SUCCESSIVE LEVELS exposed during excavation on the crest of the mound are shown in a drawing based on composite photographs. At the rear of the dig, only a little below the mound surface, are the stone foundations of mud-brick structures that had been built at Level 2. In the middle distance (*a*, *a'*), still surrounded by unremoved earth, are the bases of the two stone monoliths found at Level 4. Sections of the cobble pavement found at Level 5 are in the foreground at left. In the foreground at right is the grill-like stone foundation of the elaborate structure exposed at Level 5. The two-by-two-meter pit, foreground, descends beyond Level 6.

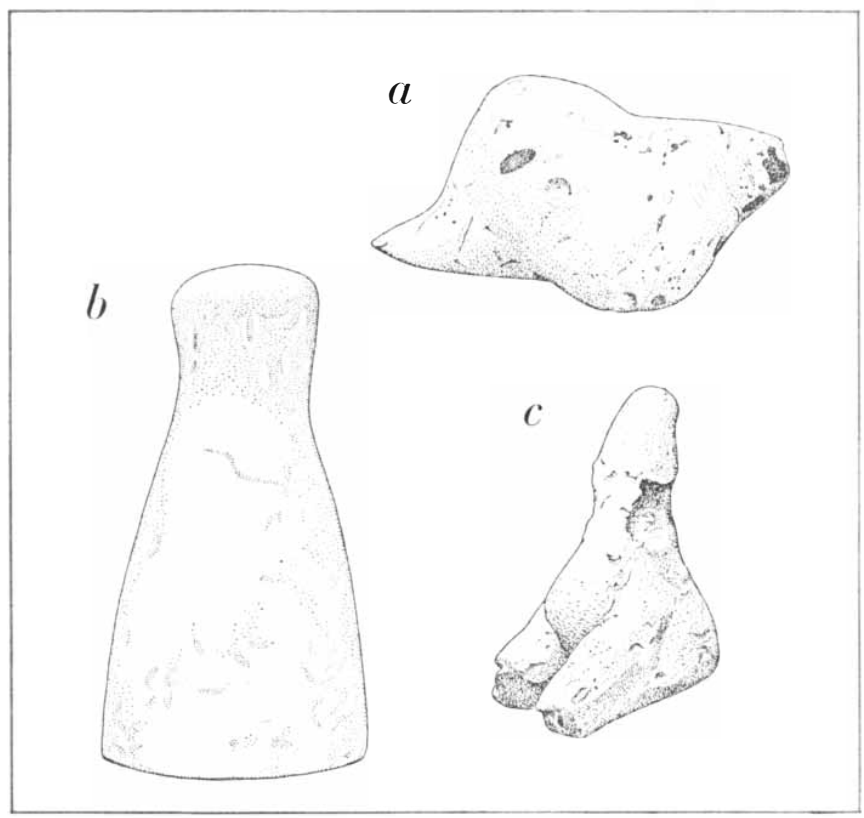
it stands on the north bank of a minor tributary of the Tigris. At some time in the past part of the mound's south side was washed away. At the foot of the talus slope on the river side we found fragments of crude and easily crumbled pottery that had been made by hand, rather than with the potter's wheel. Some additional potsherds were present on the northeast slope of the mound and in the top 10 or 15 centimeters of soil in our test excavations (about the depth to which the soil had been disturbed by modern plowing). Below that our 1964 excavations revealed no pottery. The presence in these lower levels of figurines made of clay shows that clay was known and used in the early days of Çayönü Tepesi. Like the people of Jarmo and some other early village-farming communities, however, the inhabitants of Çayönü Tepesi evidently got along without the clay bowls, jars and other containers that are commonplace in the villages of later farmers.

We worked at Çayönü Tepesi for two seasons—in 1964 and again in 1968—and we expect to work there again this year. Our main evidence concerning the early occupation of the site comes from a 10-by-15-meter area we excavated on the crest of the mound and a five-by-eight-meter trench we cut into the mound on the river side; both excavations were undertaken during the 1964 season [*see illustrations on page 50*]. Those who explore village sites in southwestern Asia come to expect that each new excavation will exhibit an exuberant characteristic that is distinctively its own. Çayönü Tepesi was no exception: its special characteristic is its architecture. Among the buildings we uncovered, several must have been quite imposing. The trench we cut back from the river revealed part of what could have been a building interior or perhaps an open court. The area was floored with a broad pavement of smooth flagstones, around which the stone bases of thick walls rose to a height of a meter or more. Spaced along the main axis of the paved area were the broken bases of a pair of large stone slabs that had once stood upright. From one of the stone walls buttresses projected at the points nearest the broken slabs. Another partly intact slab marked the area's short axis. Unfortunately erosion had eaten away the southern portions of this elaborate structure, so that its full plan is beyond recovery.

At the crest of the mound we dug down to a depth of more than three meters, encountering traces of at least six



THREE STONE IMPLEMENTS from Çayönü Tepesi are a flint projectile point (*a*), found during the 1968 season, a scraper of flint (*b*) and a polished stone celt, the bit of a compound cutting tool (*c*), unearthed in 1964. The artifacts are shown at their actual size.

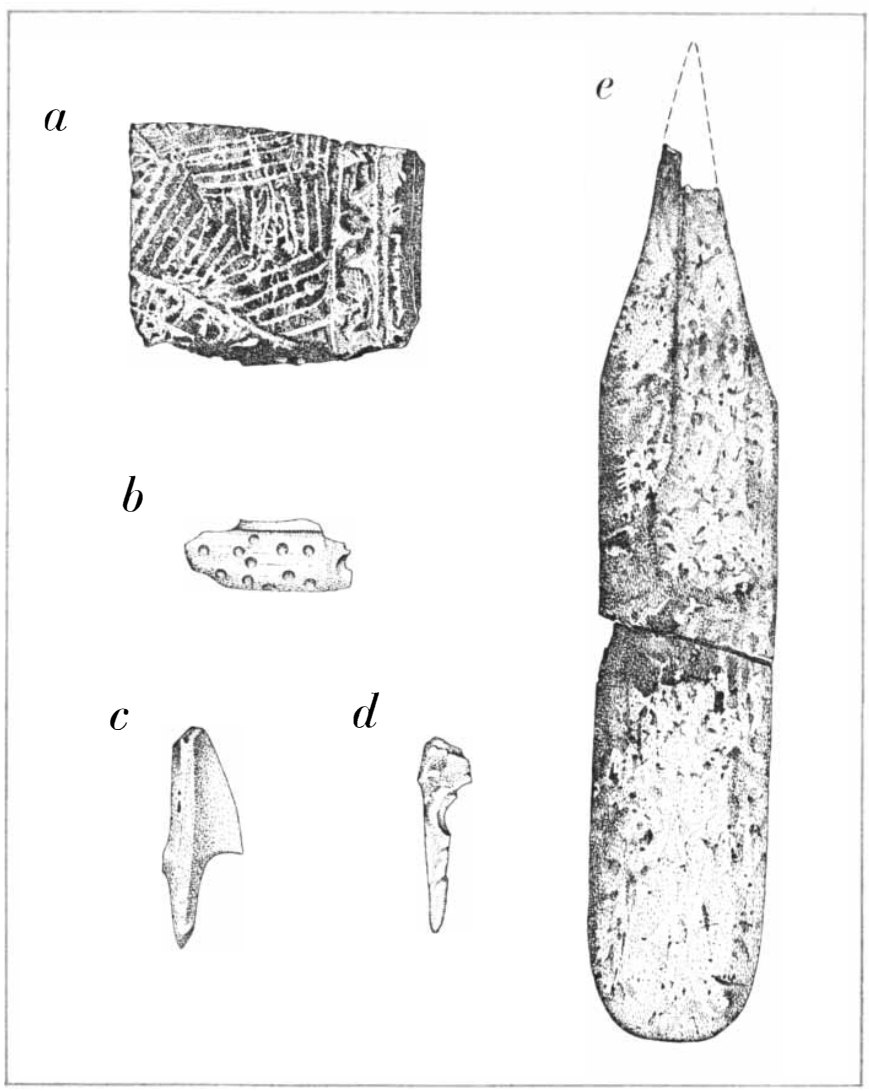


THREE ODDITIES from the site are a snail shell (*a*), a polished stone object (*b*) and a crude clay figurine (*c*). The shell, imported from the Mediterranean, has been smoothed and drilled with holes, presumably for decorative inserts. The stone, about three inches high, is one of 22 found in a cache during the 1968 season; their function is unknown. The figure seems to represent a pregnant woman; it may be a portrayal of the familiar "fertility deity."

successive levels of occupation. At the fourth level the bases of two more upright slabs rose from a broad pavement of fist-sized limestone cobbles; the broken upper portion of one slab lay beside its base. The fifth level, also paved with cobbles, contained the stone foundations of still another substantial structure. What we could perceive of the foundation plan showed a curious grill-like pattern [*see illustration on page 54*]. Our work in 1968 exposed another of these grill-like foundations. A similar foundation, although it is smaller and built of sun-dried mud walling rather than stone, was unearthed at Jarmo. We are still puzzled as to the function of such foundations.

The purpose of the upright slabs at Çayönü Tepesi is equally puzzling. We are of two minds about whether they could have been supports for roof beams. Our first notion was that the slabs might have been ceremonial stones set up within unroofed courts, but the actual function of the structures containing them is not yet clear. We are much impressed by the substantial proportions of the buildings and by the relative sophistication of their construction, but we are still loath to press any suggestion that they served a public or a sacred purpose.

In addition to its impressive architecture, Çayönü Tepesi yielded tools chipped from flint and obsidian or fashioned from stone by grinding, ornaments made of polished stone, the clay figurines mentioned above and one shell ornament. The last object indicates contact, direct or indirect, with the Mediterranean coast. If one adds to this inventory evidence what seems to be a primitive form of wheat and the remains of domesticated dogs, pigs, sheep and probably goats, one gains some sense of the quality of life here and in similar communities across southwestern Asia as the arts of farming and animal husbandry became established during the eighth millennium B.C. If that were all Çayönü Tepesi had to tell us, it would be enough. A combination of geological propinquity and archaeological good fortune, however, has made the site even more significant. We have found here what is so far the earliest evidence of man's intentional use of metal.



CRAFTSMANSHIP at Çayönü Tepesi included the decoration of stone bowls with incisions (*a*) and bone objects with drilled patterns (*b*). Drills flaked from flint (*c*, *d*) were used to work the bone. Bone awls (*e*) were probably used to produce wooden and leather items.

Turkey is rich in minerals; one of its major mining centers today—a deposit of native copper, copper ores and related minerals such as malachite—is less than 20 kilometers from Çayönü Tepesi. In our excavation at the crest of the mound we noticed, from just below the surface downward, dozens of fragments of a bright green substance that we took to be malachite. Below the fourth occupation level we began to find actual artifacts made of malachite: drilled beads, a carefully smoothed but undrilled ellipsoid and a small tablet. Next we found part of a tool—one end of a reamer with a square cross section—that had been hammered into shape out of a lump of native copper. Finally we uncovered three tiny objects of copper that are perhaps analogous to the ordinary modern straight pin. In two of these pins, which do not appear to be complete, the metal had been abraded to form a point at one end; the third pin was pointed at both ends and was sharply bent [*see illustration on page 51*].

Metallurgy, of course, involves the hot-working of metals, including such arts as smelting, alloying, casting and forging. We are making no assertion that any kind of metallurgy, however primitive, existed at Çayönü Tepesi; there is not even any unanimity of opinion among the experts about whether the reamer, the only article that had certainly been hammered, was worked cold or hot. The fact remains that sometime just before 7000 B.C. the people of Çayönü Tepesi not only were acquainted with metal but also were shaping artifacts out of native copper by abrading and hammering.

What we suggest is that the Çayönü Tepesi copper reveals the moment in man's material progress when he may first have begun to sense the properties of metal as metal, rather than as some peculiar kind of stone. Looking back from the full daylight of our own age of metals, these first faint streaks of dawn are exciting to behold.

We want to be useful ...and even interesting

Kodak

Hurry up and get well

Sir Luke Fildes' famous painting notwithstanding, a newer, cold-hearted tide of informed opinion about doctoring has begun to run. To the neglect of bedside demeanor, recognition is accorded such capabilities as resolving 30 distinct proteins in a couple of μl of serum.

Such an ability serves the public weal through science or the clinic, preventive or therapeutic. As for science, beating a drum most of the past decade for protein resolution by acrylamide-gel electrophoresis has also well served the EASTMAN Organic Chemicals business. The clinic has not yet been served so well. A procedure that takes 6 technician-hours to run costs too much. High cost, low volume. Low volume limits buildup of statistics by which to interpret a protein spectrum clinically. If computers are to help practice medicine as well as issue bills, then the doctor needs to consult the computer in terms the computer can understand.

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This new EASTMAN Organic Chemical, of all things, may help. It replaces the 2-3-hour, protein-denaturing staining and destaining step with a 2-5-minute delineation of the major zones by fluorescence. Only on the outer surface does our little lantern molecule covalently bond itself; the volume of the zone remains untouched. "Live" protein so pure and so easily isolated has obvious investigative value. Clinically, the speedup hastens the day when an acrylamide-gel protein pattern becomes as routine as weighing the patient.

Procedure was published only last month among the circle interested in —of all things—Neurospora, the bread mold beloved of geneticists. Copy from W. T. Fisher, Eastman Kodak Company, Rochester, N. Y. 14650.

Mangrove

Here's an instance where real-estate law and botany interlace in a mass as easy to penetrate as a mangrove shore.

Though shore property deeds run to the low-water line in northeastern Maine, it's the mean high-water line in South Florida. Where the Florida shore is not yet man-made, some of it is mangrove-made. With aerial roots and with vigorous germination while the fruit still hangs on the tree, mangrove has built this niche.

What with the very small elevation gradient, the human land-developers argue about where they own. We have been helping the state authorities grapple for a fair resolution.

KODAK EKTACHROME Infrared AERO Film extends color vision into the near-infrared. There it finds in plant tissues spread out beneath the aerial camera as subtle a play of colors—arbitrary though they be—as ever distinguished a Red Delicious apple from a Macintosh for a shopper who can't name a single plant pigment.

Gerald Norman of the Florida Department of Agriculture hopes a sharp split has occurred in mangrove speciation at the high-water line. Perhaps salinity makes the difference, perhaps time and distance out of water. He further hopes to show a reliable difference in infrared color. After all, in orange trees even differences in variety within a single species stand out this way from aloft. Perhaps "false color" can locate the high-water line honestly.

Mr. Norman's address is P.O. Box 1269, Gainesville, Fla. 32601, in case you'd like to keep in touch with his progress.

The novelty doesn't wear off

Most theater movie film is 35 millimeters wide. We cut it to that width to accommodate a customer named Thomas A. Edison, then moving into the business. Later we introduced 16mm movies for home entertainment. Our research director thought 16 millimeters would make a nice width for that purpose. Splitting it in half to make 8mm was a less arbitrary decision and a good one. It brought home-moviemaking down to where people could afford it. Now, of course, the home-movie market has gone to super 8, a format which uses the 8mm width more efficiently.

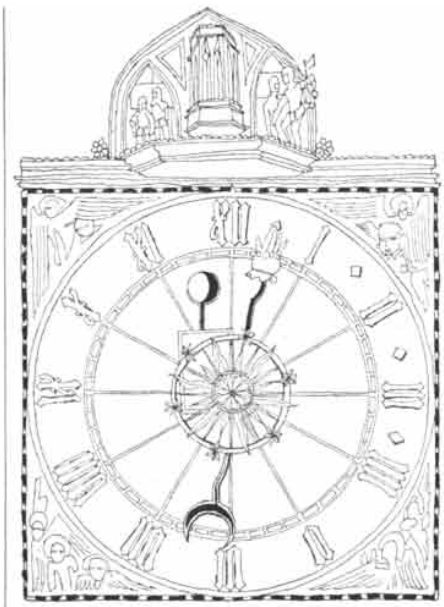
In each case, amusement of the public was the original scheme, with more serious applications developing later. Super 8 has already reached the point where much school-teaching is done by 2- or 3-minute "single-concept" films that a kid projects for himself alone; doctors counsel individual patients by handing them super 8 audience-of-one movies. At the same time, 16mm movies prosper as a medium by which the inspiration of the film artist can reach audiences assembling in larger numbers than ones and twos.

Three generations after that inquiry from Mr. Edison, the novelty of pictures that move hasn't worn off. Night after night after night the family watches images move, and yet audiences for good 16mm movies continue to assemble.

Right here we shall prove this again to ourselves. To have read this far puts you in a small minority characterized by unusual patience. Furthermore, and even less likely statistically, you are on a program committee willing to assemble at least 50 reasonably serious adults in front of a 16mm sound projector for 10 minutes of pure movie—no plot, no actors, only objects of the real world moving beautifully to music. We call it "Worth How Many Words." We have hundreds of prints we want to loan for showings.

Now watch the crunch as we invite you to request a booking from Fred German, Eastman Kodak Company, Rochester, N.Y. 14650.

SCIENCE AND



Things That Go Bump

The center of the galaxy may be emitting intense bursts of gravitational radiation, according to evidence reported at the recent annual meeting of the American Physical Society by Joseph Weber of the University of Maryland. The evidence was supplied by an array of ultrasensitive detectors designed and built by Weber over the past dozen years. The detectors are aluminum cylinders some five feet long and weighing from 1½ to four tons. Three of the cylinders are located at College Park, Md.; one is at the Argonne National Laboratory near Chicago. To isolate the cylinders from ordinary vibrations and shocks, they are suspended by wires from concrete piers. Piezoelectric crystals bonded to the surface of the cylinders detect changes in dimension as small as one part in 10^{16}, equivalent to an overall change in cylinder length of less than the diameter of a proton. The output of the Argonne detector is linked to Weber's laboratory in College Park, 600 miles away, by a high-quality telephone circuit.

Weber identifies a gravitational-wave "event" as the coincidental detection in Maryland and Illinois of a change in cylinder dimension significantly above the background noise. He regards two bursts as being coincidental if their leading edges fall within .3 second of each other. Last June in *Physical Review Letters* Weber reported a series of 17 coincidences over a three-month period. He calculated that in at least three cases the coincidences could have occurred by chance only once in more than 30,000 years. A fourth case—a triple coincidence—could have occurred only once in 70 million years.

Many physicists were skeptical. To satisfy the doubters Weber operated his equipment for a period with a time delay in one of the channels while simultaneously keeping a real-time record. With the time delay coincidences not attributable to chance were eliminated. The true record of events indicated that there had been about a dozen nonchance coincidences.

At the meeting of the Physical Society, Weber reported his most recent, and most surprising, results. An analysis of some 200 coincidences has now shown a 12-hour periodicity that is correlated with the twice-a-day passage of the center of the galaxy. Although the two detectors are not highly directional, they should respond preferentially to gravitational waves whose origin lies within 30 degrees of a plane perpendicular to the long axis of each cylinder. (The cylinders are all oriented east and west.) Weber reported that a large number of all the coincidences occurred when the galactic center was crossing the meridian or a line 180 degrees away on the other side of the earth. (The earth would be essentially transparent to gravitational waves.)

If Weber's detectors are indeed responding to gravitational radiation, what could be the significance of emanations predominantly from the center of the galaxy? Einstein's general theory of relativity predicts that gravitational waves should be produced by matter that is accelerating with respect to the observer. "Evidently," says Weber, "matter in the center of the galaxy is either collapsing or being rearranged on a grand scale."

Declassified

Two major universities have moved to dissociate themselves from secret research. Columbia University will no longer accept classified projects and Stanford University will relinquish its control of the Stanford Research Institute. The Columbia Senate, composed of faculty members, administrative officers and students, adopted new regula-

THE CITIZEN

tions in January under which the university may not participate in classified research for the Government or private industry. Nor will it accept contracts that place restrictions on the race, religion or political affiliation of the investigators or that retain a veto over the publication of results. Individual faculty members remain free to undertake classified projects as consultants if the university is not involved. Moreover, the regulations can be waived by a review board or the senate's committee on external relations and research. This may be done in the case of two of Columbia's current classified contracts, National Aeronautics and Space Administration projects that involve instrumentation for measuring lunar heat flow and seismic activity. Otherwise existing classified contracts must be terminated within a year.

The Stanford Research Institute was established in 1946 to do contract research for the Government and industry in many areas. Last May, following student demonstrations against the institute's military research, the Stanford trustees decided to separate it from the university. Under an agreement reached in January the institute will function as an independent nonprofit research organization under the control of its own board of trustees; it may continue to use the Stanford name for no more than five years. The institute will pay the university 1 percent of its gross operating revenue each year until $25 million has been paid, and then half of 1 percent a year. The institute's revenue last year was about $58 million.

Oklahoma Asteroid

The bright fireball that lit up the night sky over a large area of the Middle Western U.S. on January 3 appears to have had an orbit that extended from the asteroid belt between Mars and Jupiter to a small town near Tulsa, Okla., according to astronomers associated with the Smithsonian Astrophysical Observatory's Prairie Network, a system of 16 unmanned cameras set up six years ago to photograph such meteor trails in an effort to determine their orbits. A 22-pound fragment of the meteorite (which was estimated to have weighed perhaps as much as a ton before it broke up in

the earth's atmosphere) was recovered on January 9 in the middle of a country road outside Lost City, Okla., less than half a mile from the impact point predicted on the basis of photographs made by two of the Prairie Network's automatic cameras. A smaller fragment was discovered in the same general area a week later. The only other time a photographed meteorite was recovered was at Pribram in Czechoslovakia in 1959; it also seemed to have originated in the vicinity of the asteroid belt.

The Lost City meteorite, a common type known as a bronzite chondrite, was rushed immediately to the Smithsonian Institution in Washington for preliminary analysis. The quick recovery was deemed particularly valuable to workers engaged in the radioactive-isotope analysis of meteorites, since certain studies can be made before the low-level radioactivity created in the object by cosmic ray bombardment dissipates. Samples of the meteorite were promptly distributed for this purpose to several other laboratories.

The calculated trajectory of the meteorite appeared to support the view that many of these objects are fragments of asteroids. Nonetheless, the man who performed the orbital calculations, Richard E. McCrosky of Harvard University, added a word of caution. "The average age of this type of meteorite is about 60 million years," remarked McCrosky in a recent interview in *The Harvard Crimson*. "No one has yet found a mechanism that can move an asteroid from the asteroid belt into an earth-crossing orbit in such a short time. The only way would be a truly catastrophic event, and we would see shock effects in the meteorite if such an event occurred."

Alcator, Son of Tokamak

The recent revival of interest in the prospects for achieving a controlled thermonuclear reactor, inspired in large part by the success of the Russian Tokamak 3 experimental machine (see "Science and the Citizen," December, 1969), has led to plans for a number of modified Tokamak installations, including machines at the Oak Ridge National Laboratory and the Princeton Plasma Physics Laboratory. Now a third U.S. contender has entered the Tokamak sweepstakes in the hope of achieving a variety of new internal conditions that will be much closer to those needed to prove the feasibility of controlled fusion power. Its name is Alcator (from the Latin *alto campu torus,* or high-field torus), and it is to be built at the Massachusetts Institute of Technology by a research team from the Francis Bitter National Magnet Laboratory and the M.I.T. Plasma Physics Group.

Plasma-confinement experiments of this type use a magnetic field to confine a plasma, or gas of charged particles, while it is being heated to temperatures at which energy-releasing fusion reactions can take place between hydrogen nuclei in the plasma. In the Tokamak design a helical magnetic field surrounds a toroidal, or doughnut-shaped, plasma chamber; this field is actually a composite of two magnetic fields, one formed by an electric current flowing through coils wrapped around the outside of the chamber, and the other formed at right angles to the first by a current induced to flow within the plasma itself. The induced current heats the plasma as well as contributing to its confinement. In this respect the Tokamak design differs markedly from the American toroidal machines of the Stellarator type, in which the plasma-confining magnetic field is generated exclusively by a complex set of external coils.

Alcator will have all the basic design elements of the Russian Tokamaks but will operate at a much higher magnetic-field strength: 130,000 gauss as opposed to 25,000 gauss for Tokamak 3 and 40,000 gauss for the projected Tokamak 10. The stronger field will make possible very high induced heating currents, and hence a more rapid heating rate and much higher electron temperatures. Construction of Alcator, which has been funded by the Atomic Energy Commission, has already begun, with the first experiments expected to start in July, 1971.

Surge in Surgery

There are twice as many surgeons in proportion to the population in the U.S. as there are in England and Wales—and twice as many operations. Considering these statistics in an article in *The New England Journal of Medicine,* John P. Bunker of the Stanford University School of Medicine concludes that the major reason for the disparity is the difference in the organization of medical care in the U.S. and in Britain. The U.S. system may lead to an excess of surgeons in relation to the number of other physicians and to the provision of "luxury" surgery for the well-to-do at the expense of basic medical care for poor people.

Bunker finds that a number of factors contribute to the larger number of surgeons and operations in the U.S., including differences in populations and geography and in medical philosophy. "Given the choice of administering or withholding therapy, whether the therapy is prescribing drugs or performing an operation, the American physician appears likely to choose active therapy. The British surgeon, faced with the same choice and carrying a heavier work load, is apt to avoid surgery if the indication is in question." More important, he suggests, is the effect of Britain's National Health Service, both because it eliminates the fee-for-service consideration and because it is essentially a large group practice. Group practice, he says, encourages consultation (the British surgeon is a consultant who sees only patients referred to him by a general practitioner or internist) and ambulatory office care. These elements may decrease the need for hospital treatment, including surgery. Consultation appears also to "sharpen the criteria for surgery," reducing the number of operations. As for the method of payment, Bunker points out that in the U.S. surgical fees are larger than those in other specialties and may tend to attract physicians to the field, and that the "incentive" of the fee may tend to increase the number of operations in borderline cases. He concludes that there is probably a "disproportionate" number of surgeons in the U.S., at least in relation to total medical manpower, and that it is likely that "some unnecessary surgery is being performed."

In an editorial in the same issue of the *Journal* Francis D. Moore of the Harvard Medical School points out that the existence of differences between the British and the U.S. medical system does not in itself indicate which system is better. He grants that "for the pecuniary-minded physician and surgeon alike, or for psychiatrist or pediatrician, the American population is a happy hunting ground," and that data from Britain and from controlled clinical environments in the U.S. indicate that the American system of payment "has something to do with the frequency of operations." He maintains, however, that "we need more information on the extent to which surgical perfection is achieved in either, neither or both systems."

The Hills and Dales of Mars

The highlands and lowlands of Mars in the region of the equator have recently been mapped from the earth by two different techniques. They show that the variation from the lowest point to the highest is about 44,000 feet, which closely parallels the variation on the earth if allowance is made for Mars's

In cars, bigness for bigness' sake may soon be a thing of the past, and it's about time. Have you driven in the city lately? No doubt the utility car of the future is the very small kind that we see so many of already. But the *luxury* car of the future is,we believe, the new Rover 35OOS...

BABY V-8

TRADITIONALLY, big cars with big engines are supposed to be desirable for three reasons:

1) Because they are impressive to look at, thus winning their owners prestige; which, if it ever did make any sense, is making less sense every day as the streets and highways get more crowded.

A car's primary function is to get you to your destination, meaning it must be maneuverable in traffic and into parking places, if there is any room to maneuver and park in at all.

Take a Rover 35OOS out for a test drive in the city and you'll be amazed at its sheer manageability. Buy it and take it home and you'll be amazed at how much more easily you can get into, out of, and around it in your own garage. We think you'll agree that for this kind of convenience an impressive appearance might well be sacrificed. (But we also think you'll agree that we haven't.)

2) Big cars with big engines are more powerful, and the more power and acceleration you have, the better.

For drag-racing, perhaps. But that's not our game, and we doubt very much if it's yours. Consequently the kind of power today's automobile advertising makes so much of is really surplus power, good for nothing in real-life driving except to wear out tires and use up fuel at an appalling rate.

Ours is a Baby V-8 by those standards. By sensible ones, however, and in a sensible-sized car like ours, it has the extra power it takes to operate its automatic transmission and power steering, and to cruise for hours at freeway speeds with absolute ease. (The top speed, about 117 m.p.h.) It has the extra acceleration required in everyday emergencies such as getting *onto* a freeway. (Zero to sixty in 10.8 seconds.) And yet in high-speed transcontinental test-runs during three years of development in this country, test cars regularly averaged 17 m.p.g.

Our V-8 with a comparably priced one of Theirs, outlined, in true proportion.

So, unless conspicuous consumption is really what you want in a car, our Baby V-8 is ideal.

3) Finally, big cars are supposed to ride better and be more comfortable than smaller cars, which may be true of limousines compared to dune buggies, but hardly of outsized sedans compared to the 35OOS.

A smooth ride is a matter of suspension design, not of sheer size. And of course there is much more to a comfortable interior than mere elbow-room. Without going into the jargon of the Rover 35OOS's suspension layout or trying to describe the ambiance of its interior via air-flow, seat-contours and the like, we simply defy anyone to get more comfortable in any other car, no matter how much bigger it is.

According to *Car Life* magazine's road test report, "The engineering editor said the Rover 35OOS is the best handling boulevard-ride car he's driven, and that we could quote him."

To sum up: Bigness in cars is a thing to be avoided, short of inconveniencing the driver and passengers. The Rover 35OOS is a splendid example of how, with ingenuity, this can be done without sacrificing any of the conveniences larger cars offer. (For instance its trunk can be enlarged, for those rare occasions when trunks *are* used to capacity, by mounting the spare tire on the lid.) Indeed, we've kept it down to a handy size without even sacrificing any of the *luxuries* larger cars offer. In addition to those already mentioned, the 35OOS offers power-assisted disc brakes, electrically operated windows, integrated heating and ventilation, optional thermostatically controlled air-conditioning and heating system, and a long list of other standard equipment and options that a Rover dealer will be glad to run down with you. Then test drive it, and we believe you'll see all the bigger V-8s for what they really are. Gross.

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smaller diameter: 4,200 miles compared with 7,900 miles for the earth. The maximum variation on the earth from the depth of the Mariana Trench in the western Pacific (36,198 feet below sea level) to the top of Mount Everest (29,028 feet) is some 65,000 feet.

One determination of the surface relief on Mars was made by radar over a two-month period last summer when the planet was about 45 million miles away. The observer was Richard Goldstein of the California Institute of Technology. He used an 85-foot dish antenna at the Goldstone tracking station near Barstow, Calif., to beam 12.5-centimeter radar pulses of 450 kilowatts to Mars. A nearby 210-foot radio telescope recorded the echoes, which returned about eight minutes later. Slight variations in the round-trip travel time could be attributed to differences in elevation on the surface of the planet. Each observation indicated the average elevation of an area about 60 miles on a side. In all, 400 areas were measured in a belt 10 degrees wide around the equator of Mars.

An independent series of relief determinations was made in the same period by Ronald A. Wells of the University of California at Berkeley, who worked with the 60-inch McMath solar telescope at the Kitt Peak National Observatory near Tucson, Ariz. The telescope had previously been equipped with a multislit spectrophotometer by Michael J. S. Belton and Donald M. Hunten of the Kitt Peak staff. Their device stabilizes the image of the planet at the aperture of a spectrometer; an image slicer enables the observer to select a small spot from the image for spectral analysis. The spot measures some 800 miles on a side. Wells measured the strength of carbon dioxide absorption lines as an index of the depth of the atmosphere of Mars and from this inferred the elevation of the surface. His measurements closely supported the radar observations. The results of the two studies will be valuable in selecting landing sites for future spacecraft: a maximum depth of atmosphere will be desirable if parachutes, rather than braking rockets, are selected for the landing attempt.

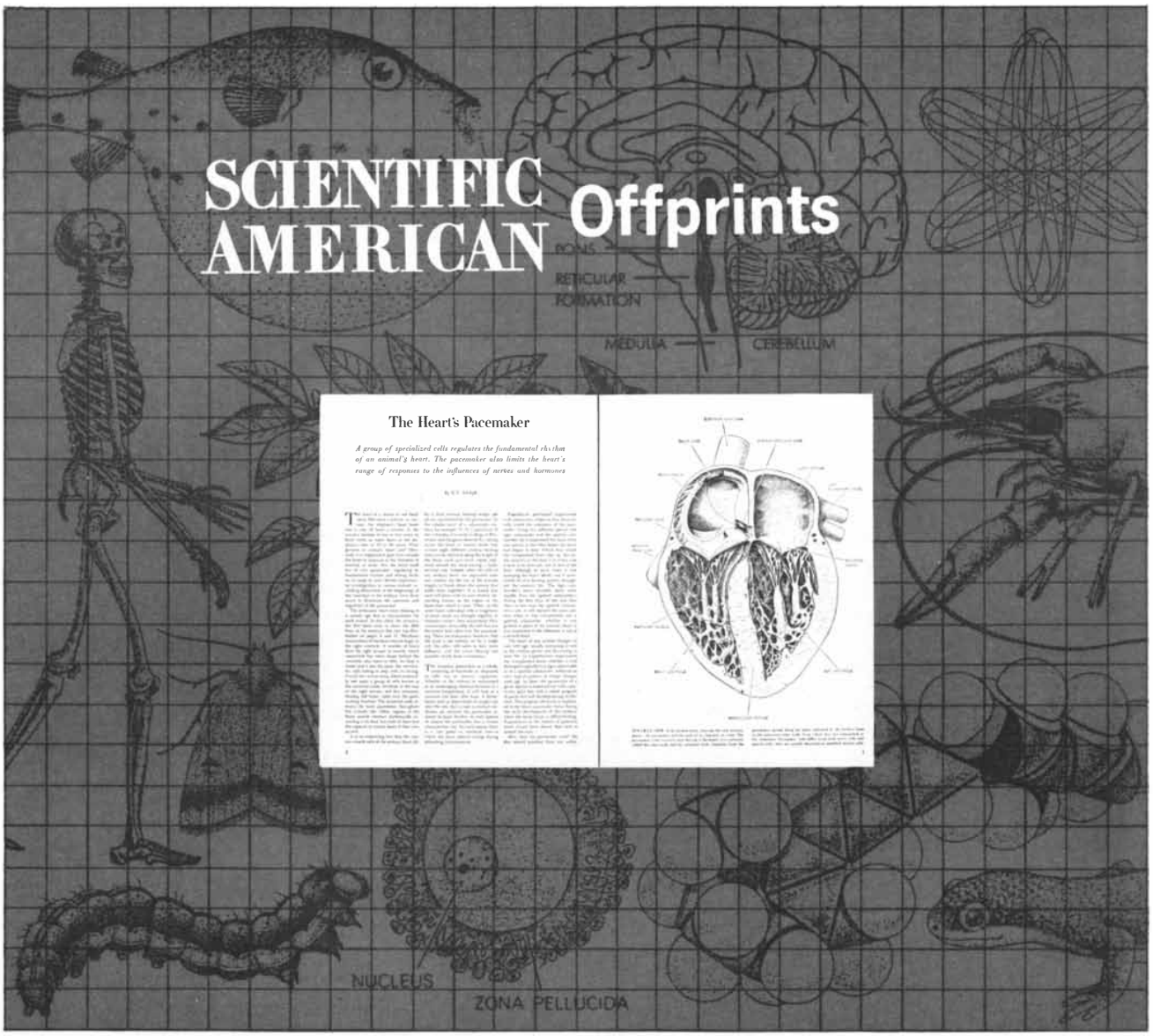
Photographic Memory

For years psychologists have sought ways to prove the existence of eidetic imagery: the reputed ability of some people to re-create and hold in their "mind's eye" an exact copy of a scene, even a page of text. A remarkable feature of an eidetic image is that it evidently remains fixed, allowing the observer to inspect it in detail by moving his eyes. In one test of eidetic imagery the observer is shown two pictures in sequence and interrogated about features that could only result from exact superpositioning of the two images. Even this test, however, fails to distinguish unequivocally between eidetic imagery and an exceptional memory.

A test that demonstrates the existence of eidetic imagery beyond all reasonable doubt is now reported in *Nature* by C. F. Stromeyer III of the Massachusetts Institute of Technology and J. Psotka of Harvard University. They employ stereoscopic pairs of computer-generated random-dot patterns, originally devised by Bela Julesz of the Bell Telephone Laboratories to investigate stereoscopic vision. Julesz proved that two patterns containing no recognizable content or structure, when viewed separately, could produce clear three-dimensional symbols or structures when fused binocularly. For example, fusion of the two dot patterns might produce a block-letter *T* that appears to float above (or, as the case may be, below) the background. The patterns are of course generated in such a way as to yield the intended result.

In the experiments described by Stromeyer and Psotka the observer views one pattern with the left eye and a short time later views the companion pattern with the right eye. The patterns are projected through Polaroid filters and viewed through Polaroid glasses so that each eye sees only the image intended. In the first set of experiments the left-eye image was presented for one minute. Following a 10-second rest the right-eye image was presented. The best subject, a 23-year-old teacher at Harvard, quickly identified the hidden figure: a *T*. Later she had no trouble seeing the intended figure (an inverted *T*) when the interval between the two projections was lengthened to 10 minutes. To the astonishment of the investigators, she was able to preserve an eidetic image of the first pattern of a different pair for 24 hours, after viewing it for a total of 12 minutes divided into four periods of three minutes each. The fused image represented a square standing in front of a background.

To demonstrate that no cheating was involved, the experiment was repeated on a double-blind basis: neither the investigator nor the subject knew what the dot pattern contained in advance. In these experiments the subject successfully fused two 10,000-dot patterns even



"...Certainly, the reading of this number of good articles in science must be making some impact on the educational process in this country..."

Philip E. Hartman, in THE QUARTERLY REVIEW OF BIOLOGY, 41(2), 1966 [commenting on the fact that some 9,000,000 SCIENTIFIC AMERICAN Offprints had been sold up to that time. The number has nearly tripled since then.]

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when the interval between the viewing of the two patterns was extended to three days.

Globe-Trotter's Peril

The painful, nauseating but feverless disease known as "traveler's diarrhea" has often been blamed on a change in water or climate, on chilled drinks and on other dietary indiscretions. Its actual cause now seems to be known; it appears to result from the sufferer's ingestion of the intestinal bacterium *Escherichia coli,* but a bacterium that belongs to a strain different from those he already harbors. Evidence for this conclusion comes from a close watch kept on 540 British soldiers during their first six weeks of duty in southwestern Arabia in 1965. The study was conducted by B. Rowe, Joan Taylor and K. A. Bettelheim, specialists in gastric diseases at the Central Public Health Laboratory in London.

Reporting in *The Lancet,* the investigators state that 38 soldiers complained of diarrhea within 14 days of their arrival by air in the crown colony of Aden. Thirty-five of the men were given detailed examinations. Two had contracted dysentery, but the remaining 33 showed no evidence of infection by the classic dysenteric organisms shigella and salmonella. Cultures from nearly two-thirds of the 33, however, contained a strange strain of *E. coli* that was present neither among the 100-odd healthy soldiers who formed a control group nor among any of the 12 additional sufferers from dysentery during the six-week period.

The Aden strain of *E. coli* is not among the more than 5,000 strains normally found in England. Further evidence that it was the cause of the soldiers' distress turned up in 1966, when a technician in England who was accidentally exposed to a culture of the strain promptly suffered an attack of diarrhea. The investigators conclude that most travelers succumb to diarrhea because they lack immunity to some alien strain of *E. coli* they encounter abroad.

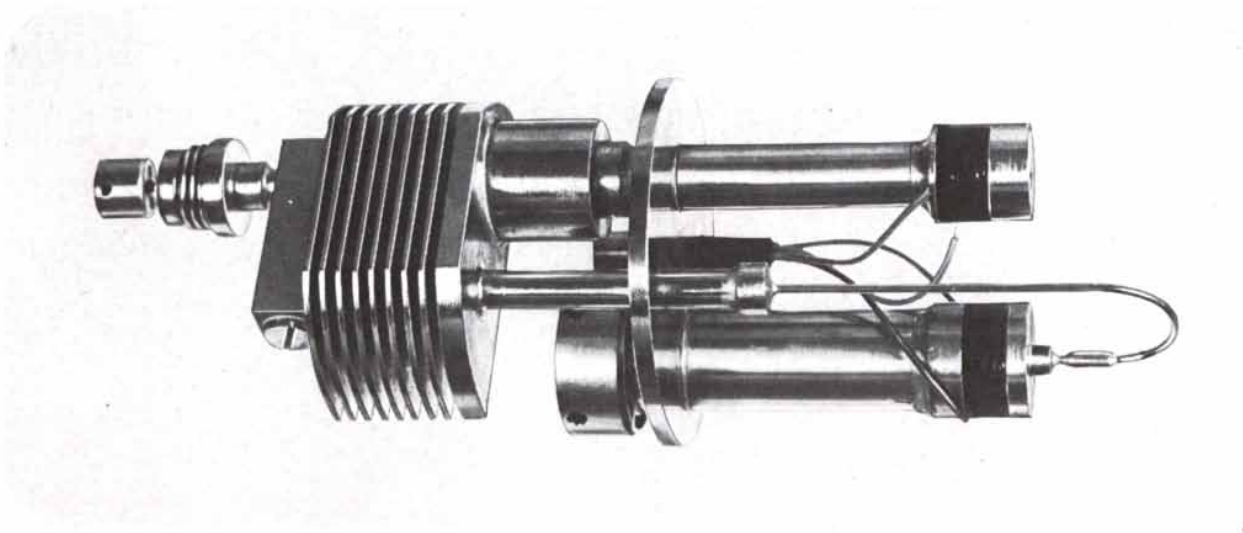
Squeeze Play

A remarkably cooperative trained dolphin has made a contribution toward answering the question of why deep-diving marine mammals do not suffer the nitrogen-induced "bends" and "rapture of the deep" that endanger human divers. Some species of seals evidently do not accumulate nitrogen in their blood because they empty their lungs before each dive. Whales, however, do not empty their lungs, and it has been suggested that the increasing pressure the animal encounters as it dives acts on its lungs in a way that prevents the transfer of nitrogen from the lungs to the blood. A study of the bottlenose dolphin (*Tursiops truncatus*) now indicates that, at least in this species of toothed whale, the pressure of deep diving does prevent significant nitrogen transfer.

A trained male bottlenose dolphin was taught to respond to underwater acoustical signals by Sam H. Ridgway and B. L. Scronce of the U.S. Navy's Undersea Research and Development Center and their colleague John Kanwisher of the Woods Hole Oceanographic Institution. They report in *Science* that the animal was rewarded after performing three different tasks: holding its breath just below the surface, swimming vigorously at a depth of 60 feet or diving to depths ranging from 300 to 900 feet. After each performance the dolphin would exhale into a funnel held underwater, enabling the experimenters to collect air samples for analysis.

While swimming at the surface the bottlenose dolphin consumes 1.3 liters of oxygen per minute. The proportion of oxygen to the other gases in its exhaled air when it is at the surface is 13 percent. The proportion drops to 3 percent after two minutes of vigorous underwater swimming and to 2 percent after four minutes of breath-holding. Under the pressure of deep diving more oxygen rather than less should enter the animal's blood, but the experimenters found that after a four-minute trip to 900 feet and back the animal exhaled air that contained more than 4 percent oxygen.

The flexible thoracic region of the bottlenose dolphin is readily deformed by increasing water pressure; the beginning of the process can be observed in as little as 30 feet of water. The experimenters suggest that the deformation somehow isolates the air sacs of the animal's lungs from the lungs' content of gas during deep dives, preventing both oxygen and nitrogen transfer. The animal's ability to survive for minutes on a supply of oxygen scarcely sufficient to maintain its heartbeat suggests to the investigators that in initially adapting to a marine environment the bottlenose dolphin (and probably most other sea mammals) became able to tolerate much greater oxygen deprivation than terrestrial mammals can.



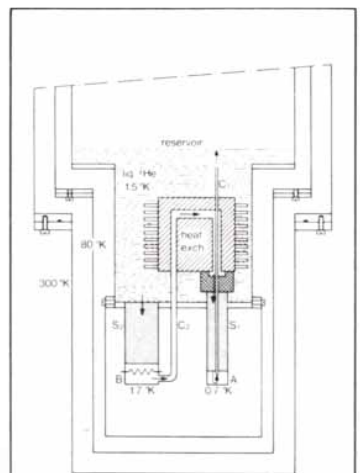
Actual size

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 of 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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The Functional Organization of the Brain

The sensory and motor functions of the human brain are well localized, but more complex functions such as speech and writing remain obscure. Injuries to the brain provide clues to how such systems are organized

by A. R. Luria

The functional organization of the human brain is a problem that is far from solved. I shall describe in this article some recent advances in the mapping of the brain. They open up a new field of exploration having to do with the structures of the brain involved in complex forms of behavior.

So far as sensory and motor functions are concerned, the brain, as is well known, has been mapped in precise detail. Studies by neurologists and psychologists over the past century have defined the centers that are responsible for some elementary functions such as seeing, hearing, other sensory functions and the control of the various muscular systems of the body. From outward symptoms or simple tests disclosing a disturbance of one of these functions it is possible to deduce the location of the lesion (a tumor or a hemorrhage, for example) causing the disturbance. Such a finding is of major importance in neurology and neurosurgery. The sensory and motor centers, however, account for only a small part of the area of the cerebral cortex. At least three-quarters of the cortex has nothing to do with sensory functions or muscle actions. In order to proceed further with the mapping of the brain's functions we must look into the systems responsible for the higher, more complex behavioral processes.

It is obvious that these processes, being social in origin and highly complex in structure and involving the elaboration and storage of information and the programming and control of actions, are not localized in particular centers of the brain. Plainly they must be managed by an elaborate apparatus consisting of various brain structures. Modern psychological investigations have made it clear that each behavioral process is a complex functional system based on a plan or program of operations that leads to a definite goal. The system is self-regulating: the brain judges the result of every action in relation to the basic plan and calls an end to the activity when it arrives at a successful completion of the program. This mechanism is equally applicable to elementary, involuntary forms of behavior such as breathing and walking and to complicated, voluntary ones such as reading, writing, decision-making and problem-solving.

What is the organizational form of this system in the brain? Our present knowledge of neurology indicates that the apparatus directing a complex behavioral process comprises a number of brain structures, each playing a highly specific role and all under coordinated control. One should therefore expect that lesions of the structures involved might result in changes in the behavior, and that the nature of the change would vary according to the particular structure that is damaged.

A New Approach

This concept forms the basis of our new approach to exploration of the functional organization of the brain—a study we call neuropsychology. The study has two objectives. First, by pinpointing the brain lesions responsible for specific behavioral disorders we hope to develop a means of early diagnosis and precise location of brain injuries (including those from tumors or from hemorrhage) so that they can be treated by surgery as soon as possible. Second, neuropsychological investigation should provide us with a factor analysis that will lead to better understanding of the components of complex psychological functions for which the operations of the different parts of the brain are responsible.

The human brain can be considered to be made up of three main blocks incorporating basic functions. Let us examine the responsibilities of each block in turn.

The first block regulates the energy level and tone of the cortex, providing it with a stable basis for the organization of its various processes. The brilliant researches of Horace W. Magoun, Giuseppe Moruzzi, Herbert H. Jasper and Donald B. Lindsley located the components of the first block in the upper and lower parts of the brain stem and particularly in the reticular formation, which controls wakefulness. If an injury occurs in some part of the first block, the cortex goes into a pathological state: the stability of its dynamic processes breaks down, there is a marked deterioration of wakefulness and memory traces become disorganized.

I. P. Pavlov observed that when the normal tone of the cortex is lowered, the "law of force" is lost and much of the brain's ability to discriminate among stimuli suffers. Normally the cortex reacts powerfully to strong or significant stimuli and responds hardly at all to feeble or insignificant stimuli, which are easily suppressed. A weakened cortex, on the other hand, has about the same response to insignificant stimuli as to significant ones, and in an extremely weakened state it may react even more strongly to weak stimuli than to strong ones. We all know about this loss of the brain's selectivity from common experience. Recall how diffuse and disorganized our thoughts become when we are drowsy, and what bizarre associations the mind may form in a state of fatigue or in dreams.

Obviously the results of injury to the first block in the brain, namely the loss of the selectivity of cortical actions and of normal discrimination of stimuli, will bring about marked changes in behavior. The control of behavior becomes deranged. In our common work with Mac-

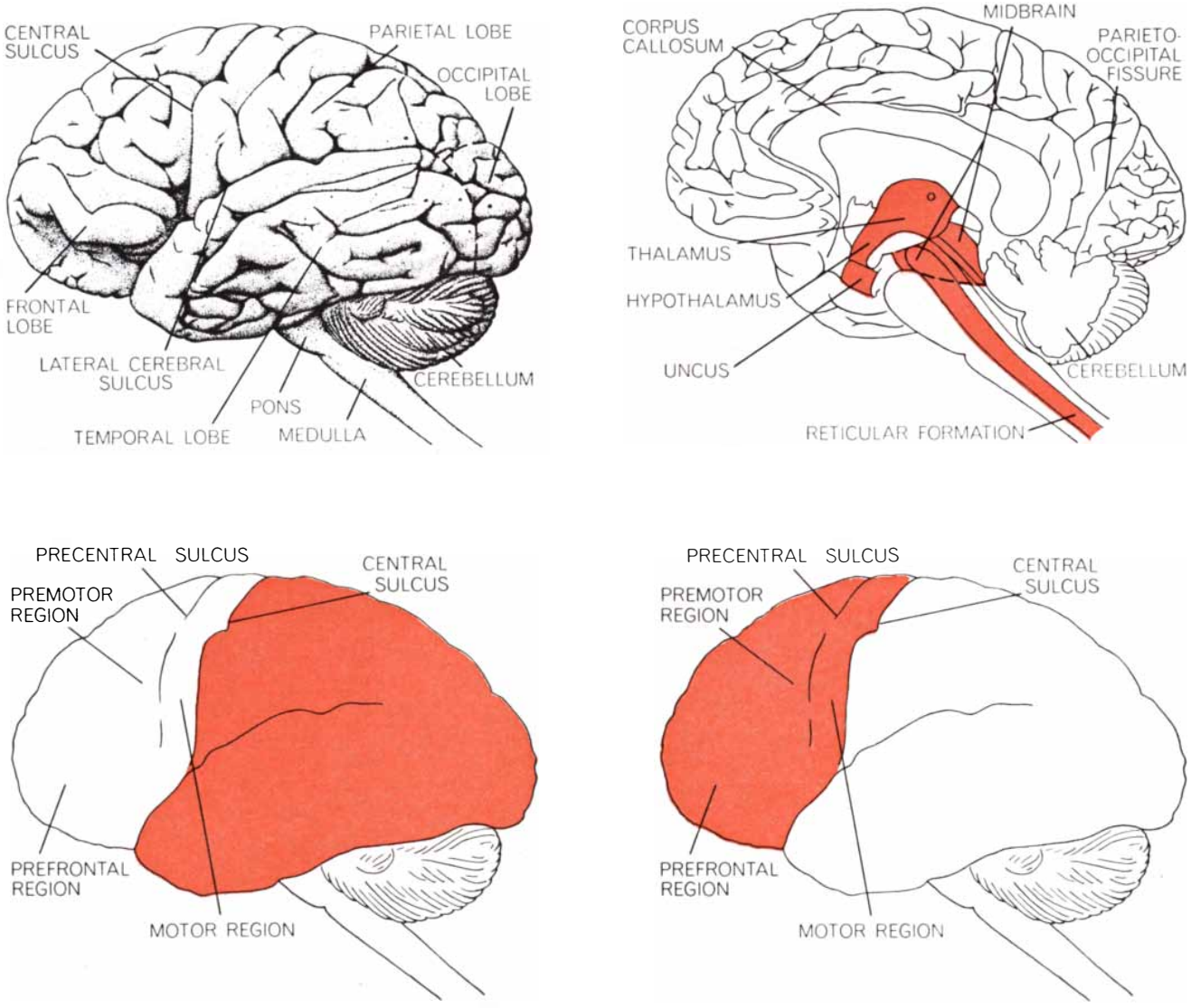
donald Critchley of England such disturbances have been observed in patients who had tumors of the middle parts of the frontal lobes, and other investigators in our laboratory in Moscow have since reported similar effects from lesions in deep parts of the brain.

The Second Block

The second block of the brain has received much more study, and its role in the organization of behavior is better known. Located in the rear parts of the cortex, it plays a decisive role in the analysis, coding and storage of information. In contrast to the functions of the first block, which are mainly of a general nature (for example controlling wakefulness), the systems of the second block have highly specific assignments. We can easily identify areas in the second block that are respectively responsible for the analysis of optic, acoustic, cutaneous and kinesthetic stimuli. Each of these cortical areas has a hierarchical organization: a primary zone that sorts and records the sensory information, a secondary zone that organizes the information further and codes it and a tertiary zone where the data from different sources overlap and are combined to lay the groundwork for the organization of behavior.

Injuries to the parts of the second block produce much more specific effects than lesions in the first block do. An injury in a primary zone of the second block results in a sensory defect (in seeing or hearing, for example); it does not, however, bring about a marked change in complex forms of behavior. A lesion in a secondary zone produces more complicated disturbances. It interferes with analysis of the sensory stimuli the zone receives and, because the coding function is impaired, the lesion leads to disorganization of all the behavioral processes that would normally respond to these particular stimuli. It does not disturb any other behavioral processes, however, which is an important aid for locating the lesion.

Of the various lesions in the second block of the brain those in the tertiary zones are particularly interesting to us as neuropsychologists. Since these zones are responsible for the synthesis of a collection of information inputs from different sources into a coherent whole, a lesion of a tertiary zone can cause such complex disturbances as visual disorientation in space. The lesion seriously im-



REGIONS OF THE BRAIN are identified. The gross anatomy of the human brain is depicted at upper left. The other drawings identify three major blocks of the brain involved in the organization of behavior. The first block (*upper right*) includes the brain stem and the old cortex. It regulates wakefulness and the response to stimuli. The second block (*lower left*) plays a key role in the analysis, coding and storage of information. The third block (*lower right*) is involved in the formation of intentions and programs.

pairs the ability to handle complex problems that entail an organization of input in simultaneous matrixes. That is why these lesions may render a person incapable of performing complex operations with numbers or of coping with a complexity in grammar logic or language structure.

The Third Block

The third block of the brain, comprising the frontal lobes, is involved in the formation of intentions and programs for behavior. Important contributions to elucidation of the functions of the frontal lobes have been made by S. I. Franz, L. Bianchi, Karl H. Pribram and Jerzy Konorski through studies of animals and by V. M. Bekhterev, C. Kleist and Derek E. Denny-Brown through clinical observations. We have devoted much study to the roles of the third block in our laboratory.

The frontal lobes perform no sensory or motor functions; sensation, movement, perception, speech and similar processes remain entirely unimpaired even after severe injury to these lobes. Nevertheless, the frontal lobes of the human brain are by no means silent. Our findings make it clear that they participate to a highly important degree in every complex behavioral process.

Intimately connected with the brain stem, including its reticular formation, the frontal lobes serve primarily to activate the brain. They regulate attention and concentration. W. Grey Walter showed a number of years ago that the activity of the brain could be measured by the appearance of certain slow brain waves in an electroencephalogram; these waves are evoked when a subject is stimulated to active expectancy and disappear when the subject's attention is exhausted [see "The Electrical Activity of the Brain," by W. Grey Walter; SCIENTIFIC AMERICAN, June, 1954]. At about the same time M. N. Livanov, a Russian investigator, found that mental activity is signaled by a complex of electrical excitations in the frontal cortex and that these excitations disappear when the subject subsides to a passive state or is lulled with tranquilizers.

Functional Systems

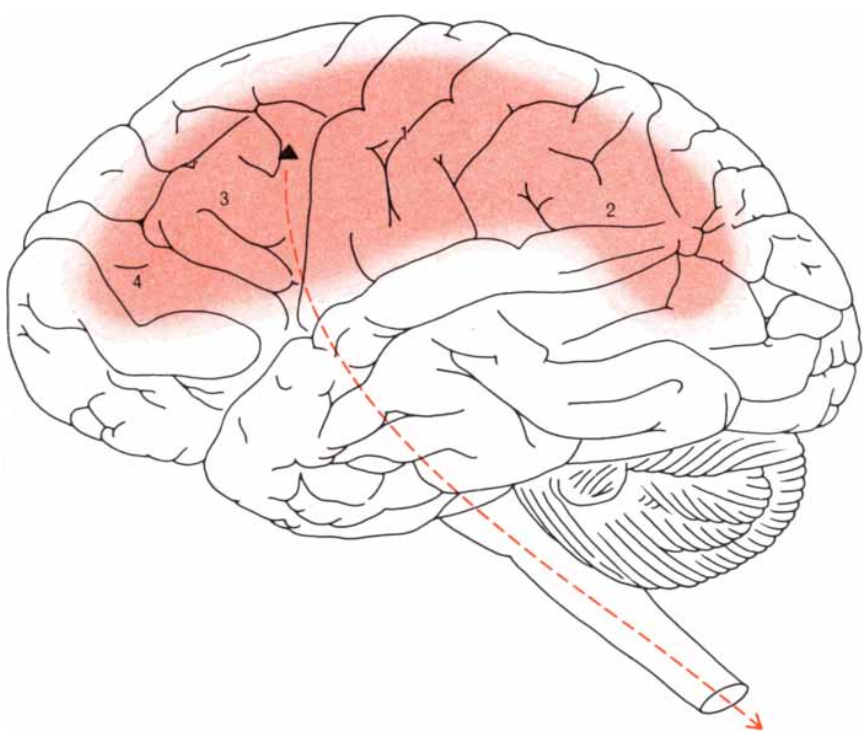
Now that we have reviewed the functions of the brain's basic blocks, let us see what we can learn about the location of specific parts of the various functional systems. It is clear that every complex form of behavior depends on the joint operation of several faculties located in different zones of the brain. A disturbance of any one faculty will affect the behavior, but each failure of a specific factor presumably will change the behavior in a different way. We have explored these effects in detail with a number of psychological experiments.

To illustrate our findings I shall discuss the results of a neuropsychological analysis of two processes. One is voluntary movement; the other is speech and in particular one of its forms, namely writing.

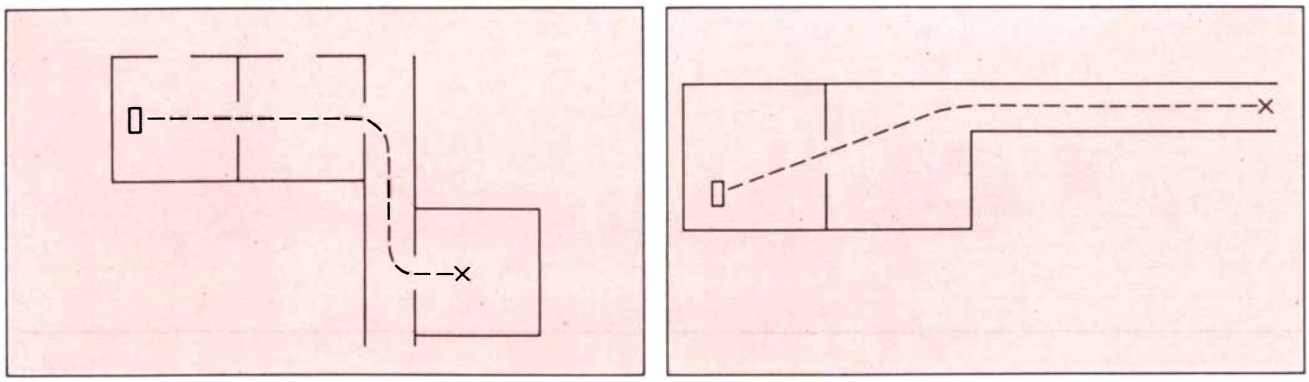
It was long supposed that voluntary movements are a function of the motor cortex, that is, the large pyramidal cells of the cortex of the anterior convolution of the brain. These cells, discovered by the Russian anatomist V. A. Betz more than 100 years ago, have exceptionally long axons that conduct the excitation toward the roots of the spinal cord. Impulses from these cells result in the constriction of muscles and are supposed to be the neurophysiological basis of voluntary movement.

Up to a certain point this is true, but the mechanism of the formation of a voluntary movement is much more complicated. To think that a voluntary action is formed in the narrow field of the motor cortex would be a mistake similar to an assumption that all the goods exported through a terminal are produced in the terminal. The system of cortical zones participating in the creation of a voluntary movement includes a complex of subcortical and cortical zones, each playing a highly specific role in the whole functional system. That is why lesions of different parts of the brain can result in the disturbance of different voluntary movements.

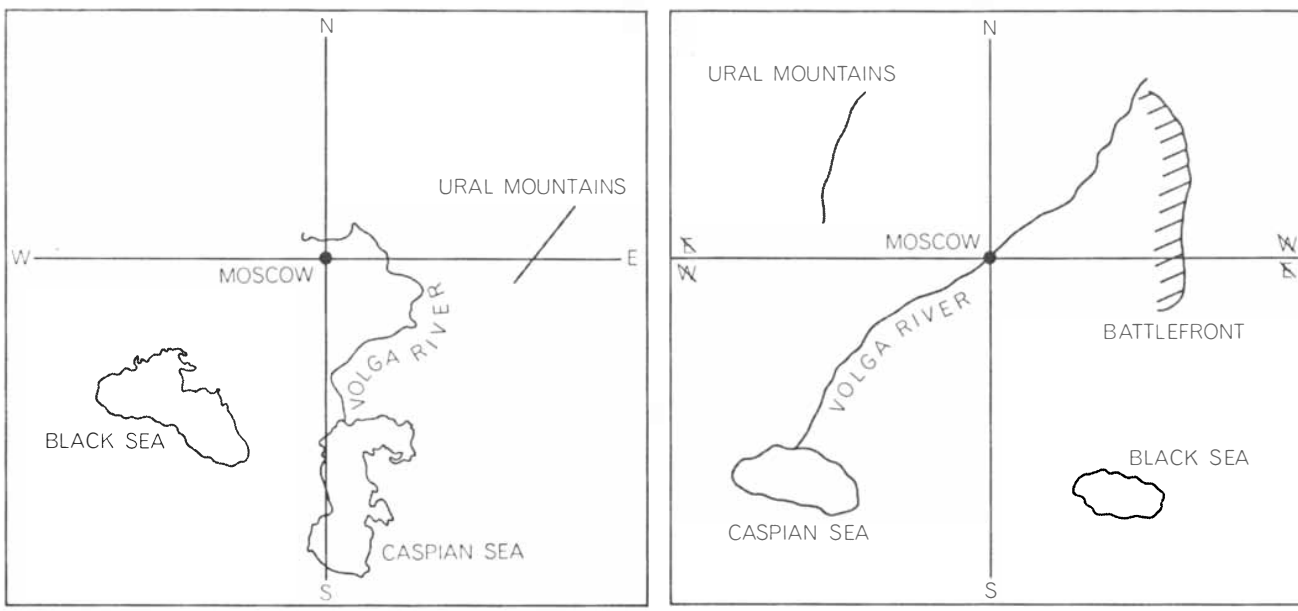
Let us examine the components of voluntary movement and see how it is affected differently by lesions in different parts of the brain. The first component is a precisely organized system of afferent (sensory) signals. The Russian physiologist N. A. Bernstein has shown in a series of studies that it is impossible to regulate a voluntary movement only by way of efferent impulses from the brain to the muscles. At every moment of the movement the position of the limb is different, and so is the density of the muscles. The brain has to receive feedback from the muscles and joints to correct the program of impulses directed to the motor apparatus. One can recognize the nature of the problem by recalling how difficult it is to start a leg movement if



VOLUNTARY MOVEMENT is controlled by a complex of cortical and subcortical zones. The classical theory was that voluntary movement originated with the large pyramidal cells (*arrowhead*) of the cortex; they have long axons that conduct impulses to the spinal cord. It is now known that other zones participating in voluntary movement are the postcentral zone (*1*), which deals with sensory feedback from the muscles; the parieto-occipital zone (*2*), which is involved in the spatial orientation of movement; the premotor zone (*3*), which deals with the separate links of motor behavior, and the frontal zone (*4*), which programs movements. Lesions in different zones give rise to different behavioral aberrations.



SPATIAL DISORGANIZATION is evident in a patient who had a gunshot wound of the right parieto-occipital part of the brain. The patient was asked to depict the layout of his hospital ward. His visualization is at right and the actual layout of the ward is at left.



CONFUSION OVER DIRECTIONS was manifested by another patient with a gunshot wound of the right parieto-occipital zone. He was asked to draw a map of the region of the U.S.S.R. where he had been involved in fighting during World War II. The actual geographical relations are shown at left; the patient's view is at right. The line of battle represented on his map was in fact west of Moscow. In addition to reversing most of the locations, the patient could not make up his mind on the labeling of east and west.

the leg has become numb. This sensory or proprioceptive base is provided by a special part of the brain: the postcentral sensory cortex. If this part of the cortex is destroyed by a wound or other injury, the patient not only loses sensation in the limb but also is unable to fulfill a well-organized voluntary movement.

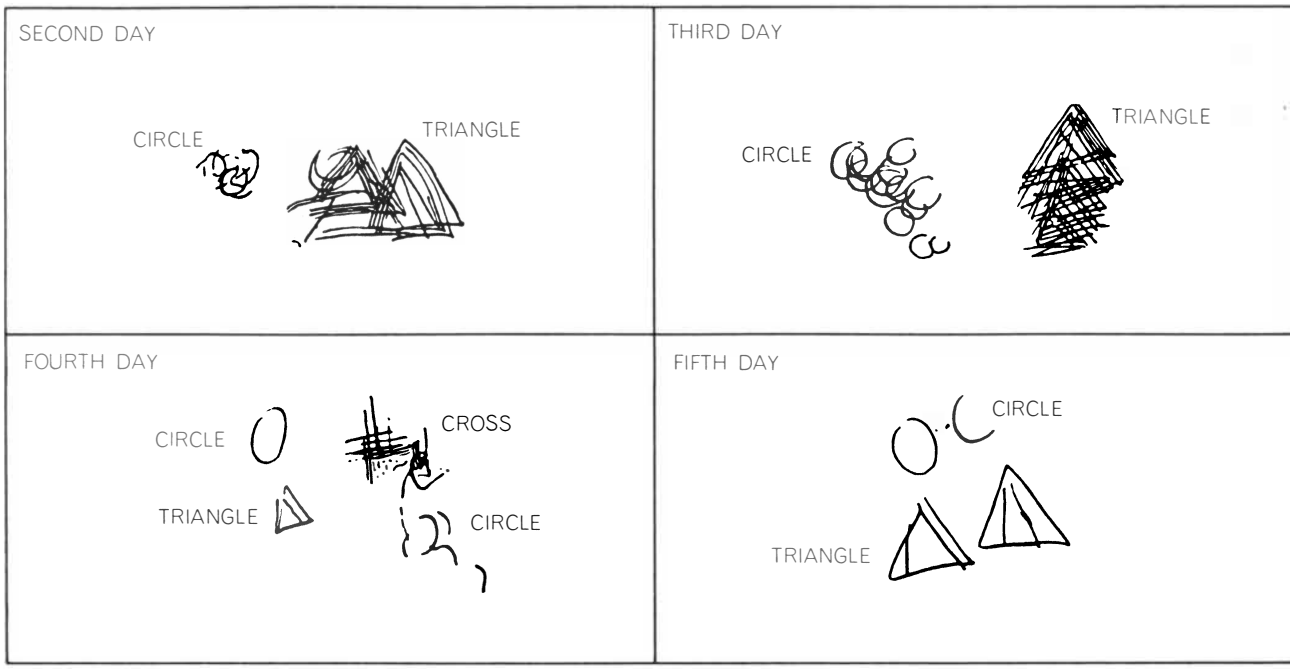
One of our co-workers has studied the physiological mechanism of such a disturbance and has shown that in lesions of the sensory part of the cortex every voluntary impulse loses its specific "address" and arrives equally at all muscles, both flexors and extensors. No organized movement can be elicited in such conditions. That is why neurologists have called this kind of motor disturbance afferent paresis.

A second component of voluntary movement is the spatial field. The movement has to be precisely oriented toward a certain point in space. Spatial analysis is done in another zone of the cortex: the tertiary parts of the parieto-occipital areas. Lesions of these highly complicated parts of the cortex result in a different kind of disturbance of voluntary movement. The sensory base of the movement remains intact, but the patient fails in a precise spatial organization of the movement. He loses the ability to evaluate spatial relations and confuses left and right. Such a patient may be unable to find his way in a familiar place or may be confused in such matters as evaluating the position of the hands of a watch or in distinguishing east and west on a map.

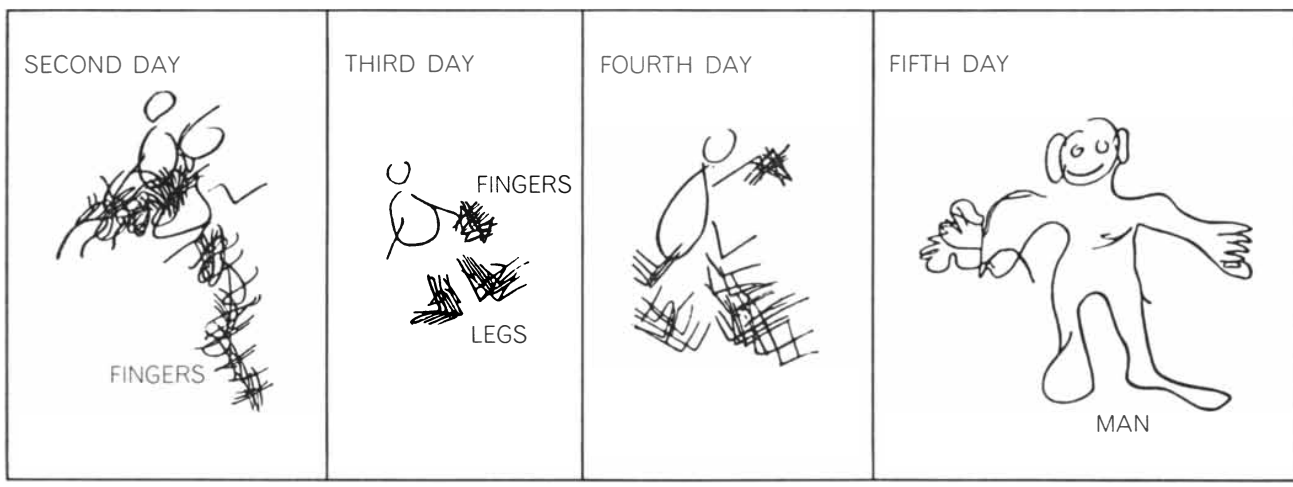
The sensory and spatial factors in the organization of a movement are basic but still insufficient to allow the completion of the movement. A voluntary movement is the result of a sequence of events. A skilled movement is really a kinetic melody of such interchangeable links. Only if one already fulfilled part of the movement is blocked and the impulse is shifted to another link can an organized skilled movement be made.

An important finding, first described by Karl S. Lashley and John F. Fulton and carefully studied in our laboratory for many years, is that a totally different part of the brain—the premotor cortex—is responsible for sequential interchanges of separate links of motor behavior. A skilled movement disintegrates when this part of the brain is injured. Such a patient still has sensory feedback and spatial orientation, but he loses the ability to arrest one of the steps of the movement and to make a transition from one step to the next.

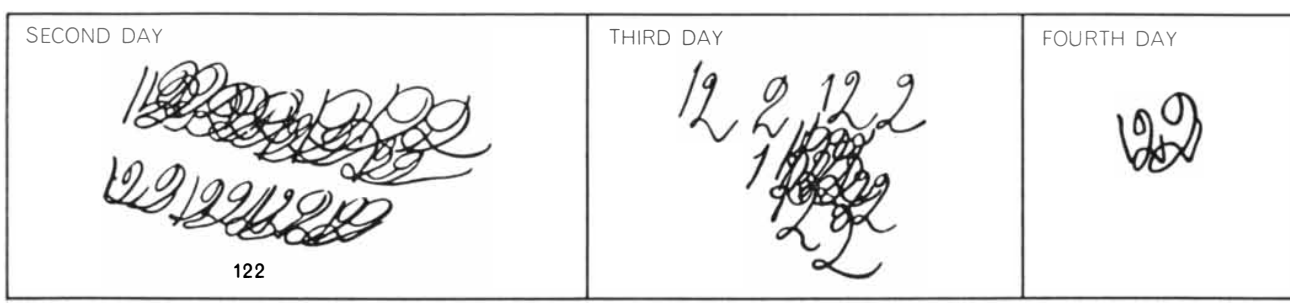
Even now I have not fully described the brain's organization of a voluntary



INFLUENCE OF PREMOTOR REGION on the organization of movement appears in drawings made by a patient after surgery for removal of a meningioma, which is a tumor arising from the meninges, from the left premotor region. On each of the days represented in the illustration the patient was asked to draw simple figures such as those shown here. Performance improved steadily.



DRAWINGS OF A MAN were attempted by the same patient during the postoperative period. At first he drew a head and body, represented by the circles at top center in the drawing at left. Then he drew a second man, whose head is to the right of the first man's body. Then he made a series of stereotyped pen strokes. The ones that trail off at lower right in the first drawing were made on moving paper. On successive days the patient's work improved. Difficulty in stopping a movement often appears in premotor lesions.



WRITING OF NUMBERS was attempted by the same patient on the second, third and fourth day after the operation. As in the other cases the patient at first showed a tendency to repeat part of the task, but the repetition diminished on the following days.

movement. Every movement has to be subordinated to a stable program or a stable intention. They are provided in the prefrontal lobes of the brain (included in the third block). If the frontal lobes are injured, the sensory base, spatial organization and plasticity of the movement remain but goal-linked actions are replaced by meaningless repetitions of already fulfilled movements or impulsive answers to outside stimuli. The whole purposive conduct of the patient is disturbed.

Speech and Writing

Let us now analyze a more complex psychological process: the ability to speak, and particularly the ability to write. It used to be thought that the operation of writing is controlled by a certain area (called Exher's center) in the middle of the premotor zone of the brain's left hemisphere (for a right-handed writer). It has since been learned, however, that this is not the case, and that a broad area of the left hemisphere is involved. We must therefore consider the effects of lesions in all parts of this region on writing.

Let us start by a psychological analysis of the processes involved in writing something in response to an instruction. Suppose one is asked to write a given word. The interpretation of the oral request turns out to be in itself a complex process. A word is composed of individual sounds, or phonemes, each coded by a letter or combination of letters. The recognition of a word may depend on the perception of very slight differences between phonemes, or acoustic cues. Consider, for example, "vine" and "wine," "special" and "spatial," "bull" and "pull," "bark" and "park." The practiced brain readily distinguishes between similar sounds, and to a person brought up in the English language the two words in these pairs sound quite different from each other. Obviously the brain must perform a sharp analysis of phonemes on the basis of learning. We become impressed with this fact when we see how difficult it is to sense distinctions in listening to a foreign language. To an English-speaking or French-speaking person, for example, three words in the Russian language—*pyl,* meaning "ardor," *pyl'* (with the *l* palatalized), meaning "dust," and *pil* (with a hard *l*), meaning "he drank"—sound almost exactly the same, yet a Russian has no difficulty distinguishing these words. Much more remarkable instances of subtle distinctions the mind is called on to make can be cited in other languages. In Chinese *ma* and *ma* have the opposite meaning ("to buy" and "to sell"), although the only difference is in the tone of the vowel. In the Vietnamese language the phoneme *tü* has at least six different meanings, depending on the pitch of the voice!

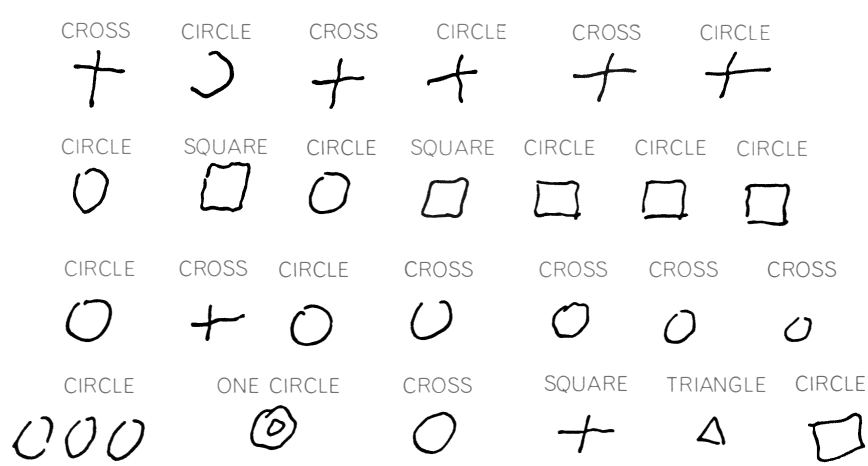
What part of the brain is responsible for recognizing phonemes? Our observations on many hundreds of patients with local brain wounds or tumors who underwent word-writing tests established clearly that the critical region lies in the secondary zones of the left temporal lobe, which are intimately connected with other parts of the brain's speech area. People with lesions in this region cannot distinguish *b* from *p* or *t* from *d,* and they may write "pull" instead of "bull" or "tome" instead of "dome." Moreover, they may make unsuccessful attempts to find the contents of the sounds of words they try to write. Interestingly enough, Chinese patients with severe injury of the acoustic region have no such difficulty, because their writing is based on ideographs instead of on words that call for the coding of phonemes.

Continuing our dissection of the process of word recognition, we must note that people commonly pronounce an unfamiliar word before writing it, and in the case of an unfamiliar name they are likely to ask the person to spell it. Articulation of the sounds helps to clarify the word's acoustic structure. A class of Russian elementary schoolchildren during a lesson in the early stages of learning to write is generally abuzz with their mouthing of the words. To find out if this activity was really helpful, I asked one of my co-workers to conduct an experiment. The children were instructed to hold their mouths open or to immobilize their tongues with their teeth while they wrote. In these circumstances, unable to articulate the words, the children made six times as many spelling mistakes!

It turns out that a separate area of the brain cortex, in the central (kinesthetic) region of the left hemisphere, controls the articulation of speech sounds. People with lesions in this area confuse the sound of *b* with that of *m* (both made with similar tongue and lip movements) and often cannot distinguish between *d, e, n* and *l.* A Russian with such a lesion may write *ston* ("groan") instead of *stol* ("table") and *khadat* (meaningless) instead of *khalat* ("dressing gown").

After evaluation of the speech sounds and recognition of the word, the next step toward writing the word is the coding of the sound units (phonemes) into the units of writing (letters). We find that this step calls into play still other parts of the brain cortex, in the visual and spatial zones. Patients with lesions in these zones (in the occipital and parietal lobes) have a perfectly normal ability to analyze speech sounds, but they show marked difficulty in recognizing and forming written letters. They find it difficult to visualize the required structure of a letter, to grasp the spatial relations among the parts of the letter and to put the parts together to form the whole.

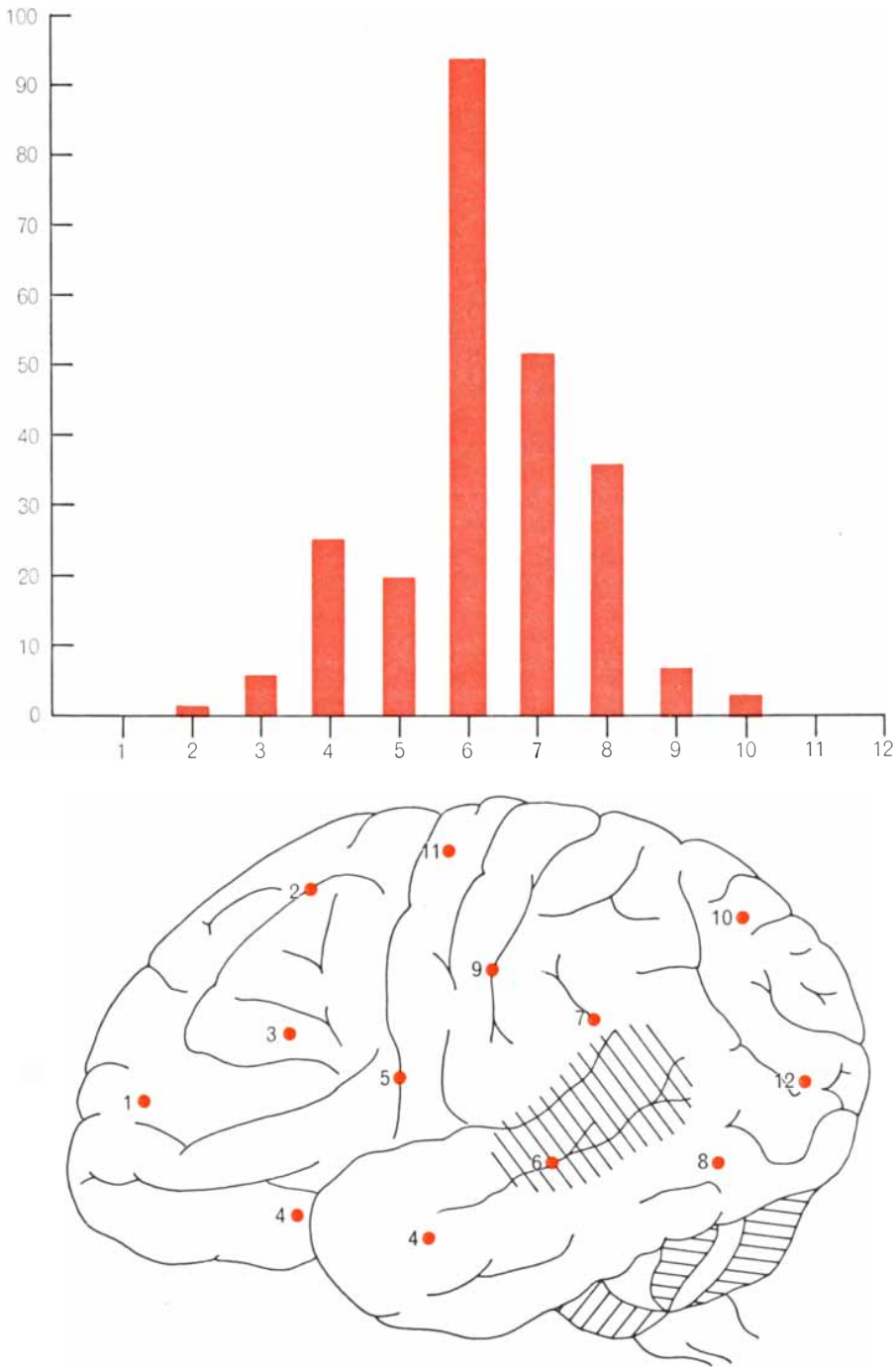
The mental process for writing a word entails still another specialization: putting the letters in the proper sequence to form the word. Lashley discovered many years ago that sequential analysis



LESIONS OF FRONTAL LOBES interfere with the programming of actions and cause errors such as repetition. On each line of the illustration are drawings made by patients; printed words show what they were asked to draw. The first, second and fourth patient had tumors of the left frontal lobe; the third patient had an abscess of the right frontal lobe.

involved a zone of the brain different from that employed for spatial analysis. In the course of our extensive studies we have located the region responsible for sequential analysis in the anterior region of the left hemisphere. Lesions in the prefrontal region disturb the ability to carry out rhythmic movements of the body, and they also give patients difficulty in writing letters in the correct order. Such patients transpose letters, are unable to proceed serially from one letter to another and often replace the required letter with a meaningless stereotype. If the lesion is located deep in the brain where it interrupts connections between the basal ganglia and the cortex, the patient becomes incapable of writing words at all; he may merely repeat fragments of letters. Yet such a patient, with the higher parts of the cortex undamaged, can recognize phonemes and letters perfectly well.

Finally, there is an overall requirement for writing that involves the apparatuses of the third block of the brain as a whole. This is the matter of writing not merely letters or words but expressing thoughts and ideas. When the third block is damaged by severe lesions of the frontal lobes, the patient becomes unable to express his thoughts either orally or in writing. I shall never forget a letter written to the noted Russian neurosurgeon N. N. Burdenko by a woman with a severe lesion of the left frontal lobe. "Dear Professor," she wrote, "I want to tell you that I want to tell you that I want to tell you..." and so on for page after page!



DISRUPTION OF HEARING in patients with bullet wounds in the left hemisphere of the cerebral cortex is charted. Affected areas of the brain are numbered, and the correspondingly numbered bars show the percent of patients who had difficulty recognizing sounds.

The analysis of the writing process is just one of the tracers we have used in our psychological exploration of the functional organization of the brain. Over the past three decades investigators in our laboratory and our clinical associates have carried out similar analyses of the brain systems involved in perception, bodily movements, performance of planned actions, memorization and problem-solving. All these studies have demonstrated that detailed investigation of the nature of a behavioral disturbance can indeed guide one to the location of the causative lesion in the brain.

Factor Analyses

Obviously the neuropsychological approach provides a valuable means of dissecting mental processes as well as diagnosing illness. It is enabling us to search out the details of the brain's normal operations and capacities. A generation ago L. L. Thurstone of the University of Chicago and C. E. Spearman of the University of London learned some of the details by the statistical technique of factor analysis based on batteries of tests administered to great numbers of subjects. With the neuropsychological technique we can now make factor analyses in individual subjects. When a particular factor is incapacitated by a brain lesion, all the complex behavior processes that involve the factor are disturbed and all others remain normal. We find, for example, that an injury in the left temporal lobe causes the patient to have serious difficulty in analyzing speech sounds, in repeating verbal sounds, in naming objects and in writing, but the person retains normal capacities in spatial orientation and in handling simple computations. On the other hand, a lesion in the left parieto-occipital region that destroys spatial organization does not affect the patient's fluency of speech or sense of rhythm.

Sorting out the various factors and

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Vishniac on Vishniac on Polaroid Land Film

Roman Vishniac, perhaps the world's most highly acclaimed photomicroscopist, is a man of enormous and varied talents. He was recently the subject of an award-winning television special on NBC, "The Great Little World of Dr. Roman Vishniac."

"When I took this assignment, I had never used Polaroid Land film before. But it has been a revelation to me. It gives me what I never realized I needed. Immediate proof of what's really happening under the microscope. And proof of whether my imagination was right.

What I mean is, I get certain unique effects in photomicroscopy because a lot of what I see, I see with my imagination. What actually meets the eye may act as a trigger.The forms suggest other possibilities, as they do to the artist.

It's all based on two different facets of my background.

First, I started fooling with a microscope, believe it or not, when I was only seven, and haven't stopped since. I wound up with an MD, and have been teaching at colleges and medical schools for years.

But the other part is, I also have a PhD in art, and do a lot of lecturing on that subject, too.

So between a knowledge of what's going on chemically and physically, and an appreciation of the visual effects that can be obtained, I project beyond the actual moment.

For the Polacolor picture you're looking at, I decided to use an amino acid under polarized light at a magnification of 1200 times. I've used amino acids before, because they're the basic building blocks for all life. And the molecules are so complex, they offer greater possibilities of form and light.

But this time, things were different. With Polaroid film, when I thought I saw something, I didn't have to wait days to develop a picture to see if I was right. And maybe set up and do it over again time after time.

This time, I had it in my hand right away. When it wasn't right, I made changes until it was.

Frankly, what bothers me is thinking about all those precious hours I've lost up to now.

I guess we're never really too old to learn."

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A $1.00 device can protect electronic equipment against damage from lightning and other voltage transients. We bring Qualitätsware to America.

Lightning strikes the earth about 100 times each second.

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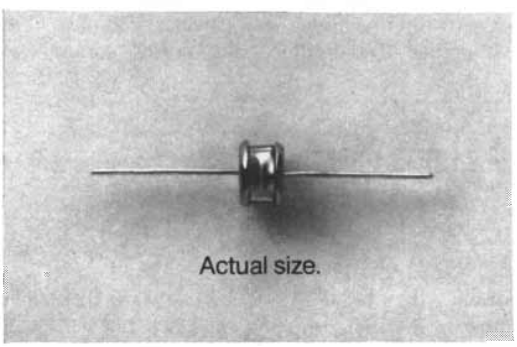
The direct damage caused by lightning is estimated to be in the neighborhood of 500 million dollars a year. What cannot be easily measured are the additional losses resulting from equipment downtime.

Lightning is just one of the many voltage transients that can affect expensive electronic equipment. Some of the other sources are static discharges, internal switching of inductive components, short circuits, and inductive influences through grounded shorts.


Actual size.

Before the use of semiconductors or other delicate components, voltage transients did not present a serious problem to the design engineer. Today, however, solid-state circuitry and a greater degree of electronic sophistication demands greater attention to voltage protection.

To meet the need for transient protection, Siemens developed a line of miniature surge voltage protectors. These tiny, gas-filled devices react rapidly, reliably and repeatedly to voltage surges.

Widely used today in communications equipment, surge voltage protectors are fast gaining acceptance in other electronics areas. Control systems, processing equipment, testing and measuring instruments, data processing and peripheral equipment are some of the new applications for surge voltage protection.

Siemens has also developed a similar device which can be triggered to achieve fast bi-polar switching of high currents up to 5,000 amps. This highly efficient device is designed to replace silicon controlled rectifiers (SCR's) in certain applications where the di/dt and dv/dt rating presents a problem. Energy required to trigger the Siemens spark gap is close to zero (10^{-6} Ws).

As a world-wide manufacturer and user of electronic components such as capacitors, resistors, transistors, electron tubes and rectifiers, Siemens has designed its surge voltage protectors with total circuit requirements in mind. They cover a dc striking voltage range from 90 volts to 6.5 kv (higher on request).

Siemens Corporation, 186 Wood Avenue South, Iselin, New Jersey 08830.

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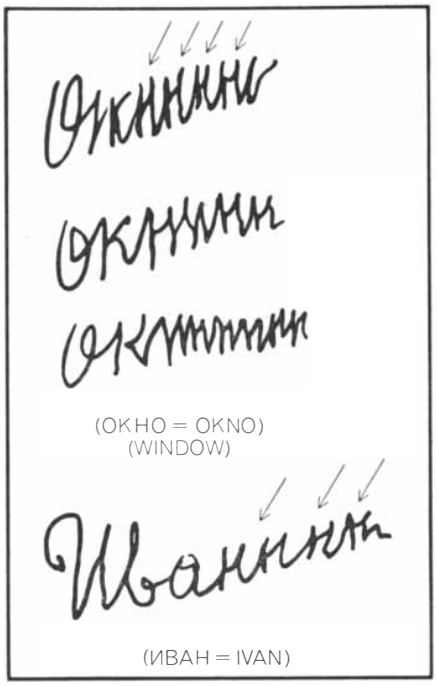


WRITING ABERRATION was shown by a patient with a tumor in the deep part of the brain's left premotor zone. He was asked to write the Russian words for window and Ivan, which are printed in Russian and in English transliteration below each example. Arrows show repetition or fragments.

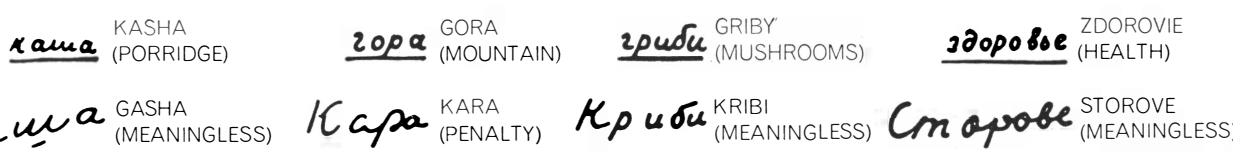
their effects, we arrive at some surprising findings. One is that behavioral processes that seem very similar or even identical may not be related to one another at all. For example, it turns out that the mechanism for perception of musical sounds is quite different from that for verbal sounds. A lesion of the left temporal lobe that destroys the ability to analyze phonemes leaves musical hearing undisturbed. I observed an outstanding Russian composer who suffered a hemorrhage in the left temporal lobe that deprived him of the ability to understand speech, yet he went on creating wonderful symphonies!

On the other hand, behavioral processes that seem to have nothing in common may actually be related through dependence on a particular brain factor. What can there be in common between the capacities for orientation in space, for doing computations and for dealing with complexities in grammar logic? Yet all three of these abilities are affected by the same lesion in the lower part of the left parietal lobe. Why so? A close analysis of the three processes suggests an explanation. Computation and the ability to handle language structure depend, like orientation, on the ability to grasp spatial relations. In order to subtract 7 from 31, for example, one first performs the operation $30 - 7 = 23$ and then adds the 1 to this preliminary result. There is a spatial factor here: one indicates unambiguously that the 1 is to be *added* by placing it to the right of the 23. A patient with a lesion disturbing his capacity for spatial organization is unable to cope with the problem because he is at a loss whether to place the 1 to the left or the right—in other words, whether to add it or subtract it.

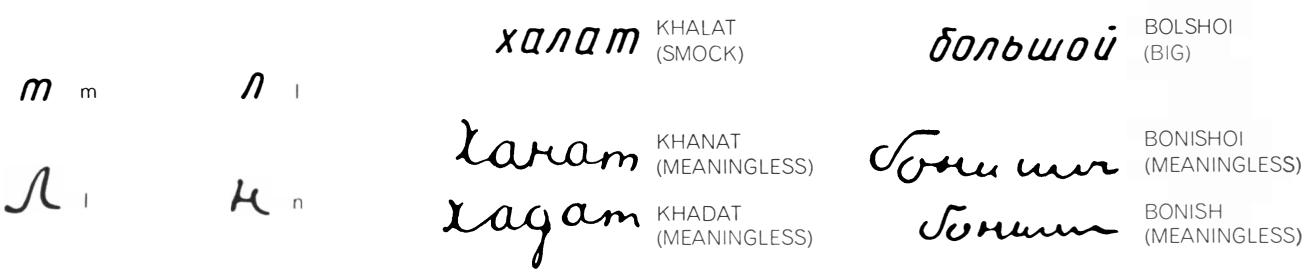
The same principle applies to understanding complex grammatical constructions. In order to grasp the difference between "father's brother" and "brother's father" or between "summer comes after spring" and "spring comes after summer," for example, one must make a clear analysis of the quasi-spatial relations between the elements in each expression.

Finally, the neuropsychological approach gives us a new insight into the effects of learning on the brain's processes. There is a well-known story of a patient of the 19th-century English neurologist Sir William Gowers who, after many unsuccessful attempts to repeat the word "no" in response to his instruction, at last burst out: "No, doctor, I can't say 'no.'" We have observed many cases of automatic performances of this kind in brain-injured patients who could not achieve a given task when they thought about it. One was an old lady who was unable to write a single word on instruction, but when she was asked to write a whole sentence quickly (a kinetic skill), she did so without hesitation. Patients who cannot write from dictation are often able to sign their names readily. It appears, therefore, that training or habituation changes the organization of the brain's activity, so that the brain comes to perform accustomed tasks without recourse to the processes of analysis. That is to say, the task may invoke a stereotype based on a network of cortical zones quite different from the one that was called on originally when the performance required the help of the analytical apparatus.

Neuropsychology has put us on a new path in the investigation of how the brain functions, and we can suppose that it is likely to lead the way to substantial changes in the design of psychological research in the future.

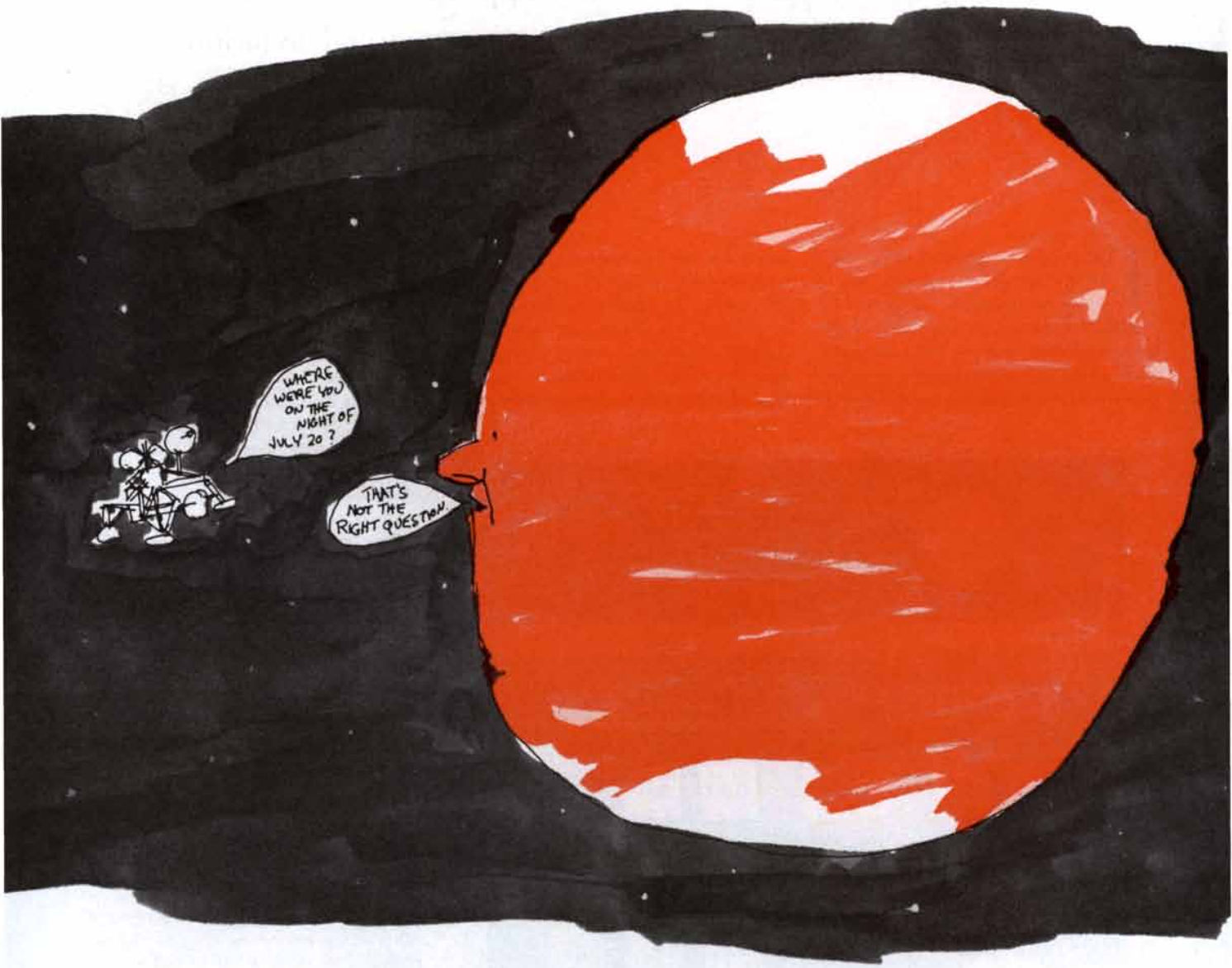


WRITING DISTURBANCES appear in a patient with a lesion of the left temporal area. The patient was writing to dictation; the dictated Russian word, its transliteration and its English meaning are on the top line. The written response of the patient in each case appears below with its transliteration and English meaning in the single instance (*kara*) where the patient wrote a meaningful word.



ERRORS IN WRITING also were shown by a patient with a lesion of the left parietal area. Again the dictated letter or word appears on the top line; the bottom lines show the written response by the patient. None of the words that the patient wrote were meaningful.

Asking Mars the right questions.



Our people are busy helping to plan and integrate the experiments Viking will carry to the surface of Mars in 1975. One of the knottiest problems is thinking up the right questions to ask the reticent red planet. The objective is to get the *maximum* amount of *pertinent* and *useful* information. Scientists, including ours, all over the nation are burning plenty of the midnight oil to achieve just that. Nobody wants to go 280-million miles and ask the wrong questions.
Martin Marietta Aerospace Group. Headquarters: Friendship International Airport, Maryland.
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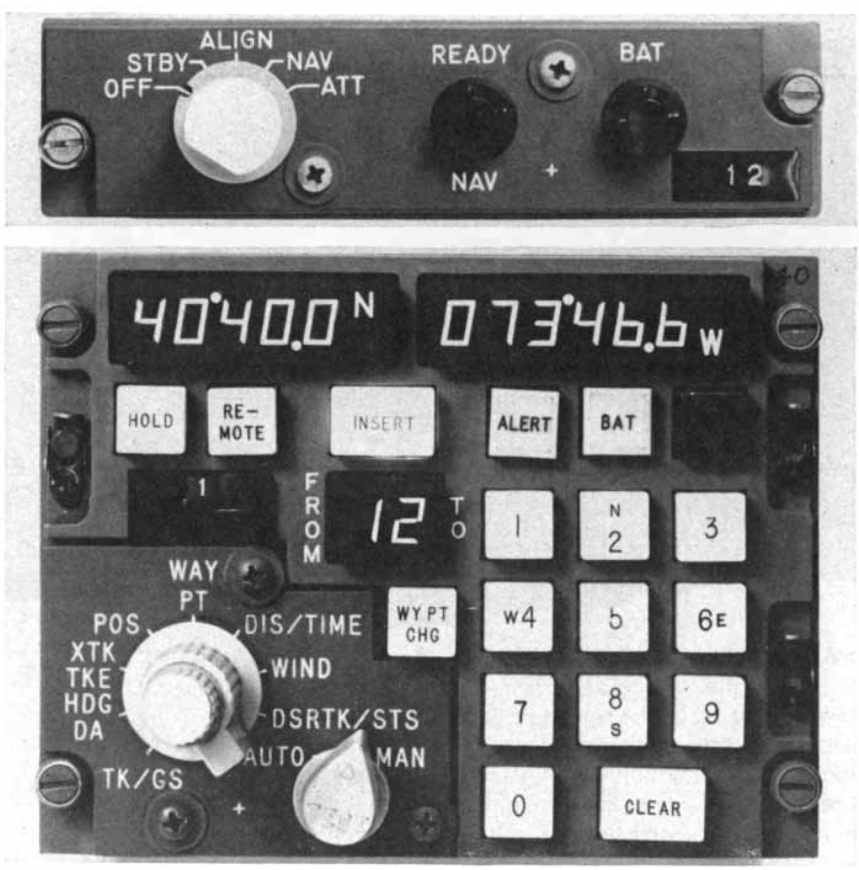
INERTIAL NAVIGATION FOR AIRCRAFT

This highly precise and automatic system of navigation, developed originally for military applications and space flight, is now being introduced to commercial aviation

by Cornelius T. Leondes

The pace and extent of man's travels by air on our planet, not to speak of journeys in space, are rapidly outgrowing the capacities of the traditional instruments of navigation. With air traffic now increasing at an exponential rate, the navigation problem is becoming too complex to be handled with complete reliability by the "manual" system, depending on devices such as sextants, star charts, compasses, chronometers, beacons, radio communication and radar. Fortunately a new system affording a high degree of precision and automatic control is already being introduced in commercial aviation. It is the system known as inertial navigation. Developed originally for use in strategic missiles, military aircraft and space vehicles, it has lived up to all the hopes invested in it. In conjunction with the use of radio devices, the system of inertial navigation will improve the safety of air travel and greatly facilitate the control of high-density air traffic at major airports.



PILOT'S CONTROLS for Carousel IV, an inertial-navigation system manufactured by the AC Electronics Division of General Motors Corporation, are shown. Device at top is called the mode-selector unit; one at bottom is the control and display unit. Abbreviated settings are STBY (standby), NAV (navigate), ATT (attitude), BAT (battery), TK/GS (track/ground speed), DA (drift angle), HDG (heading), TKE (track-angle error), XTK (cross-track distance), POS (position), WAY PT (way point), DIS (distance), DSRTK/STS (desired track/status), AUTO (automatic), MAN (manual), WY PT CHG (way-point change).

The principle of inertial navigation is certainly not new. Columbus used it in his voyages across the Atlantic. It is essentially a method of dead reckoning: one deduces where he is from a log of the course he has followed from his starting point. For Columbus the problem was the relatively simple one of tracing a course in two dimensions (the ocean's surface). Air flight adds a third dimension and many other complications connected with it. The modern technique of inertial navigation not only deals with these complications but also calculates the traveled course with extreme precision, so that one knows at every instant exactly what his geographical position is, the heading of the aircraft and its attitude. All of this is made possible by the application of three basic instruments: the gyroscope, the accelerometer and the electronic computer.

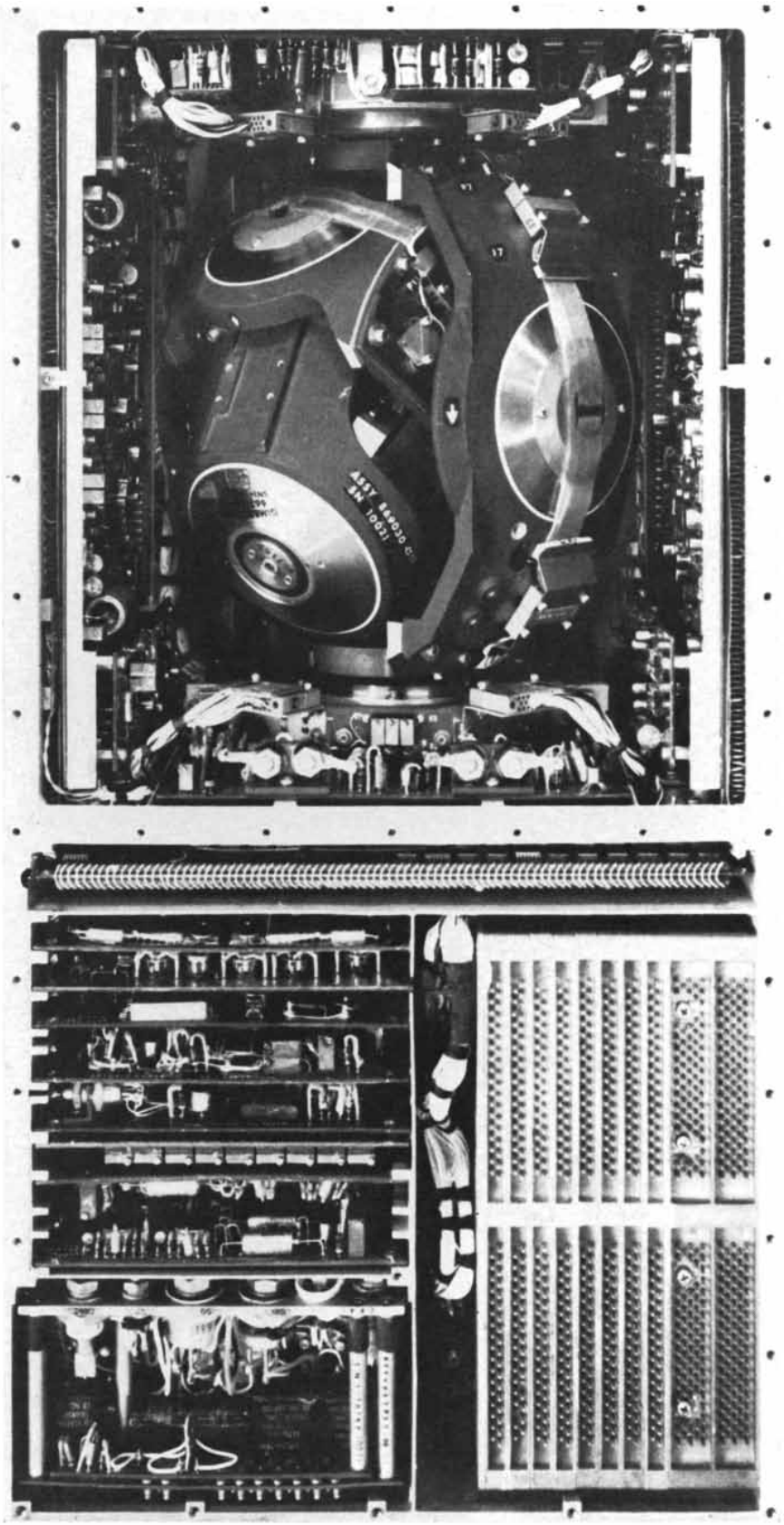
The gyroscope is of course a familiar device, widely employed for many different purposes. As early as 1914 Elmer A. Sperry developed a gyroscope system called "cruise control," which could act as an automatic pilot holding an aircraft in straight and level flight. Today gyro autopilots, electronically operated, are in common use on ships at sea and in aircraft for control under routine conditions. In inertial navigation, however, the gyroscope serves quite a different

purpose. Its function is to provide a precisely level inertial platform as a base for measurement of all accelerations of the aircraft.

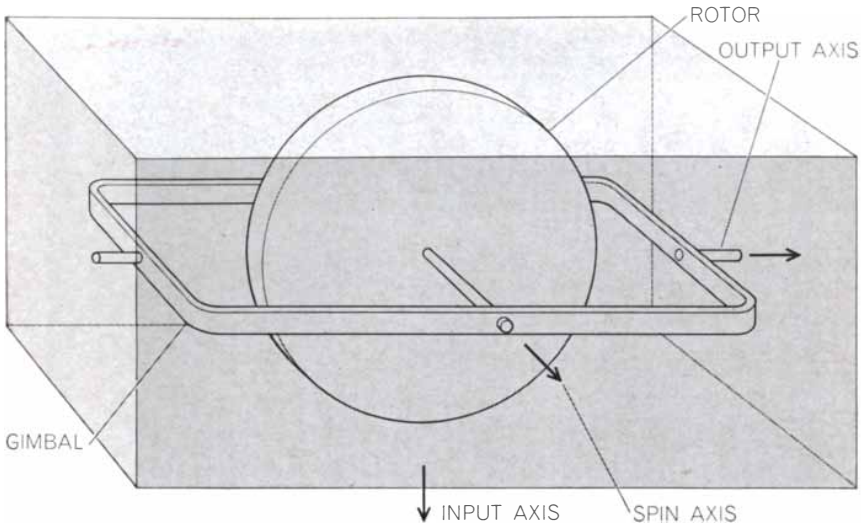
The gyroscope consists of an electrically driven spinning wheel mounted on a gimbal (frame) that in turn is mounted within a case [*see top illustration on next page*]. The gimbal can rotate freely around an "output axis" perpendicular to the axis of the wheel's spin. Any turning motion of the aircraft around the "input axis" (for example a turn of the horizontal heading) produces a torque about the output axis that counteracts this motion and thus holds the gyroscope platform in a stable position. Since such corrections must be made in three dimensions in airborne flight, the stabilizing system employs three gyroscopes, mounted at right angles to one another. The system not only keeps the platform level at all times during the aircraft's flight but also maintains the accelerometer in a level position regardless of the tilt or pitch of the aircraft.

The accelerometer, using the gyroscope platform as a reference base, provides the measurements necessary to describe the path of the flight. It is basically a simple device, exactly analogous to a spring scale with a weight hanging from it. If one jerks the scale upward, the weight's inertia causes the spring to stretch so that the indicator registers an apparent increase in weight; similarly, if one suddenly thrusts the scale downward, the spring contracts and the indicator is deflected upward, again because of the weight's inertia. In an accelerometer the inertial member is a pendulum [*see middle illustration on next page*]. In the absence of acceleration it hangs straight down in the null, or zero, position. When the aircraft accelerates, the pendulum because of its inertia is swung off that position. The distance of the swing furnishes a measure of the acceleration, which then becomes a basis for computing the distance traveled by the aircraft in the given direction within a given time.

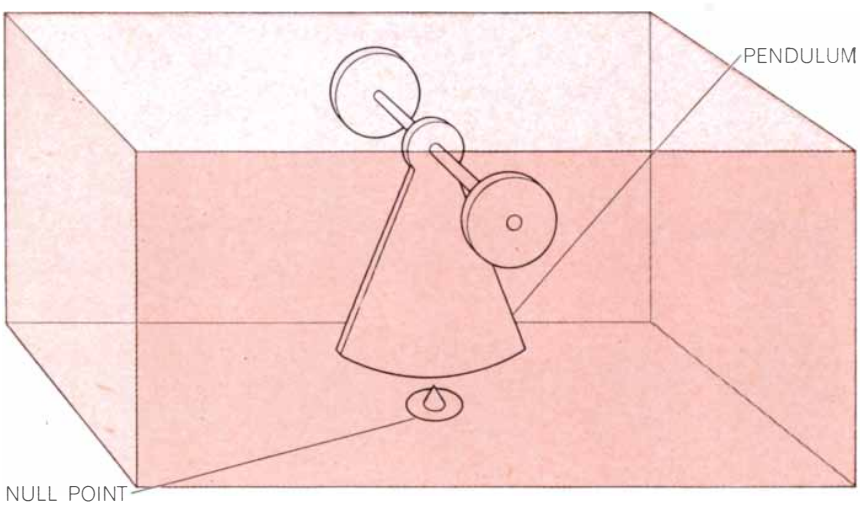
A pick-off device mounted on the pendulum's pivot axis tells how far the pendulum is off the null position. This information is translated into an electrical signal, which goes to an amplifier, which in turn sends the amplified signal to a torquing device on the pivot axis, and there the signal generates the force necessary to restore the pendulum to the null position. The amount of current going into the torquer is a function of the acceleration the device is experiencing.



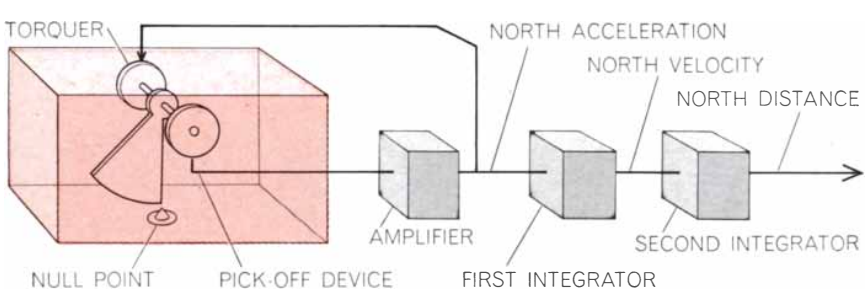
INERTIAL-NAVIGATION UNIT designated LTN-51 by its manufacturer, Litton Industries, Inc., was partially uncovered to make this photograph. The principal visible components include the gimbals, or frames, of a three-axis gyroscopic stabilization system (*top*), which provides a stable platform for an unseen pair of accelerometers, and a digital computer (*bottom*), which integrates the recorded data. The entire unit, together with its controls and power supply, weighs about 65 pounds and costs in the neighborhood of $100,000.



GYROSCOPE consists essentially of an electrically driven spinning wheel mounted on a frame that is in turn mounted within a case. The gimbal can rotate freely around an output axis perpendicular to the wheel's spin axis. Any turning motion of the aircraft around the input axis produces a torque around the output axis that counteracts this motion and thus stabilizes the gyroscope platform. In flight such corrections are made in three dimensions.



ACCELEROMETER provides the measurements necessary to describe the flight path of the aircraft. In the absence of acceleration the inertial member of the device, a pendulum, hangs straight down in the null position. When the aircraft accelerates, the pendulum is swung off that position. The acceleration indicated by the distance of the swing is then used to compute the distance traveled by the aircraft in a given direction in a given time.



ELECTRONIC CIRCUITRY translates the displacement of the accelerometer's pendulum into an electrical signal, which is amplified and sent to a torquing device on the pivot axis of the pendulum. There the signal generates the force necessary to restore the pendulum to the null position. The output of the amplifier is also sent to an integrator that multiplies the acceleration by the elapsed time to yield a velocity; this result then goes to a second integrator, where it is multiplied by time to obtain the distance traveled by the aircraft.

Meanwhile the output of the amplifier is also sent to a computer that acts as an integrator; this integrator multiplies the acceleration (in feet per second squared) by the elapsed time, which gives the velocity in feet per second; the result then goes to a second integrator, where the velocity is multiplied by time again to give the distance the aircraft has traveled in the given time [*see bottom illustration at left*].

The foregoing describes the performance of a single accelerometer. In practice, of course, the system requires two accelerometers, one measuring travel in the north-south direction, the other in the east-west direction. All the resulting information is fed into a digital computer, which on the basis of stored information giving the latitude and longitude of the point where the flight started and other data easily computes the aircraft's present position.

Two inertial-guidance systems are now in commercial use. One, called Carousel IV, is built by a division of the General Motors Corporation; the other, called LTN-51, is manufactured by a division of Litton Industries, Inc. The components have been miniaturized to remarkably small dimensions, suitable for an aircraft cockpit. The gyroscopes, for example, are only two and a half or three inches in diameter and weigh a pound or less, and the accelerometers are even smaller.

So much for the hardware. How does the navigational system work? This can be explained most easily by referring to the control and display panels for the operation of a specific system [*see illustrations on page 80*].

At the outset, with the aircraft standing in its berth, the power for the navigational apparatus is turned on by switching to "Standby" (STBY) in a "mode selector." The operator then records the present position of the craft in latitude and longitude by punching the data on a digital keyboard and inserting the information into the computer with a push button labeled "Insert." Next the mode selector is switched to "Align"; this activates the gyroscope system to level its platform automatically and align itself to true north. The operator next switches to "Navigate," and the aircraft is then ready to taxi to the runway and take off. During the taxiing operation a setting labeled TK/GS causes the instrument to record the aircraft's ground speed and the relation of its movements to the track it will follow in flight.

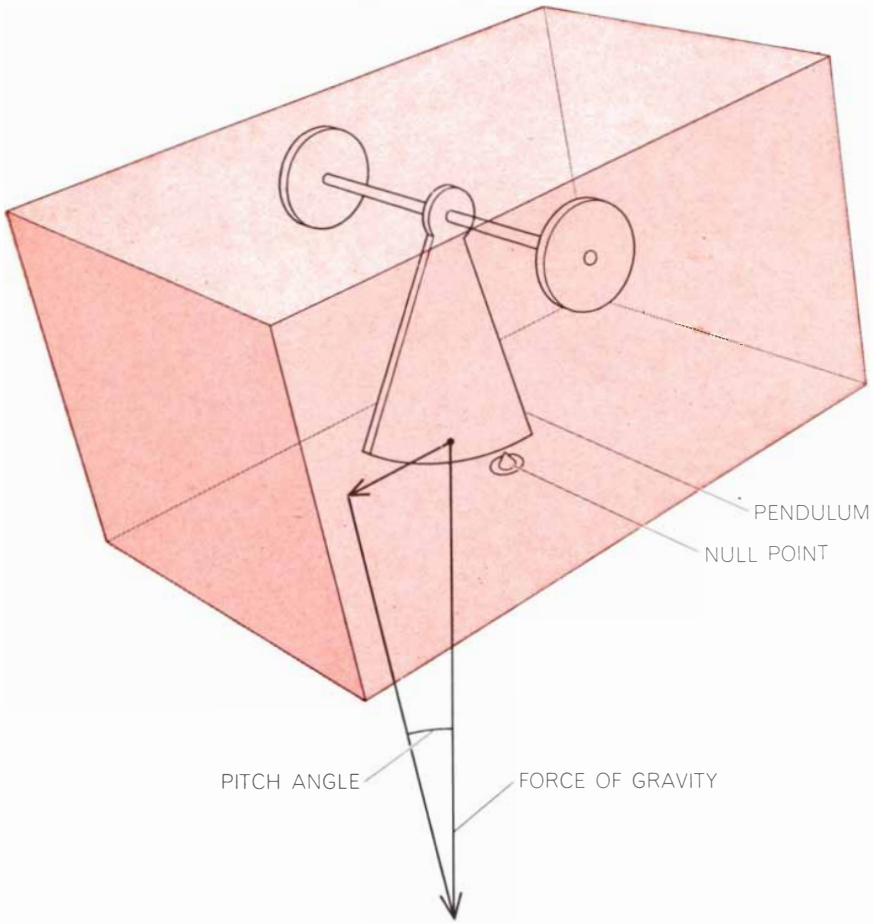
This track is determined by the loca-

tion of the craft's destination, which is stored in the computer in terms of latitude and longitude. The overall journey can actually be defined as a series of tracks, or legs, each ending at a way point. At each way point the aircraft changes tack, and the selection of the successive tracks can be made manually by the operator or can be recorded in the computer in advance so that the track selections will be made automatically. By manual operation the operator can also change the track at any point during the flight by resetting "Present position" and taking a course from that point to any way point he wishes to select. The system thus permits a great deal of flexibility, allowing the pilot to change course to bypass traffic or bad weather, to compensate for deviations from the set course caused by wind or for any other reason [*see illustration on next page*]. The inertial system senses and takes account of wind speeds and directions in relation to true north throughout the flight. It displays this information on command, as well as the aircraft's travel rate in terms of ground speed and the distance and time to the next way point.

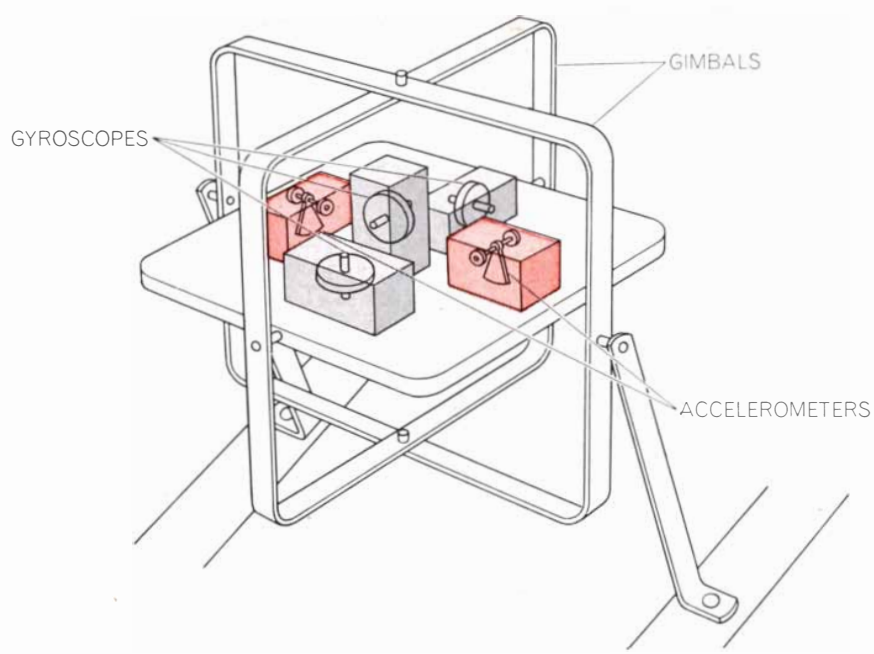
The accuracy requirements for inertial systems have been established by the Federal Aviation Administration in terms of performance on long-range overwater flights. A system must be able to navigate to within a rectangle 20 miles wide by 25 miles long after a 10-hour flight. This accuracy is of course attained by the currently available inertial-navigation systems, and when transferred to shorter flights is an extremely demanding requirement indeed. Current technological trends promise substantial improvement in the performance of inertial systems.

Obviously the instruments involved in the inertial system must possess a very high degree of precision if they are to provide reliable guidance. Their precision is in fact so good that they can be depended on for automatic control of the aircraft's flight, by hookups to the control instruments. It has been shown that they are more accurate and efficient than a human pilot in many operations, such as maintaining the aircraft's desired heading, controlling its attitude during takeoff and landing, holding it at the specified altitude during a turn and keeping it on course in turbulent air.

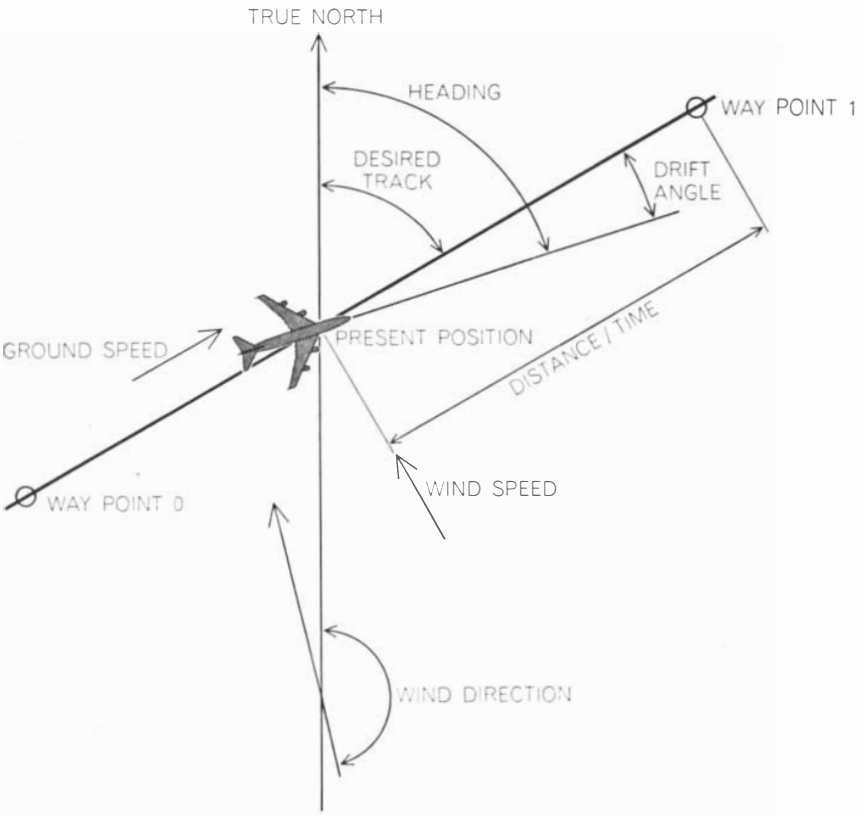
The most critical safety problem in aviation is the control of the takeoff and landing operations. Most accidents occur in these operations, and often the cause of the accident is instrument inaccuracy.

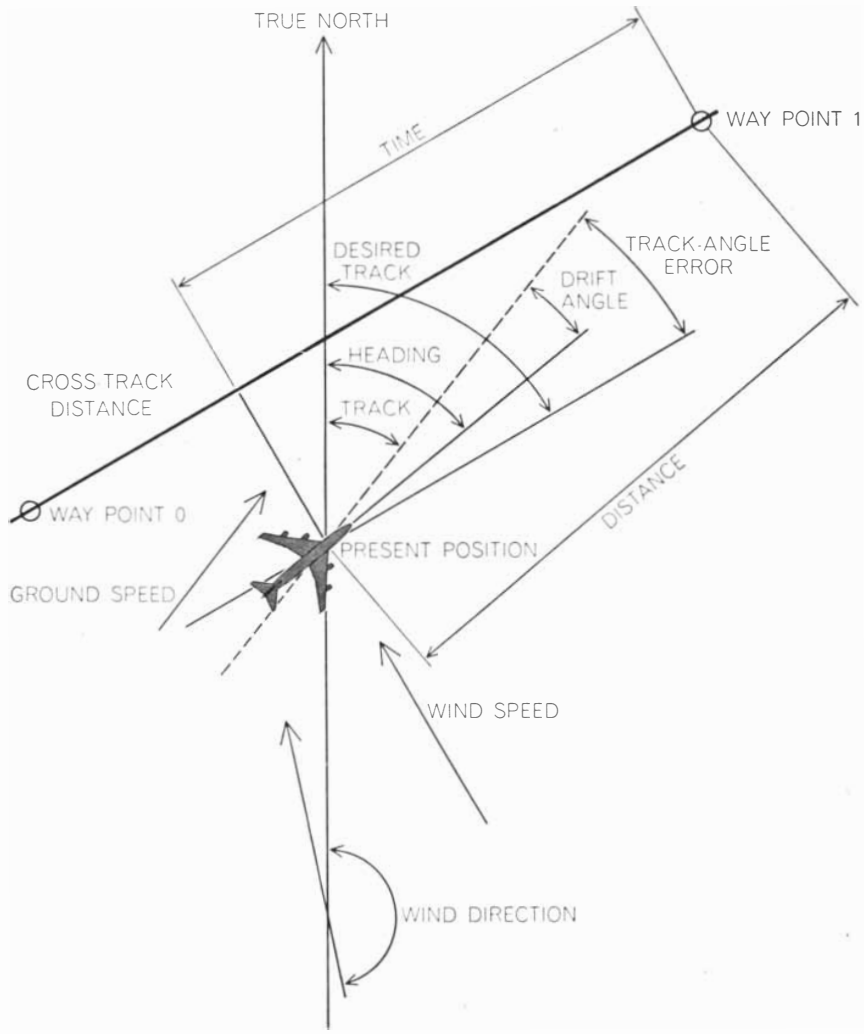


NECESSITY OF STABILIZATION is demonstrated by this illustration, in which a false accelerometer reading is shown resulting from a change in the pitch of the aircraft.



GYROSCOPIC STABILIZATION isolates the accelerometers of an inertial-navigation system from the effects of gravity. In this simplified diagram of a three-axis stabilizing system the three gyroscopes are mounted at right angles to one another on the stabilized platform, which also contains the two accelerometers. An extra outermost gimbal would be required to mount the other three gimbals at right angles to one another in order to avoid unwanted gimbal torques. Several other arrangements of the gyroscopes and gimbals are possible.





Conventional instruments for sensing the vertical attitude and other aspects of a plane's bearing are least accurate during acceleration or deceleration. Here the instruments in an inertial system can be of particular service, because they are far more accurate than the conventional gyroscopes. Recognizing this, civil air operators have begun to turn to inertial-navigation equipment primarily for this purpose: to serve as the basic sensors for the attitude and heading of the aircraft.

Among the airlines, Pan American World Airways, Inc., has experimented with an inertial system and American Airlines, Inc., and Air France have put such systems into certified, regular use for certain flights: American for charter flights to South Vietnam, Air France for all its transoceanic flights. Several other airlines have purchased or are testing inertial equipment. All the new Boeing 747 aircraft, now being delivered to many of the world's air transport systems, will be equipped with inertial systems.

The adoption of inertial navigation will bring closer the day of fully automatic control of air flight from takeoff to landing. The first step presumably will be to couple the inertial system's excellent sensing capabilities in the aircraft with radio navigation aids on the ground. The principal radio aids, now available all over the world, are VOR and DME. VOR (Very-high-frequency Omnidirectional Range) provides bearing information to or from a selected station; DME (Distance Measuring Equipment), usually in conjunction with VOR, provides distance information. Information from the radio aids, combined with that from

FLEXIBILITY of an inertial-navigation system (which normally operates automatically) is demonstrated by the fact that a pilot can manually activate track changes. The top illustration at left shows the normal "on track" configuration: a flight along a desired track between two way points. The present position can be determined at any time in current latitude and longitude coordinates. The aircraft heading with respect to true north or to the desired track or to the drift angle can also be obtained. In addition the speed and direction of the wind, the ground speed and the distance and time to the next way point are continuously computed and can be displayed on command. The bottom illustration shows an "off track" situation, which might occur when changes are made in flight (for example to avoid bad weather or to switch destinations). Here the inertial system, in addition to functioning in the normal mode, computes and displays cross-track distance and track-angle error.

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the inertial system in its digital computer, will provide accurate, updated data for the guidance and control of the aircraft throughout its flight.

As traffic increases, the passenger airlines are finding that their most troublesome problem, that of landing in bad weather, is becoming ever more serious. Unsafe weather conditions at airports, forcing the stack-up and diversion of aircraft, missed connections and cancellation of flights, take an immense annual toll in inconvenience for the passengers and financial costs for the airlines. Substantial progress is being made in the improvement of navigation aids both in the aircraft and on the ground, but these facilities are still far from the goal of enabling planes to land with assured safety in all weather conditions. It appears, however, that inertial navigation, in combination with ground aids, could soon solve the problem. Tests of the performance of the inertial system for landing under adverse weather conditions have been most encouraging.

The technical facilities are available; what is holding up the general application of inertial-navigation systems is the economic factor. The airlines, now under severe economic pressure, are naturally hesitant about making expensive investments in new equipment unless it can clearly be shown that they will obtain financial benefits commensurate with the cost. The costs of operating with the present conventional navigation equipment, however, are already high and will rise higher as the traffic and the demands for improved service increase. The necessity for more accurate aircraft navigation and control, for the sake both of safety and of operational efficiency, will certainly increase as time goes on, and the financial cost of inertial-navigation systems can be expected to diminish.

INSTRUMENT PANEL of a Boeing 747 commercial passenger aircraft includes the control and display devices associated with three complete Carousel IV inertial-navigation systems (*bottom center, middle left, middle right*). Two of the systems will be in operation while the third will be in reserve. The aircraft shown in this photograph is operated by Pan American World Airways, Inc.

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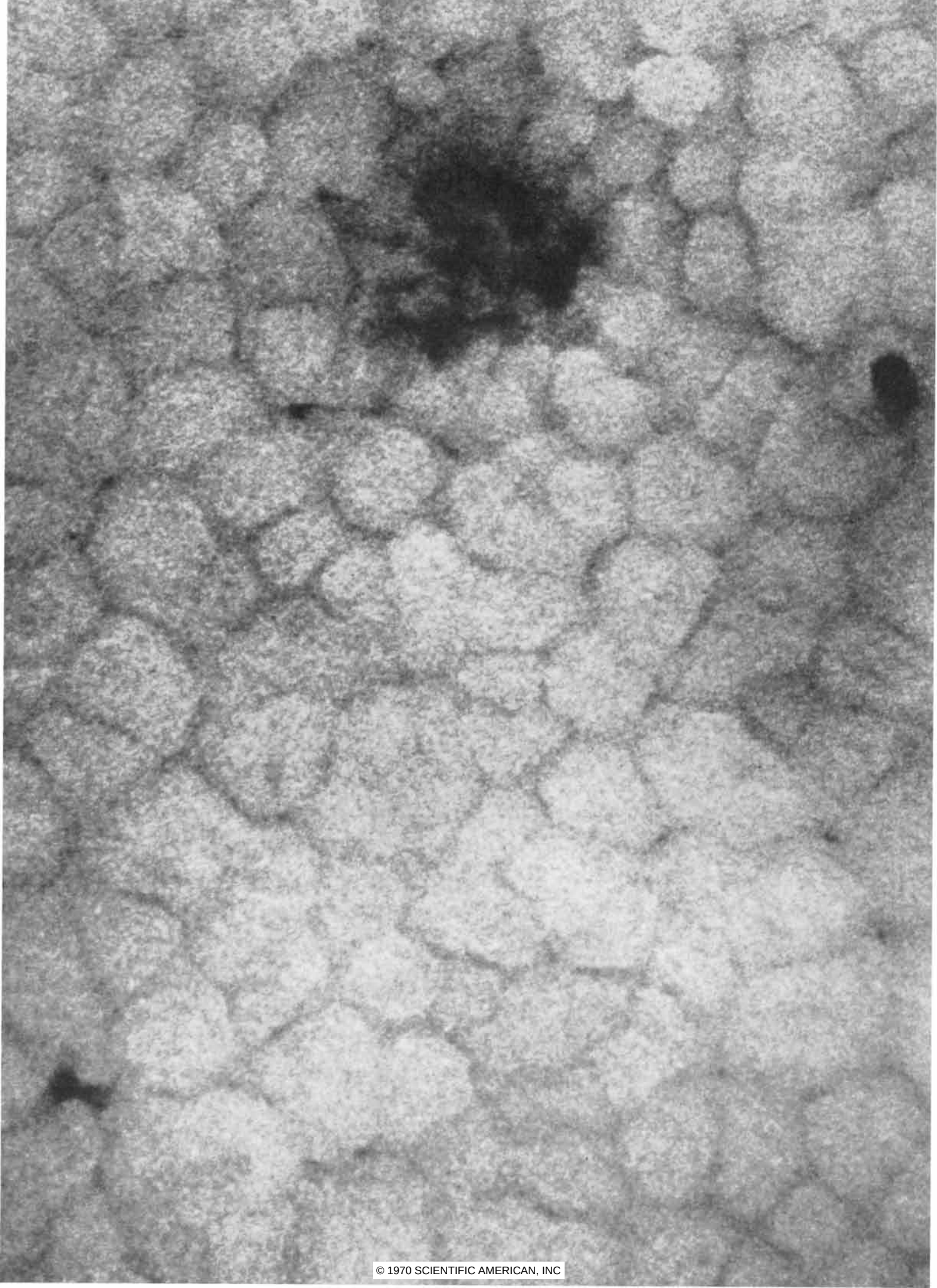


How an Eggshell Is Made

Eggshell is largely crystalline calcium carbonate. The calcium comes partly from the hen's bones, and when necessary the hen can mobilize 10 percent of her bone for this purpose in a day

by T. G. Taylor

To a housewife an egg is an article of food, and its shell serves to protect it from physical damage and to prevent the entry of dirt and microorganisms. To the hen an egg is a potential chick, and the shell serves not only as a protective covering but also as a source of calcium for the embryo and as a membrane through which the embryo respires. The eggshell performs its various functions with high efficiency, which is remarkable considering the number of eggs (five to seven a week) that the hen turns out. What is even more remarkable is the process whereby the hen obtains the substantial supply of calcium needed for the formation of the eggshells. The element comes in large part from her bones. Indeed, in extreme cases the hen can mobilize for this purpose as much as 10 percent of her total bone substance in less than a day! The physiology of this unusual process rewards close examination.

In its immature state the egg is one of many oöcytes, or unripened ova, in the ovary of the hen. Each oöcyte is encased in a membrane one cell thick; the entire structure is termed a follicle. At any one time follicles of various sizes, containing yolks at different stages of development, can be found in the ovary. Normally follicles ripen singly at a rate of one a day in hens that are laying regularly. There are occasional pauses. On the other hand, two follicles sometimes ovulate at the same time, giving rise to a double-yolk egg.

Ovulation takes place within six or eight hours after the release of a high level of a hormone produced by the pituitary gland. The release of the hormone is related to the time of onset of darkness, and it normally occurs between midnight and about 8:00 A.M. It follows that the hen always ovulates in daylight. Moreover, since it takes about 24 hours after ovulation to complete the formation of the egg, the egg is also laid during the daylight hours.

Once the yolk is released from the ovary all the remaining stages of egg formation take place in the oviduct, which consists of several distinct regions: the infundibulum, the magnum, the isthmus, the shell gland (uterus) and the vagina [*see illustration on page 91*]. The oviduct, like the ovary, is on the left side of the hen's body; a vestigial ovary and a vestigial oviduct are sometimes found on the right side in a mature bird, but they normally degenerate completely during the development of the embryo. One can only speculate on the evolutionary reason for the disappearance of the right ovary and oviduct. A reasonable guess is that two ovaries were disadvantageous because of the problem of providing enough calcium for the shells of two eggs at once. Birds have enough of a job supplying calcium for one egg a day. Certain species of wild birds have retained two functional ovaries and oviducts. It is not known how ovulation is controlled in these species, but apparently wild birds do not lay two eggs in one day.

After the ovum is released from the follicle it is engulfed by the funnel-like infundibulum of the oviduct. It is here that the egg is fertilized in hens that have been mated. As the yolk passes along the oviduct, layers of albumen are laid down in the magnum. The proteins of the albumen, which constitute the egg white, are synthesized in the magnum from amino acids removed from the blood. The synthesis is continuous, and in the periods between the passage of yolks down the oviduct albumen is stored in the tissue of the magnum. The addition of the layers of albumen to the yolk takes about four hours.

The next stage in the formation of the egg is the laying down of two shell membranes, an inner one and an outer one, around the albumen. The membranes are formed in the thin, tubular isthmus. When the membranes are first laid down, they cover the albumen tightly, but they soon stretch. By the time the egg enters the shell gland they fit quite loosely.

The egg passes the next five hours in the process known as "plumping." This entails the entry of water and salts through the membranes until the egg is swollen. The plumping period appears to be an essential preliminary to the main process of shell calcification, which occupies the next 15 to 16 hours.

The shell is composed of calcite, which is one of the crystalline forms of calcium carbonate. A sparse matrix of protein runs through the crystals of the shell. The final stage in the formation of the egg is the deposition of a cuticle on the fully calcified shell; this is accomplished just before the egg is laid.

Let us now look at the structure of the eggshell in rather more detail. From the accompanying illustration [*bottom of page 93*] it will be seen that the shell is attached to the outer membrane by hemispherical structures known as mam-

CHICKEN'S EGGSHELL consists mainly of columns of calcite, a crystalline form of calcium carbonate. They appear on the opposite page in an X-ray micrograph made through the thickness of a shell by A. R. Terepka of the University of Rochester; enlargement is 370 diameters. Large dark spot at top center is a "glassy" region of less opaque mineral; to its right is a pore.

millary knobs. Histochemical studies have shown that the cores of the knobs consist of a protein-mucopolysaccharide complex rich in acid groups, and that anchoring fibers run from the outer membrane into the knobs.

The cores of the mammillary knobs are laid down as the membrane-covered egg passes through the part of the oviduct called the isthmo-uterine junction; it is between the isthmus and the shell gland. It seems probable that the knobs are calcified soon after they are formed, before the egg enters the shell gland, and that they subsequently act as nuclei for the growth of the calcite crystals comprising the shell. Modern ideas on the mechanism of biological calcification—whether in bones, teeth, eggshells or any of the other places where calcium is deposited in animal bodies—emphasize the importance of crystal growth. Earlier theories seeking to explain the mechanism laid much stress on the role of precipitation of calcium salts from supersaturated solutions, but in the light of more recent evidence this concept no longer seems valid.

The mechanism whereby the mammillary knobs are calcified is not well understood. It is thought to involve the binding of calcium ions to the organic cores of the knobs by means of the sulfonic acid groups on the acid-mucopolysaccharide-protein material of which the cores are composed. It is suggested that the spatial arrangement of the bound calcium ions is the same as it is in the lattice of the calcite crystal, so that these oriented calcium ions act as seeds or nuclei for the growth of calcite crystals forming the shell. Some years ago my colleagues and I found that the isthmus contains extremely high concentrations of both calcium and citric acid, the former reaching a maximum of about 90 milligrams per 100 grams of fresh tissue and the latter about 360 milligrams. We concluded that the high level of calcium in this region may be of significance in the calcification of the mammillary knobs.

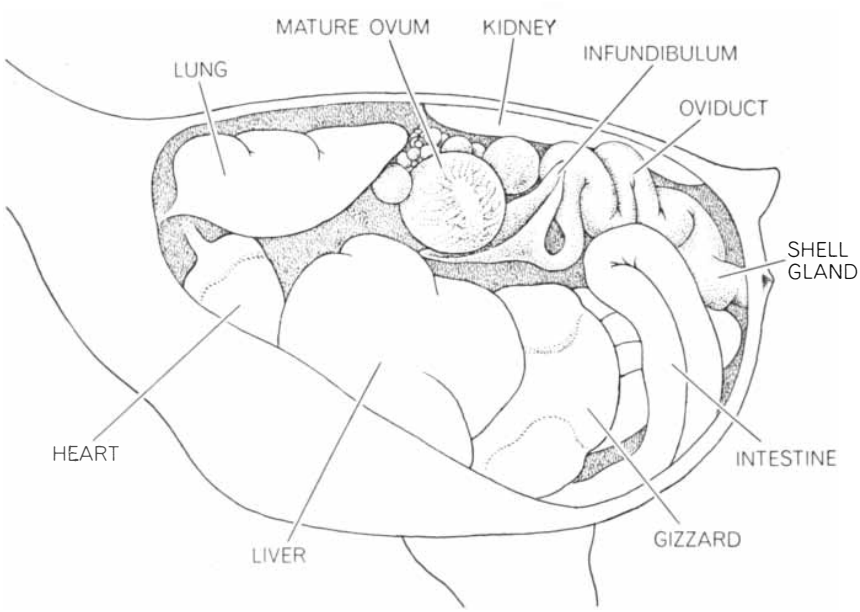
The main part of the shell was once known as the spongy layer but has more recently come to be called the palisade layer. It is composed of columns of tightly packed calcite crystals; the columns extend from the mammillary knobs to the cuticle. Occasional pores run up between the crystals from spaces formed where groups of knobs come together. The pores reach the surface in small depressions that are just visible to the unaided eye on the outside of the shell. It is through these pores that the embryo takes in oxygen and gives out carbon dioxide during the incubation of the egg.

The raw materials for the formation of the calcite crystals, namely the ions of calcium and carbonate, come from the blood plasma. The shell gland is provided with an extremely rich supply of blood. Careful measurements have shown that the level of plasma calcium falls as the blood passes through the gland when the calcification of a shell is in progress but does not fall when there is no egg in the gland.

Changes in the level of calcium in the blood of female birds during the breeding season have engaged the attention of many workers since 1926, when Oscar Riddle and Warren H. Reinhart of the Carnegie Institution of Washington discovered that breeding hen doves and pigeons had blood calcium levels more than twice as high as those found in cocks or nonbreeding hens. Adult males, nonbreeding females and immature birds of both sexes have plasma calcium levels of about 10 milligrams per 100 milliliters, whereas the level in females during the reproductive period is usually between 20 and 30 milligrams per 100 milliliters. For many years it was assumed that the high level of plasma calcium found in laying females was related to the trait of producing eggs with calcified shells, but it is generally recognized now that it is related to the production of large, yolky eggs. The extra calcium in the blood of laying birds (as compared with nonlaying ones) is almost entirely bound to protein. In contrast, the level of ionic calcium, which is the form of calcium mainly used in the formation of the eggshell, is about the same in laying and nonlaying hens.

The particular protein concerned in the binding of the increased plasma calcium is the phosphorus-containing protein phosvitin. It is the characteristic protein of the egg yolk. Phosvitin has a great affinity for calcium: the greater the amount of this phosphoprotein in the blood, the higher the level of plasma calcium. Phosvitin is synthesized in the liver under the influence of estrogen and is carried in the blood (in combination with lipid material) to the follicles developing in the ovary. Similar proteins are found in the blood of all animals that lay yolky eggs, including fishes, amphibians and reptiles, and yet neither fishes nor amphibians lay eggs with calcified shells, and among the reptiles only the Chelonia (turtles and tortoises) and the Crocodilia do so.

In the passage of blood through the shell gland there is a fall in both the protein-bound calcium (also termed nondiffusible calcium because the molecules of the protein to which it is bound are too large to diffuse through a semipermeable membrane) and in the diffusible calcium, the latter being mainly in the form of calcium ions. The two forms of calcium appear to be in equilibrium with each other. It seems likely that calcium



REPRODUCTIVE TRACT of the chicken is indicated in relation to the other organs in the body cavity. The single ovary and oviduct are on the hen's left side; an undeveloped ovary and an oviduct are sometimes found on the right side, having degenerated in the embryo.

in the form of ions is taken up from the plasma by the shell gland and that the level of ionic calcium is partly restored by the dissociation of a portion of the protein-bound calcium.

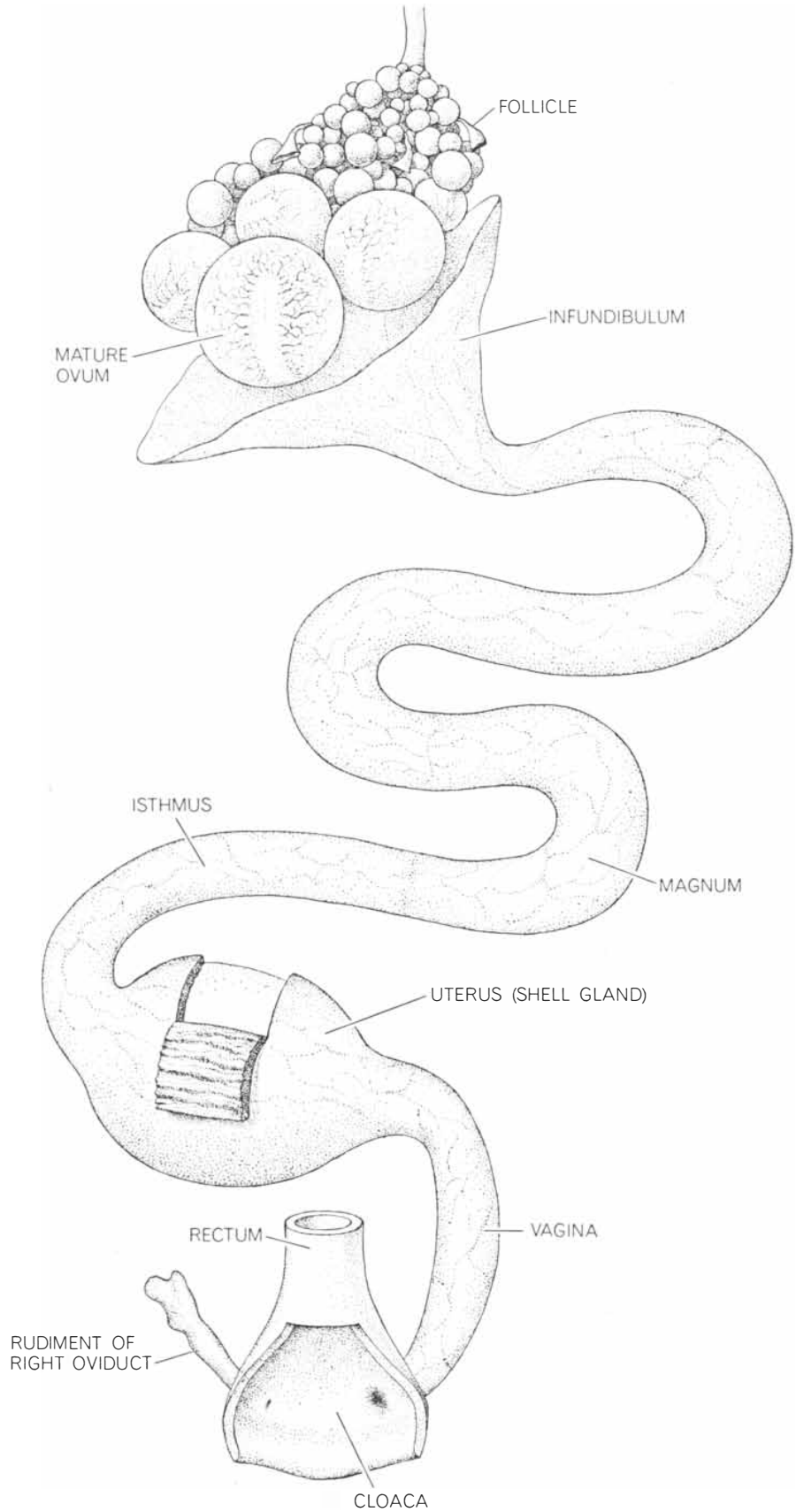
So much for the calcium ions. The origin of the carbonate ions is much harder to explain. At the slightly alkaline level of normal blood (*p*H 7.4) their concentration is extremely low, and it is the bicarbonate ion that predominates.

Theories to explain the formation of carbonate ions center on the enzyme carbonic anhydrase, which is present in high concentration in the cells lining the shell gland. One theory assumes that two bicarbonate ions are in equilibrium with a molecule of carbonic acid and a carbonate ion, with the equilibrium strongly in favor of the bicarbonate ions. The hypothesis is that the carbonic acid is continuously being dehydrated to carbon dioxide gas under the influence of the carbonic anhydrase, and that carbonate ions continuously diffuse or are pumped across the cell membranes into the shell gland, where they join calcium ions to form the calcite lattice of the growing crystals in the eggshell. An alternative theory, proposed by Kenneth Simkiss of Queen Mary College in London, is that the carbonate arises directly in the shell gland by the hydration of metabolic carbon dioxide under the influence of carbonic anhydrase.

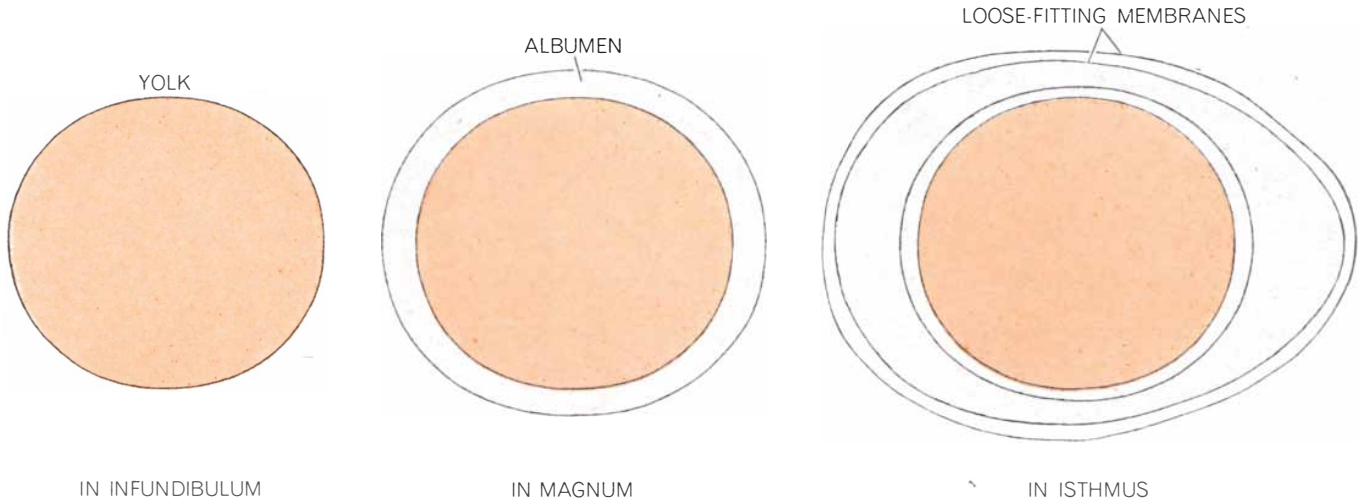
The main evidence in support of the intimate involvement of carbonic anhydrase in eggshell formation is that certain sulfonamide drugs, which are powerful inhibitors of the enzyme, inhibit the calcification of shells. By feeding laying hens graded amounts of sulfanilamide, for example, it is possible to bring about a progressive thinning of the shells. Eventually, at the highest levels of treatment, completely shell-less eggs are laid.

On the average the shell of a chicken's egg weighs about five grams. Some 40 percent of the weight, or two grams, is calcium. Most of the calcium is laid down in the final 16 hours of the calcification process, which means that it is deposited at a mean rate of 125 milligrams per hour.

The total amount of calcium circulating in the blood of an average hen at any one time is about 25 milligrams. Hence an amount of calcium equal to the weight of calcium present in the circulation is removed from the blood every 12 minutes during the main period of shell calcification. Where does this calcium come from? The immediate source is the



OVARY AND OVIDUCT of the chicken are involved in the formation of the egg. The shell is formed in the uterus, which is also called the shell gland. The principal steps in the formation of a chicken's egg are shown in the illustration at the top of the next two pages.



DEVELOPMENT OF EGG begins with the ovulation of a fully developed yolk from the ovary. It enters the infundibulum and begins moving along the oviduct. Layers of albumen are laid down in the magnum; the process takes about four hours. Two membranes

blood, but the ultimate source is the food. It has been demonstrated, however, that during the period of shell formation the hen is unable to absorb calcium from the intestines rapidly enough to meet the full requirement of the shell gland, no matter how much calcium is supplied in the food. When the rate of absorption from the gut falls short of the rate at which calcium is removed from the blood by the shell gland, the deficit is made good by the liberation of calcium from the skeleton.

This process has been demonstrated convincingly by the use of a radioactive isotope of calcium, calcium 45. Cyril Tyler of the University of Reading fed the isotope to laying hens daily and employed autoradiography to detect the amount of radioactive calcium deposited in the eggshells. (Beta particles given off by the calcium 45 of dietary origin blackened the X-ray film that was in contact with sections of shell, and the distribution of the isotope was thus visualized.) After the hens had been fed the radioactive calcium for a week the skeleton became intensely labeled, so that it was no longer possible to distinguish food calcium from bone calcium deposited in the shell. Accordingly the labeled calcium was withdrawn from the food, so that any calcium 45 deposited in the shells from then on must have come from the skeleton. Radioactive calcium appeared in abundance in the shells.

The mobilization of skeletal calcium for the formation of eggshell increases as the dietary supply of calcium decreases. When food completely devoid of calcium is fed, all the shell calcium comes from the bones. If a hen is fed a low-calcium diet, she will mobilize something like two grams of skeletal calcium in 15 to 16 hours. That is 8 to 10 percent of the total amount of calcium in her bones. Clearly hens cannot continue depleting their skeleton at this rate for long. When the food is continuously low in calcium, the shells become progressively thinner.

The hen's ability to mobilize 10 percent of her total bone substance in less than a day is quite fantastic but not unique: all birds that have been studied are able to call on their skeletal reserves of calcium for eggshell formation, and the rate of withdrawal is impressively high. This ability is associated with a system of secondary bone in the marrow cavities of most of the animal's bones. The secondary bone, which is called medullary bone, appears to have developed in birds during the course of evolution in direct relation to the laying of eggs with thick, calcified shells.

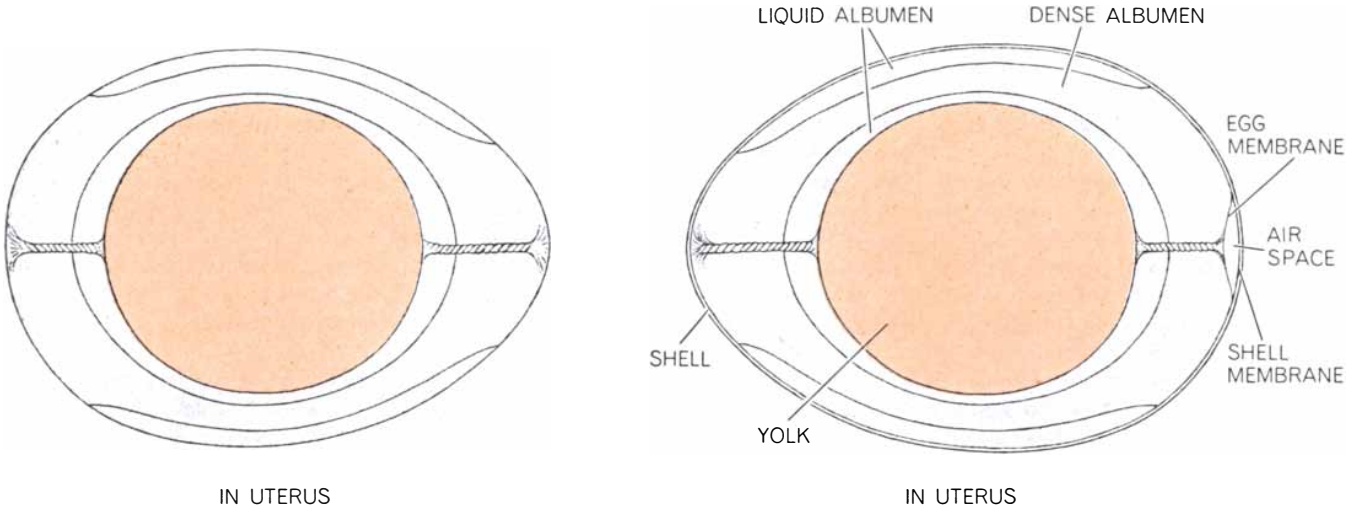
Strange to say, considering the fact that people had been killing birds for food for thousands of years and examining bones scientifically for at least a century, this unusual bone was not reported until 1916, when J. S. Foote of Creighton Medical College observed it in leg bones of the yellowhammer and the white pelican. The phenomenon was then forgotten until Preston Kyes and Truman S. Potter of the University of Chicago discovered it in the pigeon in 1934.

Medullary bone is quite similar in structure to the cancellous, or spongy, bone commonly found in the epiphyses (the growing ends) of bones. It occurs in the form of trabeculae, or fine spicules, which grow out into the marrow cavity from the inner surface of the structural bone. In males and nonbreeding females the marrow cavities of most bones are filled with red marrow tissue, which is involved in the production of blood cells. The spicules of medullary bone ramify through the marrow without interfering with the blood supply.

Medullary bone is found only in female birds during the reproductive period, which in the domestic fowl lasts many months. (In wild birds it lasts only a few weeks.) Medullary bone is never found in male birds under normal conditions, but it can be induced in males by injections of female sex hormones (estrogens). In hen birds medullary bone is produced under the combined influence of both estrogens and male sex hormones (androgens). It is thought that the developing ovary produces both kinds of hormone.

The formation and breakdown of medullary bone have been studied more closely in the pigeon than in any other bird. Pigeons lay only two eggs in a clutch; the second egg is laid two days after the first one. A pigeon normally lays the first egg about seven days after mating. The medullary bone is formed during this prelaying period. By the time the first egg is due to be provided with its shell, the marrow cavities of many bones of the skeleton are almost filled with bone spicules, which have grown steadily since the follicles developing in the ovary first started to secrete sex hormones.

About four hours after the egg enters the shell gland marked changes begin in

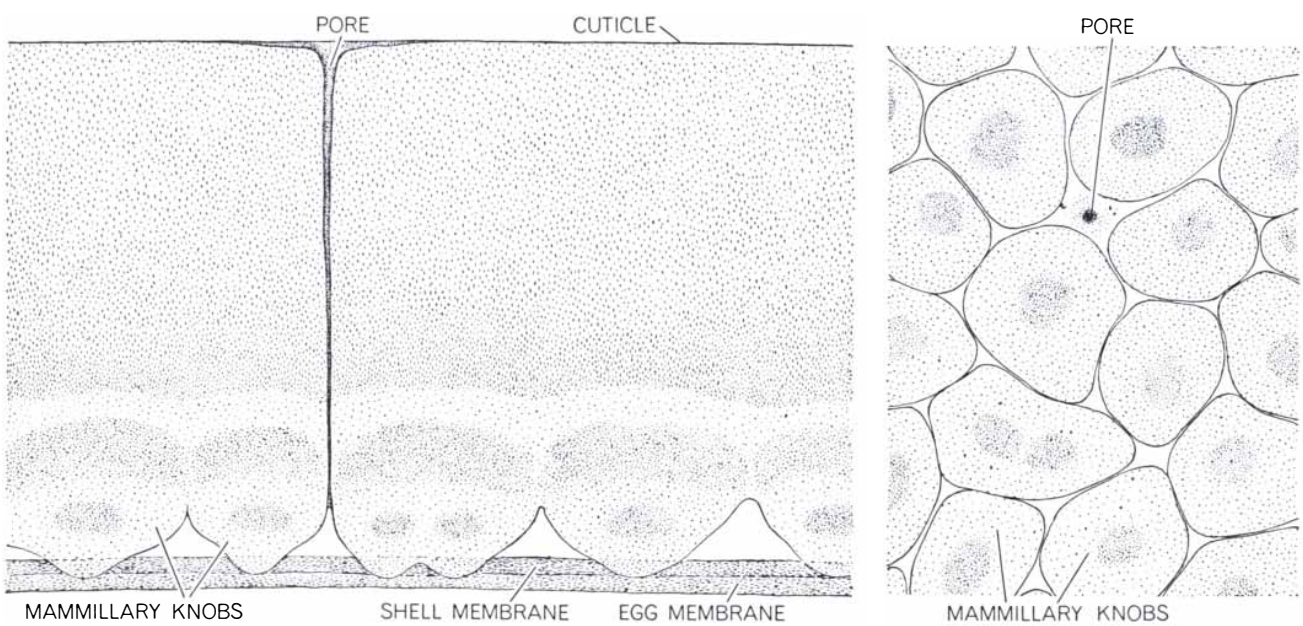


are added in the isthmus. At first they fit tightly, but by the time the egg enters the shell gland they have stretched so that the egg can undergo a five-hour process called plumping. The formation of the shell occupies the 15 to 16 hours needed to complete the egg.

the medullary bone. Within a few hours its cellular population has been transferred from one dominated by osteoblasts, or bone-forming cells, to one dominated by osteoclasts, or bone-destroying cells. The phase of bone destruction continues throughout the period of shell calcification. The calcium released from the bone mineral is deposited on the shell as calcium carbonate, and the phosphate liberated simultaneously is excreted in the urine.

The breakdown of the medullary bone persists for a few hours after the egg is laid. Then, quite suddenly, another phase of intense bone formation begins. This phase lasts until the calcification of the shell of the second egg starts; at that time another phase of bone destruction begins. No more bone is formed in this cycle. Resorption of the medullary bone continues after the second egg of the clutch is laid until, a week or so later, all traces of the special bone structure have disappeared and the marrow cavity regains its original appearance.

What mechanism might account for the rapid change from bone formation to bone destruction and vice versa? One suggestion is that variations in the level of estrogen control the cyclic changes in the medullary bone. There can be little doubt that the high level of estrogen plus androgen in the blood plasma is primarily responsible for the induction of medullary bone during the prelaying period; the drop in the level of estrogen or androgen or both after the second egg of the clutch is laid might well give rise to the bone destruction. It is difficult to see, however, how the fine degree of control necessary to induce bone destruction when calcification of the first eggshell is due to start, and to



STRUCTURE OF EGGSHELL is portrayed in cross section (*left*) and in a tangential section (*right*) made through the layer containing the hemispherical mammillary knobs. The knobs, which attach the shell to the outer membrane of the egg by fibers, have an organic core; the rest of the structure is made of oriented ions of calcium that apparently act as seeds for the shell's calcite crystals.

reverse the process soon after it is completed, can be exercised by changes in the secretion of sex hormones, presumably from the single follicle present in the ovary and possibly from the recently ruptured follicle.

The control mechanism that my colleagues and I consider more likely is one mediated by the parathyroid gland. The role of this gland is to regulate the level of calcium ions in the blood. A drop in the level of plasma calcium causes the release of parathyroid hormone from the gland, and the hormone brings about a resorption of bone tissue through the agency of the bone cells (osteoclasts and enlarged osteocytes). Both organic matrix and bone mineral are removed together, and the calcium and phosphate are released into the blood. The level of plasma calcium is thus restored; the phosphate is excreted.

Bone resorption under the influence of parathyroid hormone is largely due to an increase in the number and activity of osteoclasts. The histological picture observed in the medullary bone of pigeons at the height of eggshell calcification bears a strong resemblance to the resorption of bone in rats and dogs following the administration of parathyroid hormone. Leonard F. Bélanger of the University of Ottawa and I have recently shown that the histological changes in the medullary bone of hens treated with parathyroid hormone were very similar to those occurring naturally during eggshell formation.

It has been shown that the level of diffusible calcium in the blood drops during eggshell calcification in the hen; the stimulus for the release of parathyroid hormone is therefore present. The hypothesis that the parathyroid hormone is responsible for the induction of bone resorption associated with shell formation is also consistent with the time lag between the end of the calcification of the eggshell of the first egg in the pigeon's clutch and the resumption of medullary bone formation.

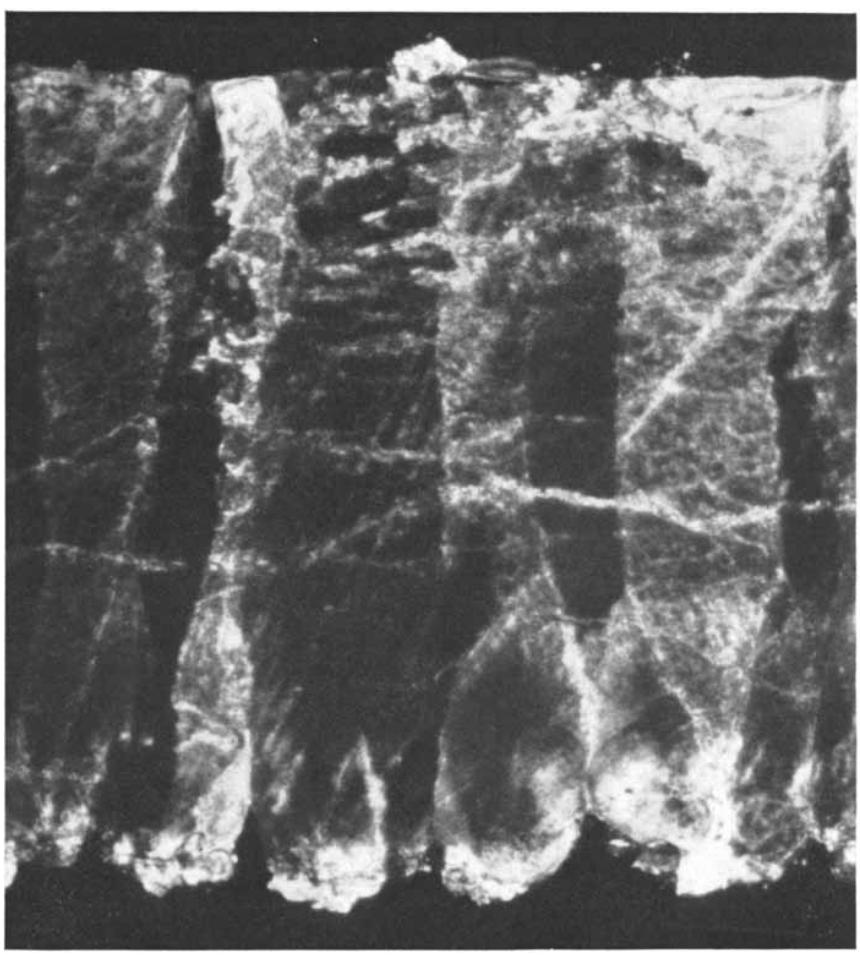
When hens are fed a diet deficient in calcium, they normally stop laying in 10 to 14 days, having laid some six to eight eggs. During this period they may deplete their skeleton of calcium to the extent of almost 40 percent. It is interesting to inquire why they should stop laying instead of continuing to lay but producing eggs without shells. Failure to lay is a result of failure to ovulate; once ovulation takes place and the ovum enters the oviduct, an egg will be laid, with or without a hard shell.

The question therefore becomes: Why do hens cease to ovulate when calcium is withheld from their diet? The most probable answer seemed to us to be that the release of gonadotrophic hormones from the anterior pituitary gland is reduced under these conditions. To test this hypothesis we placed six pullets, which had been laying for about a month, on a diet containing only .2 percent calcium—less than a tenth of the amount normally supplied in laying rations.

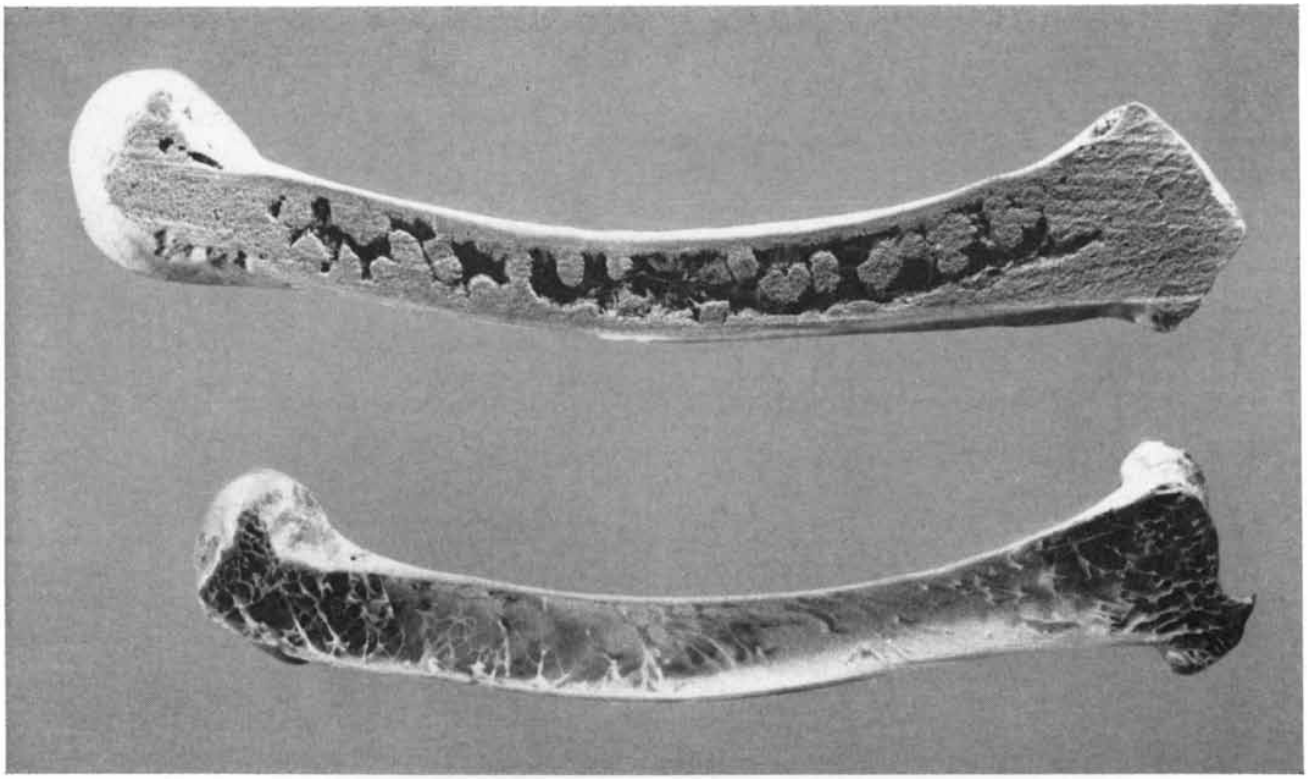
After five days on the deficient diet, when each hen had laid three or four eggs, we administered daily injections of an extract of avian pituitary glands to three of the experimental birds. During the next five days each of these hens laid an egg a day, whereas two of the untreated hens laid one egg each during the five days and the third untreated hen laid three eggs. We concluded that the failure to produce eggs on a diet deficient in calcium is indeed due to a reduction in the secretion of pituitary gonadotrophic hormones.

The mechanism of pituitary inhibition under these conditions has not been established. It is possible that the severe depression of the level of plasma calcium inhibits the part of the brain known as the hypothalamus, which is known to be sensitive to a number of chemical influences. The secretion of gonadotrophins in mammals is brought about by hormone-like factors released by the hypothalamus, but it is not known if the same mechanism operates in birds.

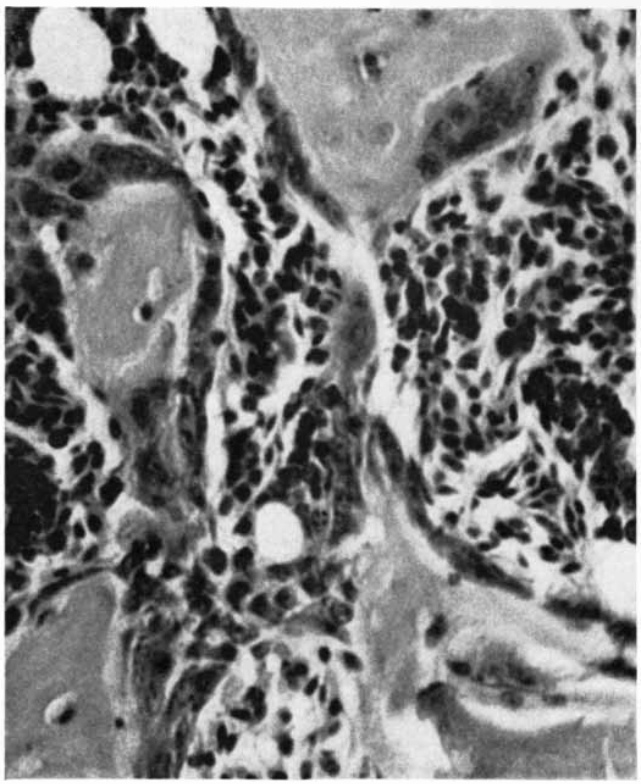
Plainly the laying of eggs with highly calcified shells has profound repercussions on the physiology of the bird. The success of birds in the struggle for existence indicates that they have been able to meet the challenge imposed on them by the evolution of shell making. Many facets of the intricate relations between eggshell formation, the skeletal mobilization of calcium, the ovary and the parathyroid and anterior pituitary glands await elucidation, but the general picture is now clear.

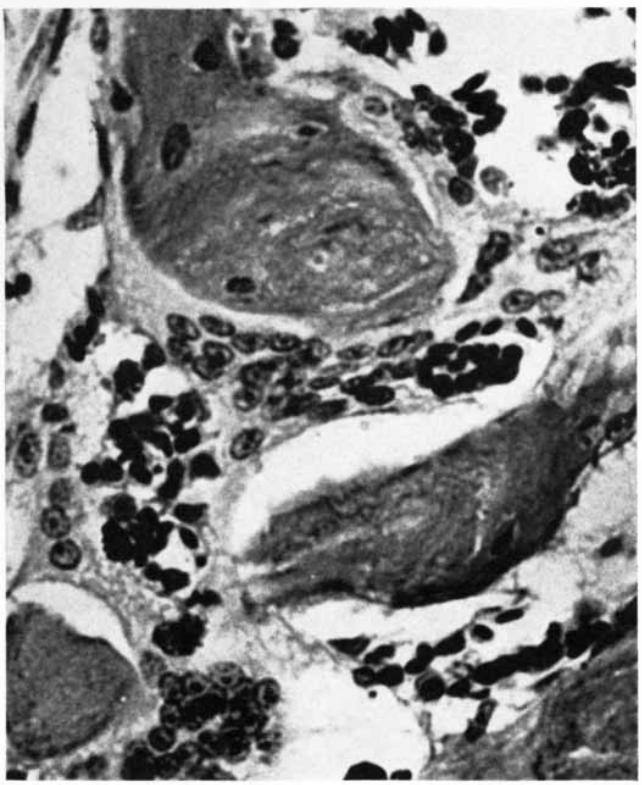


COLUMNAR STRUCTURE of an eggshell stands out in a photomicrograph also made by Terepka, using polarized light. The shell is seen in cross section at an enlargement of 325 diameters. The lumpy structures at bottom are the mammillary knobs of the eggshell.



MEDULLARY BONE of a laying chicken contains the reserve of calcium that the hen draws on in forming the eggshell. Medullary bone in the femur of a laying chicken is shown at top; the structure consists of trabeculae, or fine spicules, of bone that grow into the marrow cavity from the inside of the structural bone. The femur of a nonlaying bird (*bottom*) shows no medullary bone.





CELL POPULATION of medullary bone differs according to whether the bone is being built up or broken down. The bone is dominated by osteoblast cells (*left*) when the hen is accumulating a reserve of calcium and by osteoclast cells (*right*) when she is drawing on the reserve. The cells are the small, dark objects; the larger, gray objects are trabeculae. The bone is femur of a chicken; enlargement is 600 diameters. These micrographs were made by Werner J. Mueller and A. Zambonin of Pennsylvania State University.

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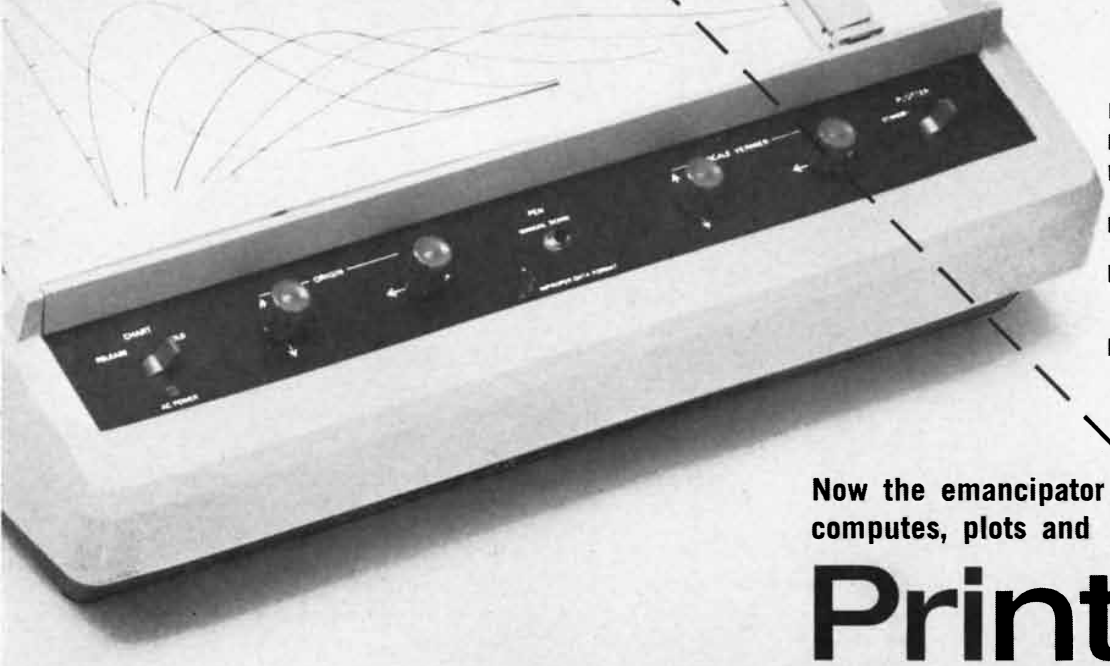

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GENETIC LOAD

The term refers to the accumulated mutations in the gene pool of an entire species. Part of the load reduces the viability of the species; the rest may be a priceless genetic resource

by Christopher Wills

Every human being has tens of thousands (possibly hundreds of thousands) of genes, each a small part of the long chains of deoxyribonucleic acid in his cells. When this DNA is duplicated and passed on to the next generation through the reproductive cells, there is a certain probability that one or more genes have mutated. That is, they have changed in such a way that the enzyme or other protein they specify is also changed. Over a period of time, as each generation gives rise to the next, such mutations accumulate in the pool of genes of all members of the species living at a particular moment. Since the process of evolution consists of changes in the quality and quantity of the genetic variability stored in the gene pool, it is a matter of some importance to consider the role of mutations, which provide this variability.

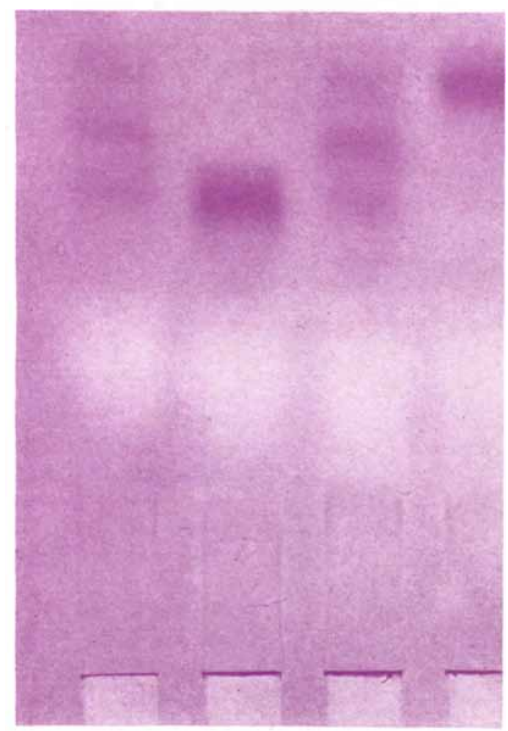
Some mutations are "beneficial," that is, the individual in whom they are expressed is better able to adapt to a given set of environmental circumstances. The large majority of mutations, however, are harmful or even lethal to the individual in whom they are expressed. Such mutations can be regarded as introducing a "load," or genetic burden, into the pool. The term "genetic load" was first used by the late H. J. Muller, who recognized that the rate of mutations is increased by numerous agents man has introduced into his environment, notably ionizing radiation and mutagenic chemicals. We now know that this mutational load is not the only kind of genetic load. We must ask the question: What is the overall load on the gene pool, and how does it affect living populations? The answer is currently being sought in genetic studies of many different organisms from man to yeasts.

One might suppose that harmful or lethal genes could not survive for very long in the gene pool because the individuals who carry them are less likely to reproduce than other individuals. The fact is, however, that such genes can survive in spite of the strong negative pressures of natural selection. The reason is that the genetic material of man, like that of all other sexually reproducing organisms, is diploid: human body cells (as distinct from human reproductive cells) have a double set of genes. As is well known, each individual receives a complete set of chromosomes from each parent. Hence every individual has two genes for every genetic function, one from his mother and one from his father. (The sex chromosomes, two of the 46 chromosomes in man, are a complication that need not concern us here.)

For each maternal chromosome, then, there is a corresponding chromosome in the paternal set. If each of these chromosomes has the same gene at exactly the same locus, the individual is said to be homozygous for that gene. If the gene happens to be a lethal mutant, the individual will of course die, by definition without being able to reproduce. If the gene is "subvital" (harmful without being lethal), the homozygous individual will often survive to transmit it to the next generation.

An individual who has two different genes at the same locus is said to be heterozygous. He might be heterozygous for (1) a mutant gene and a "normal" one, (2) two different "normal" genes or (3) two different mutant genes. The effect of the mutant genes in the heterozygote can vary from complete recessiveness (their effect is completely masked by a normal gene) to complete dominance (the normal gene is masked). Partial dominance is not uncommon; what it means is that the effect of the mutant gene is not completely masked but leaks through to a greater or lesser degree. Because of the masking effect a heterozygote can carry either lethal or subvital genes and transmit them to the next generation. All that is required is that the individual have a normally functioning gene that compensates for the mutant one.

Considering the complexity of the genetic material, mutations are remarkably rare. Nonetheless, they do arise con-



HIDDEN DIFFERENCES in the genetic material of fruit flies are revealed by this electrophoretic pattern on a slab of polyacrylamide gel. Such genetic variation, originally caused by mutation, can form a part of the genetic load. Each slot at the bottom of the slab was filled with juice from an in-

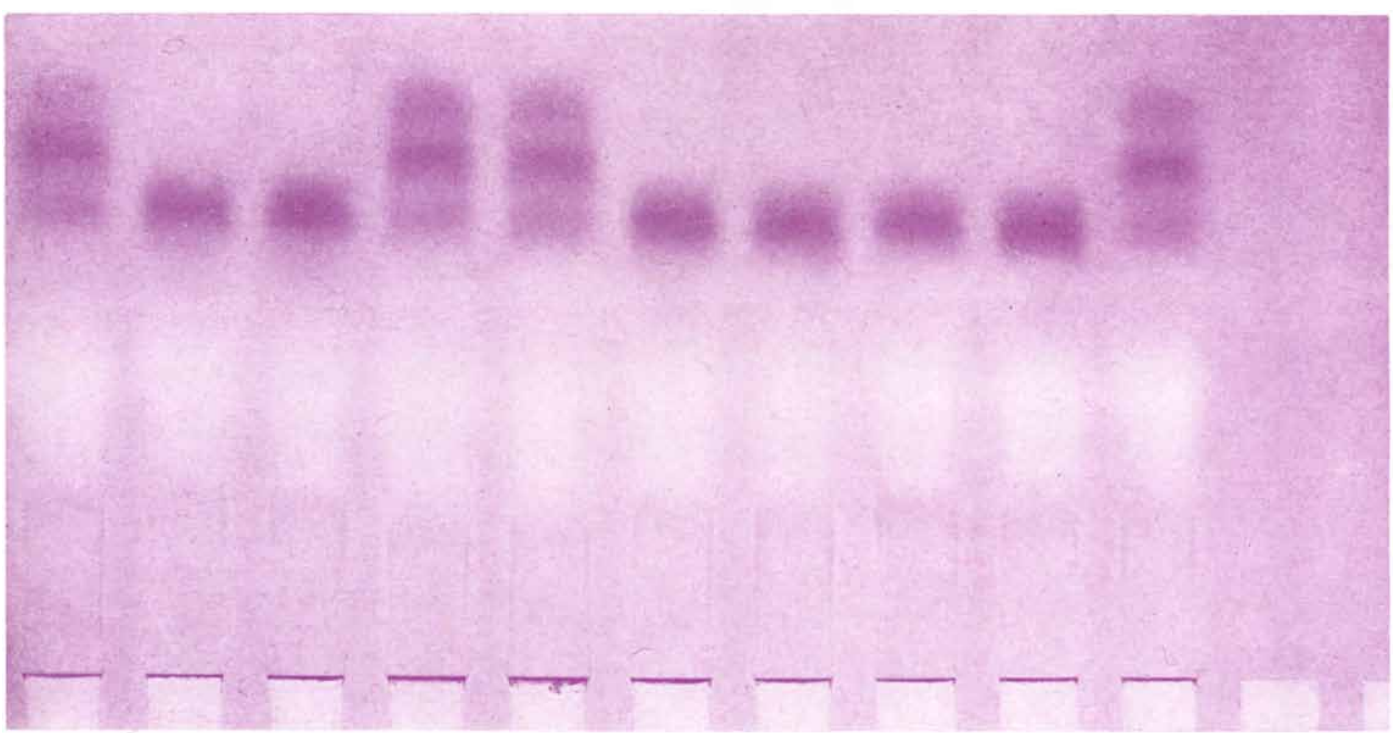
stantly; indeed, they are occurring in the reader as he reads this article. Fortunately most of them take place in cells that are not involved in reproduction, and hence they are not conveyed to the next generation. Any influence that increases the rate of mutation of those genes that are passed on to the next generation will also increase the chance of homozygosity for recessive genes. If the mutation rate remains constant for some time, there will be an equilibrium in the population between the rate at which new recessive lethals appear at a particular locus, and the rate at which they are removed by premature death as two of them turn up by chance in the same individual. If a harmful gene is dominant or partially dominant, its effects will appear right away in the heterozygote, and it will not be as common in a population at equilibrium as a completely recessive lethal with the same mutation rate would be.

From studies of marriages between close relatives Muller, Newton E. Morton and James F. Crow estimated that between 6 and 15 percent of human egg and sperm cells carry new recessive lethal mutations or mutations that are so harmful that they are "lethal equivalents." These workers calculated that the average individual is heterozygous for three to five lethals or lethal equivalents. Will such a gene leak through a masking gene? In order to find out Terumi Mukai and his co-workers at the National Institute of Genetics in Japan and later at North Carolina State University conducted a Herculean set of experiments with the fruit fly *Drosophila*. Mukai patterned his experiments on a technique developed by Muller that has become standard in modern genetics.

The consequences of a given level of genetic load can be examined experimentally by causing mutations in the gene pool of the experimental population through exposure to X rays or a chemical mutagen. There is, however, a difficulty in this simple strategy. The effects of such agents may not be easy to detect because the mutations they cause are mostly recessive. In fact, Muller worked for a decade before he was able to show in 1927 that X rays actually do produce mutations in *Drosophila*. Muller and later workers solved the problem by taking advantage of certain genetic peculiarities of *Drosophila* that allowed an entire chromosome to be passed from one generation to the next as a unit. This made it possible to produce flies that were, for example, completely homozygous for one or more chromosomes, so that new mutations would be revealed. Once the effects of a chromosome have been demonstrated in this way, new crosses can be made to pair it with other chromosomes of known effects in order to form heterozygous combinations. The results of these crosses reveal what consequences the genes have when they are heterozygous [*see illustration on pages 102 and 103*].

Mukai and his colleagues examined millions of flies that had been made either homozygous or heterozygous for chromosomes that had a known effect on the flies' survival. They discovered (among other interesting facts) that recessive lethals were hardly expressed at all in the heterozygote but that subvital genes leaked through the masking gene to a startling extent: about 40 percent of the homozygous effect.

Why should a subvital gene be expressed while a lethal one is almost completely concealed? There may be a good biochemical reason. If the product of a recessive lethal gene is so changed that it no longer functions, then in the hetero-

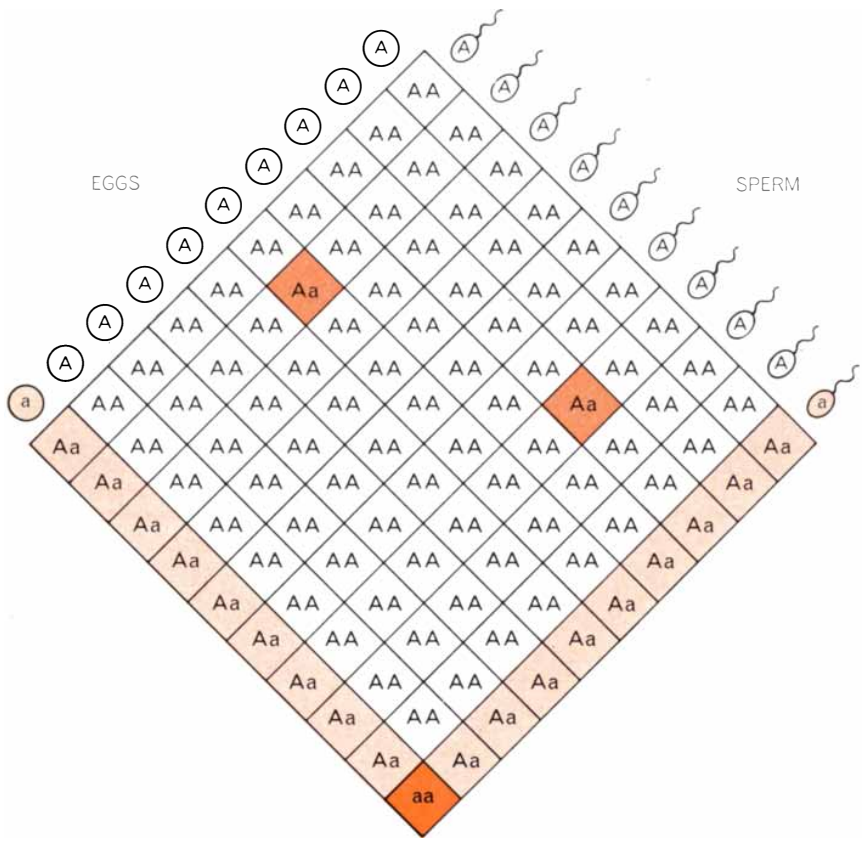


dividual fly containing the enzyme octanol dehydrogenase (among many others). When an electric current was passed through the gel, each enzyme was carried toward the top at a characteristic speed determined by minute charge differences among enzyme molecules. After current was stopped, staining of the product of the octanol dehydrogenase revealed three types (*visible as purple bands*). Fly second from left has two genes, each of which produces a slow-moving form of the enzyme. Fly fourth from left carries two genes for a fast-moving form of the enzyme. Some flies, such as the one at left and the one third from left, have genes for "fast" and "slow" enzymes and therefore also produce an intermediate form (*middle band*) made up of fast and slow subunits. Subunits produced by genes are polypeptide chains that are not yet functional. Such subunits must combine to form a normal enzyme or other protein.

zygote the normal gene for that function could take over completely without too much harm to the organism. The product of a subvital gene may be partially functional (as is suggested by the fact that some of the homozygotes survive), and it may interfere in some way with the "good" product from the other gene in the heterozygote so that its effect is felt. For example, many genes give rise to protein subunits rather than complete gene products, and these subunits are put together in the cell. Subunits from normal and subvital genes could combine to yield an abnormal product [*see bottom illustration on opposite page*].

In order to test this assumption my colleagues and I at Wesleyan University turned to the common one-celled brewer's yeast *Saccharomyces,* which has the advantage over *Drosophila* that millions of cells can quickly be screened for mutants. Yeast also has the interesting property that during its life cycle it exists in both a diploid phase and a haploid phase. In the haploid phase the yeast cells have only one set of chromosomes instead of two. Both of these phases can be maintained and studied at leisure. The effect of mutations can be observed in the haploid phase, when they are fully expressed, and then in the heterozygous diploid phase, when they are masked. The system thus resembles the *Drosophila* one, but the experiments are much easier to do. It is impractical to follow individual yeast cells to see if they die or exhibit defects, and so we used as a measure of genetic effect the rate of increase in the size of a small yeast colony viewed under the microscope.

The yeast cells were exposed to two types of chemical mutagen. One kind of agent apparently inserts or deletes bits of genetic code, so that the sense of that particular gene is usually destroyed. Agents of this type produced large numbers of recessive genes that were completely masked in the heterozygote, and these colonies grew at normal rates. The other kind of agent produces small mistakes in the genes that do not destroy sense completely; these genes did show through in the heterozygote by diminishing the growth of the experimental colonies. In outline, then, the theory seems to be correct, but we are now working on individual genes in an effort to determine the actual mechanisms involved in this partial dominance.

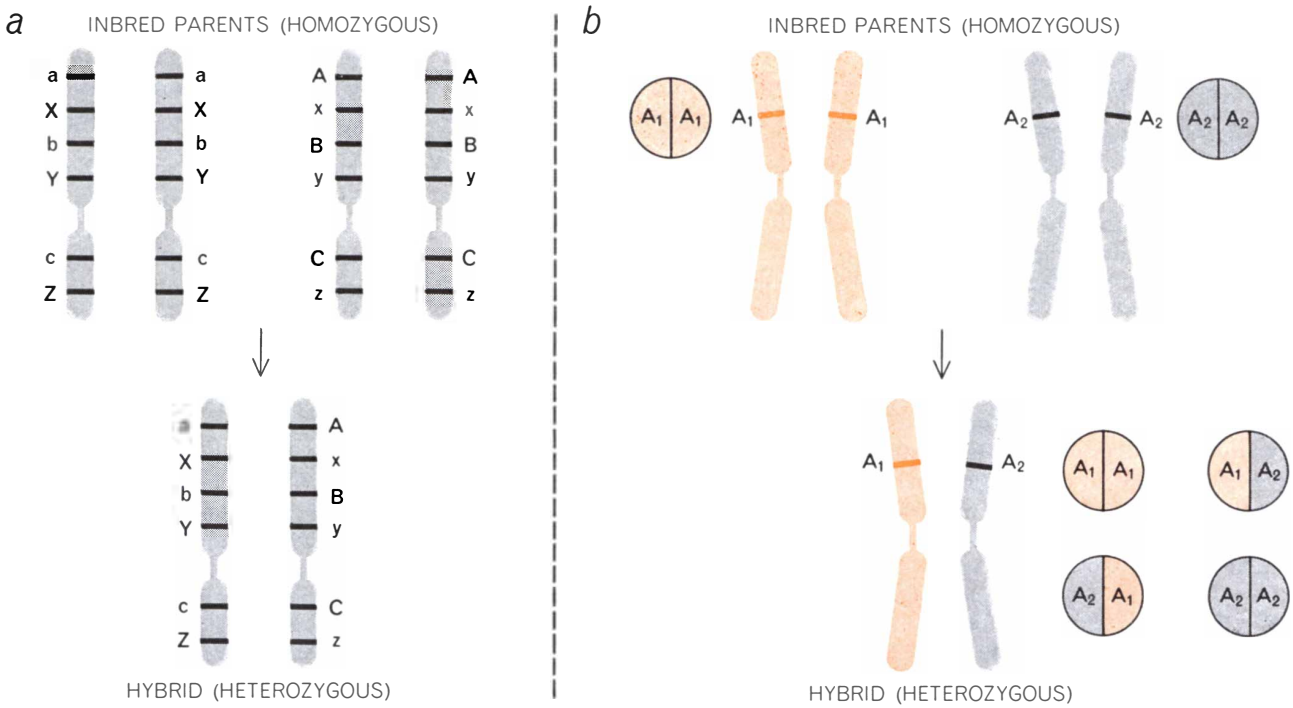


MASKING of a harmful or a lethal gene by a normal gene is demonstrated in a hypothetical population. Nine out of every 10 of the sperm and the eggs that produced this population carried gene *A*; the rest carried gene *a*. When sperm fertilized the eggs at random, 100 individuals were produced. Eighty-one are homozygous, that is, they carry two identical genes, *A* and *A*, for the same function. Eighteen individuals are heterozygous (*shading*); they carry two different genes for the same function, *A* and *a*. The *a* gene is lethal, but because each heterozygote carries a normal *A* gene that masks the *a* gene, none displays a defect. One individual, however, carries two lethal genes (*solid color*). It dies because it has no normal gene to compensate for the lethal one. Two individuals within diagram are mutants (*color*); they carry an *A* gene that was changed into an *a* gene. An average of two mutations must arise in each generation in order to maintain the ratio of *A* to *a* as *aa* homozygotes die.

A start has thus been made on classifying the genes that constitute the mutational load. There is, however, a different kind of burden that is also a part of the genetic load. This burden primarily consists not of harmful mutations that are masked in the heterozygote but strangely enough of apparently normal homozygotes. In order for the load to appear the gene pool must contain two or more functioning genes at a locus, and circumstances must be such that organisms heterozygous for these genes have an apparent selective advantage, that is, they can leave more offspring than the homozygotes can. There is thus a load associated with being homozygous, even for normal genes. Such circumstances might include environmental conditions that favor a heterozygote over a homozygote or conditions that select against the homozygote but do not affect the heterozygote. This kind of load is called a balanced load because, as we shall see, a balance in the population is struck between the heterozygotes and the homozygotes.

The term "balanced load" encompasses many phenomena, but the most important is hybrid vigor, a remarkable effect observable in many organisms that was first put to work by geneticists when they crossed different inbred lines of corn to produce vigorous strains with greatly increased yield. A number of mechanisms have been proposed for hybrid vigor, but regardless of the mechanism the end result is the same: an organism heterozygous at a large number of loci is "fitter" in some sense than one that is heterozygous at fewer loci. There must accordingly be a load attached to being homozygous, because the homozygous organism often leaves fewer and less vigorous offspring than the heterozygous one.

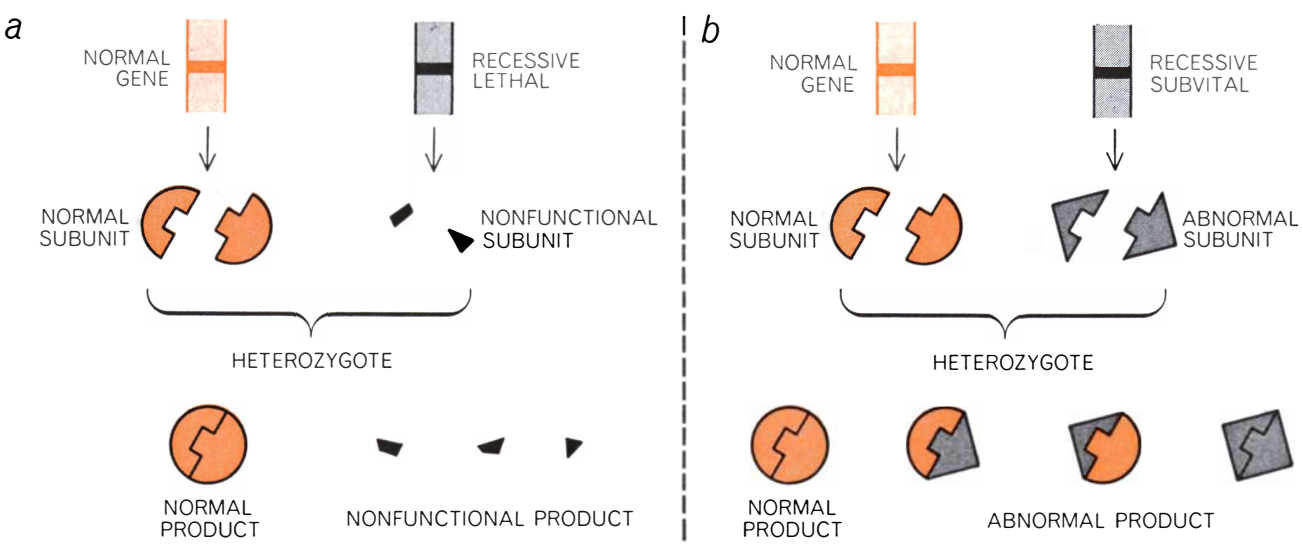
The balanced load is different from the mutational load in another respect. The frequency of a recessive gene in the mutational load depends directly on the mutation rate. An altered gene that gives an advantage to the heterozygote, however, might appear only once and then



HYBRID VIGOR may be explained as a masking of harmful genes by normal genes in the heterozygote. In *a* one homozygous parent plant is crossed with another. Both parents carry homozygous harmful genes and homozygous normal genes. The offspring produced is heterozygous (*bottom*). In this hybrid the genes on each parental chromosome are paired so that the harmful genes (*small letters*) are masked by normal genes (*capital letters*). Another explanation of hybrid vigor that does not exclude the first is shown in *b*. Here the *A* genes of homozygous parents at top are each capable of producing only one kind of subunit of the functioning gene product, A_1 or A_2, and one product, A_1A_1 or A_2A_2. The hybrid offspring, however, can produce both kinds of subunit (a nonfunctioning polypeptide chain) and three kinds of gene product (an enzyme or functioning protein) because it has both kinds of *A* gene.

automatically build up to a high level in the population as the number of heterozygotes increases. It is important to realize that no matter how strong the heterozygote appears to be, the homozygotes never disappear; they continue to occur in each generation by the normal mechanisms of the production and the subsequent fusion of haploid reproductive cells. In other words, when two heterozygotes mate and reproduce, a certain number of their offspring will inevitably be homozygotes. Eventually, therefore, a balance is struck between the heterozygotes and the homozygotes at that locus [*see illustration on page 104*].

The dependence of the balanced load on environmental conditions has been conclusively demonstrated by Theodosius Dobzhansky and his colleagues at Columbia University and at Rockefeller University. The demonstration has been achieved by experiments with inversions in the chromosomes of *Drosophila*. Such



LEAKAGE of a subvital gene through a masking gene is shown schematically. In heterozygote at left (*a*) normal gene (*color*) is paired with a recessive lethal that produces nonfunctional subunits. Because the normal gene produces a normal subunit and normal product, however, the individual carrying the genes appears normal. In heterozygote at right (*b*) the same normal gene is paired with a subvital gene. The subunit of the subvital is partly functional and therefore can combine randomly with a normal subunit to form an abnormal but functioning product. Only a quarter of the product of this heterozygote is normal and a defect is obvious.

inversions are reversed segments of chromosomes, and they are themselves under genetic control; they have been found in wild populations of many *Drosophila* species. The normal mechanism of crossing-over, which exchanges individual genes between maternal and paternal chromosomes in each generation, is disrupted in flies that are heterozygous for these inversions. Specifically the genes within the inversion are "locked in" and pass from one generation to the next in a group that Kenneth Mather has called a supergene, with inheritance just like that for a single gene. These supergenes are visible in the giant chromosomes of *Drosophila* larvae. In a heterozygous larva one can see corresponding maternal and paternal chromosomes paired so that the normal and the inverted segments form a loop [*see illustration on page 105*]. Because inversions are so easily recognizable their frequencies can be followed in either laboratory populations or wild ones.

One of Dobzhansky's experimental populations consisted of flies carrying a normal chromosome and an inverted chromosome from a particular wild population, maintained in the laboratory at 25 degrees Celsius. The population included three kinds of flies: flies homozygous for the normal chromosome, flies homozygous for the inverted chromosome and heterozygous flies, that is, flies that carried both the inverted chromosome and the normal one. If the conditions of the experiment are such as to give a selective advantage to the heterozygotes, one would predict that, whatever the initial ratios in the population, the proportions of the three types of flies would reach some specific equilibrium value.

Such was the case. Regardless of the number of each type of fly present in the original population, the population reached an equilibrium after a certain number of generations. In this equilibrium state 49 percent of the flies were homozygous for the normal chromosome, 9 percent were homozygous for the inverted chromosome and the remainder (42 percent) were heterozygous. The unequal numbers of the two types of homozygote in the equilibrium population can be explained if the normal homozygote is fitter than the homozygote for the inverted chromosome. Subsequent experiments showed that this was true, and also showed that the heterozygotes clearly had an advantage over the two kinds of homozygote in many factors that together make up genetic fitness: ability to survive to adulthood, number of eggs laid and so on. This explained the stability of the frequencies, which were governed not by mutation rate but by the relative genetic fitness of the two kinds of homozygote and the heterozygotes. The two kinds of homozygote carried a balanced load, since they were at a disadvantage compared with the heterozygotes.

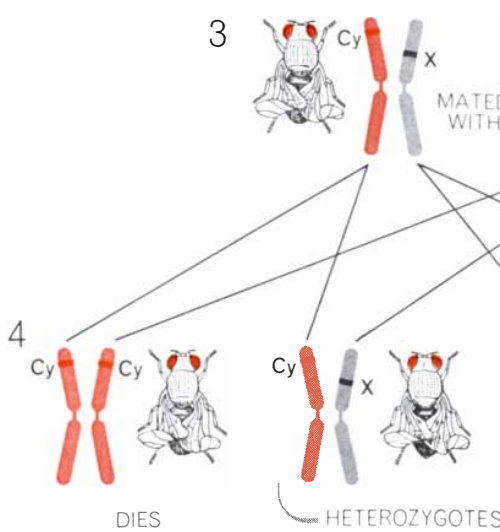
When the temperature was lowered to 16.5 degrees C., however, the advantage of the heterozygotes—and the balanced load—disappeared. The frequencies of normal and inverted chromosomes now stayed at about the frequencies in the starting populations. In other words, the homozygote disadvantage was conditional on temperature. One explanation (there are others) might be that certain mutant genes on both the normal and the inverted chromosomes worked well at 16.5 degrees but poorly at 25 degrees. These genes were matched with normal ones in the heterozygote, which would therefore be fitter than the homozygotes at 25 degrees. At the lower temperature, however, the balanced load had disappeared, and all three kinds of flies were equally fit.

Flies homozygous for either of these chromosomes do perfectly well by themselves in the laboratory, producing large, healthy populations that look perfectly normal. Dobzhansky's experiments, and those of many other workers, have repeatedly demonstrated the now-you-see-it, now-you-don't quality of the balanced load, with its extreme dependence on the environment. The heterozygote is often fitter, but not under all conditions.

Could the heterozygous advantage that Dobzhansky observed arise at any locus, or were the supergenes unique in some way? Much indirect evidence had accumulated that they were not, but an elegant experiment performed by Edwin Vann at Cornell University provided a direct answer. If such heterozygosity were common, Vann reasoned, it might be observed at many loci on the chromosomes. The problem was finding a way of detecting the heterozygous loci. Vann solved this problem by creating inversions of varying lengths in the chromosomes of a population of highly homozygous *Drosophila*. Next he mated carriers of the newly created supergenes with members of the same population without the inversion, or with members of other populations. The gene pools of these populations were also homozygous; some were related to the original population and some were not. The offspring of these last matings, because of the diverse genetic background of the parents, could be expected to be heterozygous at a great many of the loci covered by an inversion. Equally important, the fate of this group of loci could be followed by using the inversion as a marker.

If heterozygous advantage had actually been produced by such matings, the inversions would probably remain in the population and increase in frequency, since heterozygotes for the inversion would also always be heterozygous for the genes within the inversion. After several generations had passed Vann observed that in fact the longer inversions (containing more genes and therefore preserving more heterozygosity) were much less likely to be lost than the shorter ones. He also found that the longer inversions often tended to achieve high frequencies. Finally, because Vann's supergenes covered varying lengths of all the chromosomes, it could be concluded that heterozygote advantage existed up and down the chromosomes and needed only to be revealed by a suitable genetic marker.

One proposition remained to be disproved. It seemed possible that an inversion at any point on a chromosome might have some selective advantage per se that had nothing to do with heterozygosity at all. The reader will recall that Vann also introduced his inversions back into the populations from which the inversions had been derived in the first place. In these crosses the genes on the inverted and the uninverted chromosomes were the same, and little if any heterozygosity was present in these flies. After several generations had passed Vann found that the inversions had completely disappeared. It seemed, then, that the mere production of an inversion, rather than providing an advantage, actually constituted a genetic liability that caused the individuals carrying them to



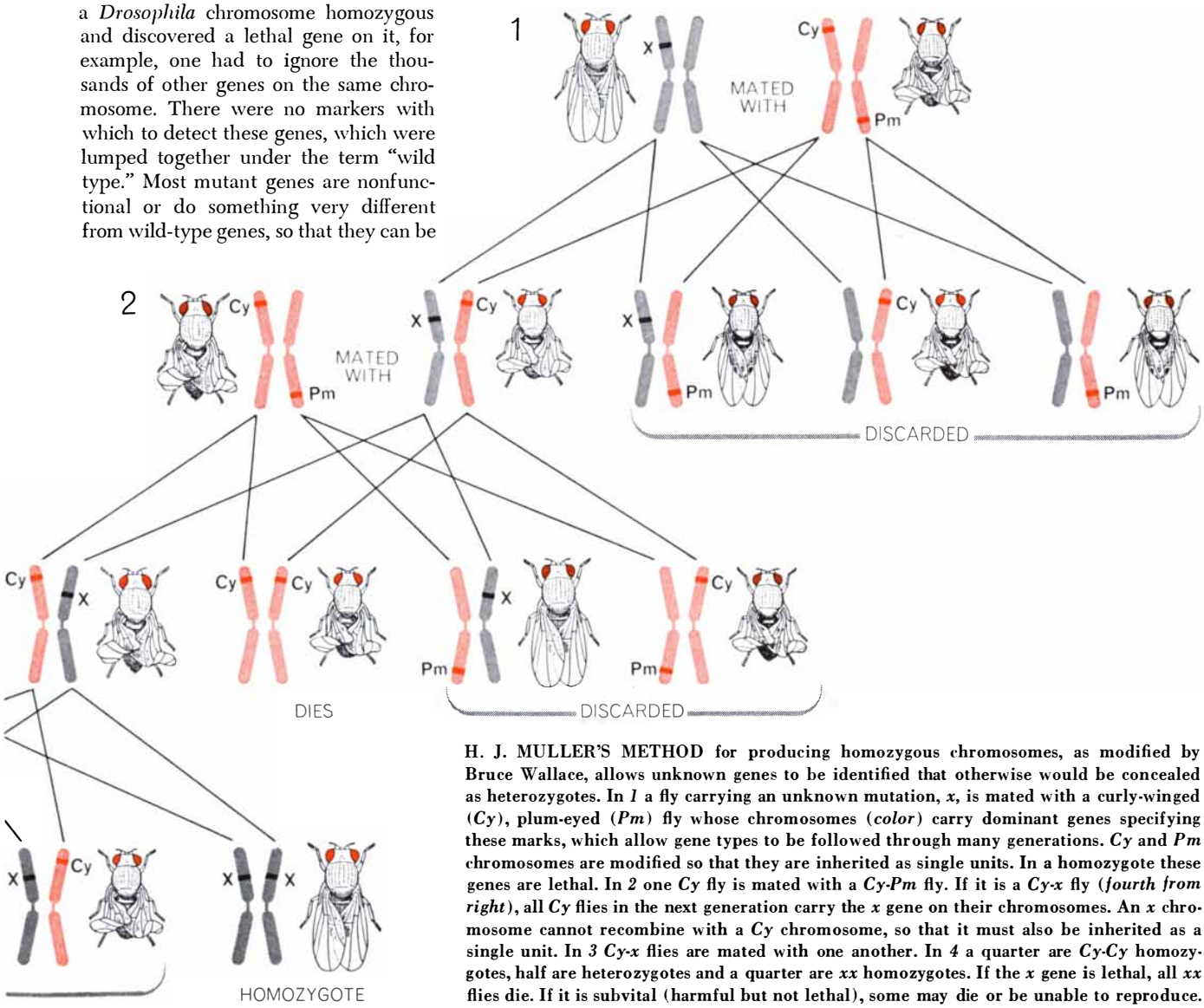
be eliminated from the population after a few generations.

Vann had proved that heterozygous advantage could exist at many places on a chromosome, but there was no way of directly determining what functions, if any, these genes performed. Clearly they could not be lethals or subvitals. A fly heterozygous for more than a few severe subvitals would be very sick indeed, and if it were heterozygous for too many lethals, there would be a good chance it would be homozygous for at least one. In order to prove that these genes were normal it was necessary to develop a method for identifying the function of an individual gene.

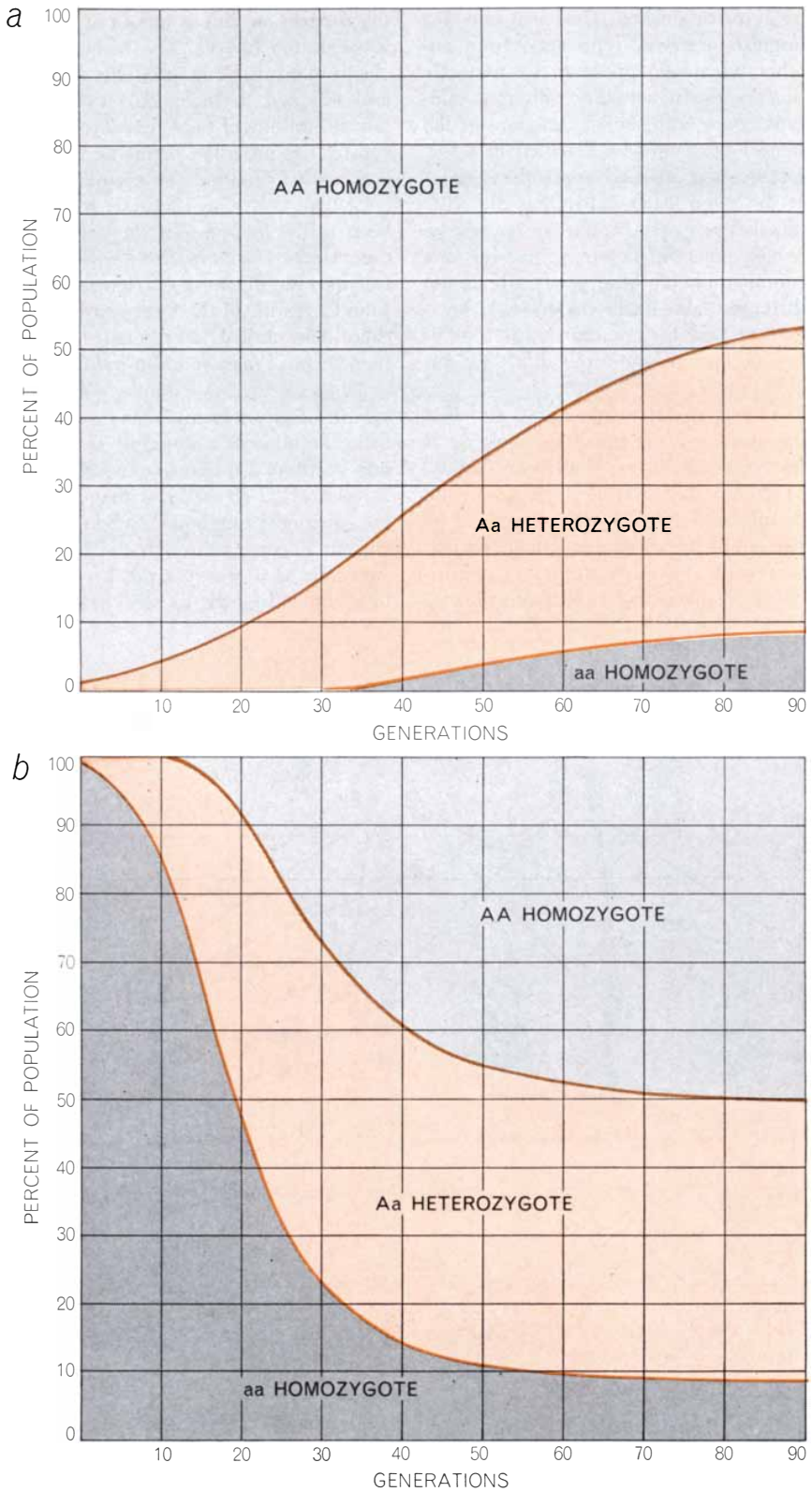
Until recently population geneticists investigating such problems were in the position of early oceanographers, who tried to reconstruct the bottom of the ocean from a few soundings and samples of sand and mud taken at random over thousands of square miles. If one made a *Drosophila* chromosome homozygous and discovered a lethal gene on it, for example, one had to ignore the thousands of other genes on the same chromosome. There were no markers with which to detect these genes, which were lumped together under the term "wild type." Most mutant genes are nonfunctional or do something very different from wild-type genes, so that they can be easily distinguished. How can one distinguish one wild-type gene from another when all appear to be perfectly functional? In actuality different wild-type genes with similar functions at the same locus could be detected in a few instances. In man there are three genes at the same locus controlling the ABO blood-type system, and a person may be homozygous or heterozygous for any combination of these genes. He is not distinguishable from his fellows, however, except by immunological tests of himself and in some cases of his parents or children.

Some population geneticists felt that this was only the tip of the iceberg. A few years ago Bruce Wallace at Cornell suggested that a fruit fly from a wild population might be heterozygous at 50 percent of its paired genes, a suggestion that was met with consternation and disbelief. Wallace may have overestimated the proportion, but it turns out that he was not too far off. The technique of electrophoresis, long used by chemists and adapted to biological systems by Oliver Smithies of the University of Wisconsin, has provided population geneticists with a method for examining the gene pool that is as useful as sonar has been to the mapping of the ocean bottom. Harry Harris of the University of London and Richard C. Lewontin and John L. Hubby of the University of Chicago have used it to examine the wild-type genes of man and *Drosophila.*

The technique is a simple one. A tiny sample of serum from a man or the juice from the body of a single fly is inserted into a strip of a supporting medium such as a slab of starch soaked with an electrolyte, or conducting liquid. When a direct current is passed through the medium, molecules that are very much alike but that differ slightly in size or electric



H. J. MULLER'S METHOD for producing homozygous chromosomes, as modified by Bruce Wallace, allows unknown genes to be identified that otherwise would be concealed as heterozygotes. In *1* a fly carrying an unknown mutation, *x*, is mated with a curly-winged (*Cy*), plum-eyed (*Pm*) fly whose chromosomes (*color*) carry dominant genes specifying these marks, which allow gene types to be followed through many generations. *Cy* and *Pm* chromosomes are modified so that they are inherited as single units. In a homozygote these genes are lethal. In *2* one *Cy* fly is mated with a *Cy-Pm* fly. If it is a *Cy-x* fly (*fourth from right*), all *Cy* flies in the next generation carry the *x* gene on their chromosomes. An *x* chromosome cannot recombine with a *Cy* chromosome, so that it must also be inherited as a single unit. In *3* *Cy-x* flies are mated with one another. In *4* a quarter are *Cy-Cy* homozygotes, half are heterozygotes and a quarter are *xx* homozygotes. If the *x* gene is lethal, all *xx* flies die. If it is subvital (harmful but not lethal), some may die or be unable to reproduce.



BALANCED LOAD appears in a population when heterozygotes seem to have a selective advantage over homozygotes, so that a load is borne by the normal genes. In this idealized case (*a*) *Aa* heterozygotes have a fitness of 100 percent, *AA* homozygotes are 92 percent as fit as the heterozygotes, and *aa* homozygotes are 80 percent as fit. In first generation 98 percent of the population consist of *AA* homozygotes and about 2 percent are *Aa* heterozygotes. By the 90th generation 42 percent are the favored *Aa* heterozygotes, whereas 9 percent are *aa* homozygotes that have merged through recombination. In the reverse situation (*b*), where *aa* homozygotes form 98 percent of the first generation and 2 percent are *Aa* heterozygotes, the latter still increase to 42 percent. The percentage of *Aa* chromosomes cannot increase further in this case because the three kinds of gene type balance one another.

charge migrate at different rates in the electric field. When the current is turned off, the protein (or protein subunit) products of different genes will have migrated to different places in the gel, where each forms a band. The products of two wild-type genes differing by as little as one amino acid can be separated in this way. They can then be made visible in the starch by staining them [*see illustration on pages 98 and 99*].

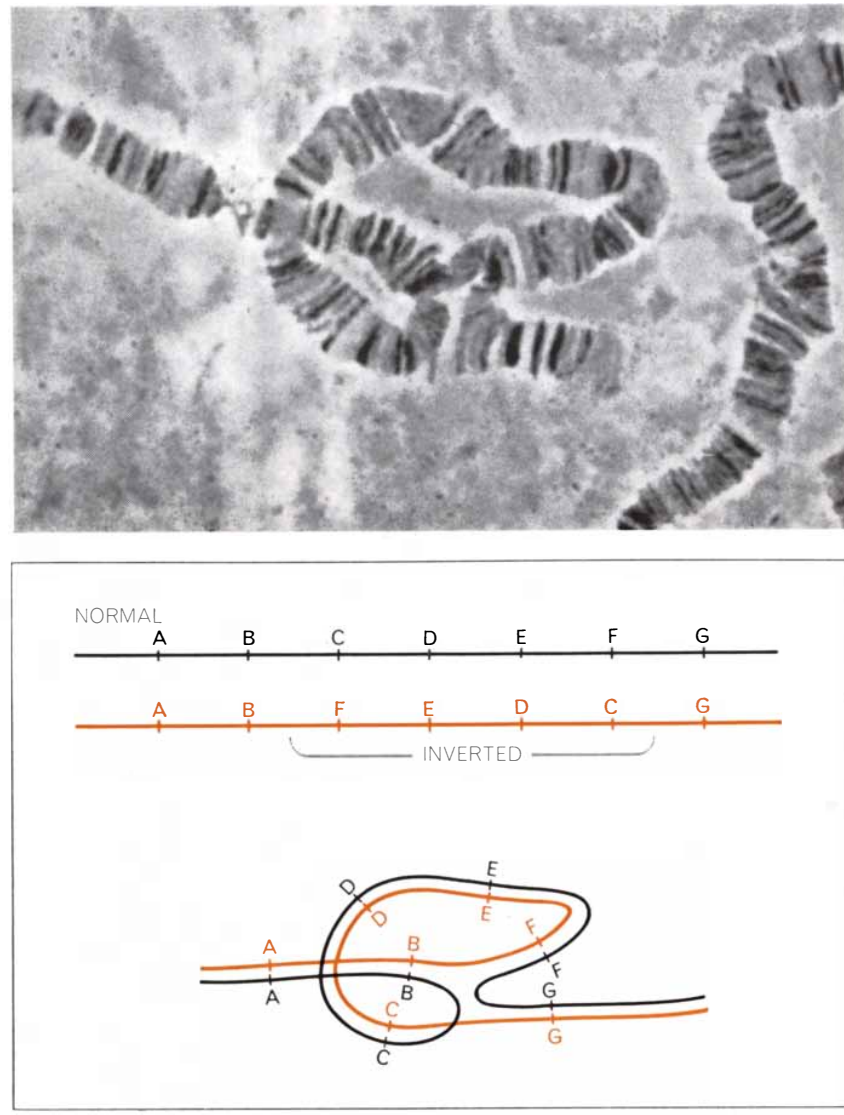
Not all gene products can be examined by electrophoresis, but from those that can it is possible to make an estimate of the hidden differences between paired wild-type genes. Lewontin and Hubby calculated that their flies were heterozygous at 10 to 14 percent of their gene pairs. They emphasized that, since not all the differences can be detected by electrophoresis, this was a minimum estimate. Harris' results for man, although they were obtained from smaller numbers of genes, agreed. Other workers have found similar differences between the paired genes of organisms as diverse as butterflies and mice.

These slightly different forms of the same gene that perform the same function are called isoalleles. They are, of course, produced by mutation from other forms of the same gene, but mutations to functionally useful isoalleles must occur very rarely. One can take two extreme positions with regard to isoallelic differences. The first is that they are entirely accidental, and that the homozygosity or heterozygosity of the isoalleles makes no difference whatsoever to the fitness of the organism. The second is that the differences (or most of them) are held in the population by heterozygous advantage, and that the homozygotes for the isoalleles contribute to the balanced load. Ingenious mathematical arguments have been advanced in favor of the first view, but strong experimental evidence has now appeared against it.

Satya Prakash, working with Lewontin and Hubby, used electrophoresis to examine populations of *Drosophila* separated from one another by hundreds or thousands of miles. Many of the isoalleles the investigators detected had the same frequencies in these far-flung populations, and those that did not varied in a regular way depending on the geographic location of the sample. Other evidence of strong selection of isoalleles in wild populations of mice has been provided by Robert K. Selander and his co-workers at the University of Texas. Selection must be holding most of these genes in the population, because if they were selectively neutral, their frequency from

place to place would vary greatly. It is almost certainly these functional isoalleles, rather than the harmful genes of the mutational load, that provide the variability on which natural selection acts. Isoalleles in the gene pool make a species far more responsive to natural selection than it would be if there were simply one kind of gene at each locus and every organism in the species were homozygous for that gene.

If we can extrapolate from the few genes sampled to the entire gene pool, there would appear to be thousands of isoalleles held in the population by some form of heterozygous advantage, and homozygotes for these isoalleles must be contributing to the balanced load. Therefore either there is a very large load or the selection against any particular gene must be very slight. The former possibility can be ruled out; the balanced load is simply not very large. If it were, most of the offspring of an organism would die from its effects. If we accept the latter possibility, however, we are faced with a difficulty. In any sexually reproducing population (small ones in particular) there is a random effect, known as genetic drift, that causes isoalleles at a locus to be lost simply by chance. Selection pressures have to be large enough to overcome such random forces if these genes are to be retained. The difficulty can be overcome if one assumes that genes, even on chromosomes free of inversions, have a tendency to hold together in groups. Within these groups selection pressures that are individually very small might be large enough in the aggregate to overcome the random drift forces.



INVERSION in salivary-gland chromosome of a fruit fly (*top*) was produced with X rays by Edwin Vann. The inversion, similar to those found in wild populations, upsets the order of genes (*bottom*). One chromosome must therefore form loop so that genes at the same locus can be paired. A locus is a place on a chromosome for a gene with a specific function.

Recently John W. Crenshaw of the University of Rhode Island, Joseph N. Vitale of the Yale Computer Center and I collaborated in an attempt to test this assumption by following a population of sexually reproducing organisms simulated by means of a computer program. We gave this "population" a balanced load but left out the mutational one, since it is relatively well understood. In addition we tried to make the balanced load as realistic as possible. It may be recalled that the flies homozygous for chromosomal inversions in Dobzhansky's experiment could fend perfectly well for themselves. In competition and under certain environmental conditions, however, the heterozygotes had a slight advantage. Similarly, the isoalleles discovered by electrophoresis are apparently perfectly functional and do no detectable harm to an organism homozygous for them, but such an organism might not do quite so well in competition as a heterozygote would. This conditional kind of selection has been considered theoretically by a number of workers, notably Wallace, who has called selection against the mutational type of load "hard" selection (since it occurs under almost all conditions) and selection against the balanced type of load "soft" selection.

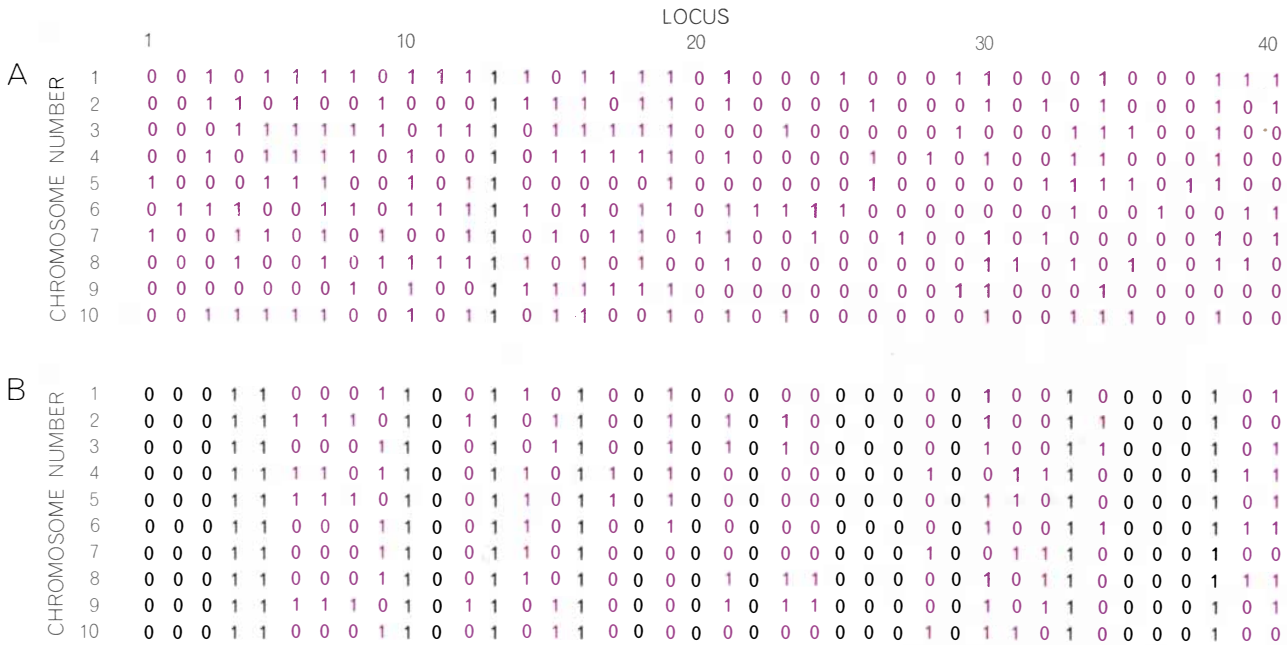
Our computer organisms consisted of strings of digits. Each organism was a pair of such strings, one representing a maternal chromosome and one a paternal. These "chromosomes" could be manipulated to mimic sexual reproduction and recombination. Genes along the string were represented by a 1 or a 0, so that if an organism had a 1 or a 0 at a particular locus on both of its chromosomes, it was homozygous at that locus. If it had a 1 on one chromosome and a 0 on the other, it was heterozygous. At the beginning of each computer run the population contained a mixture of 1's and 0's, so that each organism was heterozygous at many loci. During many generations of simulated sexual reproduction we monitored the population to see how much of this variability would be retained.

Some of our populations were subjected to soft selection, by surveying them each generation and removing a few of the organisms homozygous at the largest number of loci, regardless of which loci. The places of these organisms in the population were then filled with duplicates of those organisms that were heterozygous at the largest number

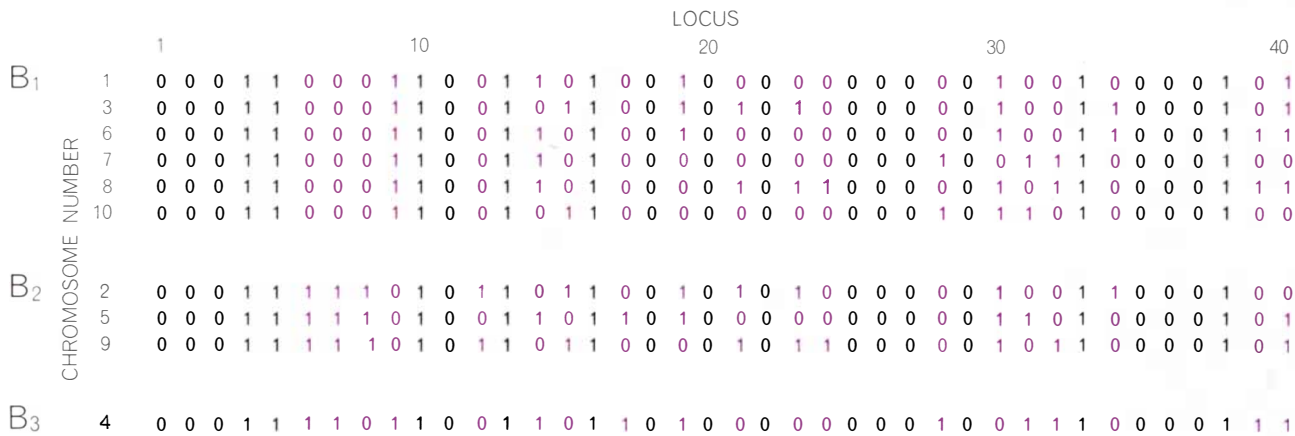
of loci. We found that by doing this we could maintain a surprising amount of variability in the population, even by removing as few as 5 percent of the organisms each generation. As time went on the genes actually did become organized into blocks along the chromosomes, and the patterns that appeared helped to preserve the variability [*see upper illustration below*]. It will be most interesting to see if such patterns are eventually detected in nature as well as in the computer.

We are learning more about the gene pool and genetic load, but many questions remain unanswered. We know very little about the biochemical reasons for heterozygote advantage, or about the relative proportions of balanced and mutational load produced by the common mutagenic agents. In our laboratory we are able to classify the genetic variability of yeast as "rigid" (expressed in a similar way in many different environments) or "flexible" (expressed in different ways in different environments). Most of the variability we have produced with our mutagenic agents is rigid, and we suspect that this is mutational load. The flexible variability is therefore presumably the same as the balanced load, but this relation has not been proved.

We must seek a better understanding of the size and nature of the human mutational load. Certain genetic diseases are clear-cut members of the mutational load, and until such time as genetic repair work can be done on the chromosomes themselves carriers of these diseases should be informed about the probability of their having defective



COMPUTERIZED GENE POOL consists of chromosomes made up of genes (represented by 1 or 0) that are simulated in a program and subjected to "natural selection." (Only short sections of a few chromosomes are shown.) The experiment, conducted by the author, John W. Crenshaw and Joseph N. Vitale, consisted of following chromosomes through many generations. Without selective pressure the pronounced variability (*colored digits*) in *A* would have been eradicated by random forces. Column of black digits represents a locus occupied by a "fixed" gene, one for which every "organism" (that is, pair of chromosomes) is homozygous. In *B*, generations later, selection has helped to retain variability (*color*), although homozygosity (*black digits*) has advanced markedly.



HOW HETEROZYGOSITY IS MAXIMIZED by selection is demonstrated with chromosomes of *B* in upper illustration. Chromosomes with genes 0001 at loci 6 through 9 are in B_1; those with genes 1110 at those loci are in B_2. Any organism in the next generation getting one chromosome from B_2 and the other from B_1 will therefore be heterozygous at these loci. Recombination breaks up these groups so that new ones form such as loci 6 through 9 in B_3, a pairing of loci 6 and 7 from B_2 and loci 8 and 9 from B_1. Such chromosomes are selected against because they cannot pair with other chromosomes to give maximum heterozygosity.

children. A small start has been made on this reasonable form of negative eugenics. Genetic counseling services associated with many of our larger hospitals and universities are providing such information, and they are being aided by the fact that an increasing number of genetic diseases can be detected when they are heterozygous. The most important actions that need to be taken, however, are in the area of minimizing the addition of new mutagens to those already present in the environment. Any increase in the mutational load is harmful, if not immediately, then certainly to future generations.

What of positive eugenics? The human gene pool is made up of a complex array of isoalleles, the product of a long and largely unknown genetic history. In most cases there is no way of telling which isoalleles of particular genes are outmoded relics of our past that no longer have a function. We have some examples of such genetic relics, which are detectable because of their striking effects. Populations inhabiting certain malarial regions carry a gene for sickle-cell anemia that kills homozygotes but helps to protect heterozygotes against malaria. In these regions this gene is part (in fact a large part) of the balanced load. It changes to mutational load, however, when malaria is eradicated and the heterozygote advantage disappears. How many less drastic genes of this kind do we still carry that once gave us protection against the plague or smallpox but now serve no useful function? Even if we were to discover many such genes, we dare not select against them. Whatever the optimum gene pool is for technological man, it should enable him to survive if circumstances suddenly change.

Conceivably a changed social climate and increased knowledge will make it possible for positive eugenics to be practiced on man. I suspect that the only rational course would be to select for genetic diversity. Such selection would have to favor isoalleles that pair to produce balanced heterozygosity but are not detectably harmful as homozygotes. This approach would have at least two advantages: actually or potentially valuable isoalleles would not be lost, and the balanced load would increase directly with added heterozygosity as the mutational load does. No one knows if a more heterozygous human population would in fact be "better" in some sense, but any other kind of selection would literally paint us into an evolutionary corner. Our mutational load is a true burden, but it appears that our balanced load may be a priceless resource.

MONOMOLECULAR LAYERS AND LIGHT

Multilayer systems of long-chain fatty-acid molecules and fluorescent dye molecules are used to study the structure of light waves, revealing a close analogy between a radio antenna and a light-emitting molecule

by Karl H. Drexhage

Visible light is the most familiar form of electromagnetic radiation. Nonetheless, some aspects of the generation and propagation of light waves have not been as carefully studied as the corresponding behavior of, say, microwaves or radio waves. The reason for this can be traced to the short wavelength of visible light, which is small compared with the dimensions of most physical apparatus; light waves range in length from about 4,000 to 7,000 angstroms (ten-millionths of a millimeter), whereas microwaves and radio waves vary from a few millimeters to hundreds of meters.

Recently a new investigative technique has become available that avoids the difficulties traditionally associated with the short wavelength of visible light. The technique, which was developed largely by my colleagues and me at the University of Marburg in Germany, makes use of thin layers of matter—multilayer systems of long-chain fatty-acid molecules and fluorescent-dye molecules—to probe the structure of various light waves. Among other things, we have found that when an excited dye molecule emits light by the process of fluorescence, its behavior is remarkably analogous to that of an antenna emitting radio waves.

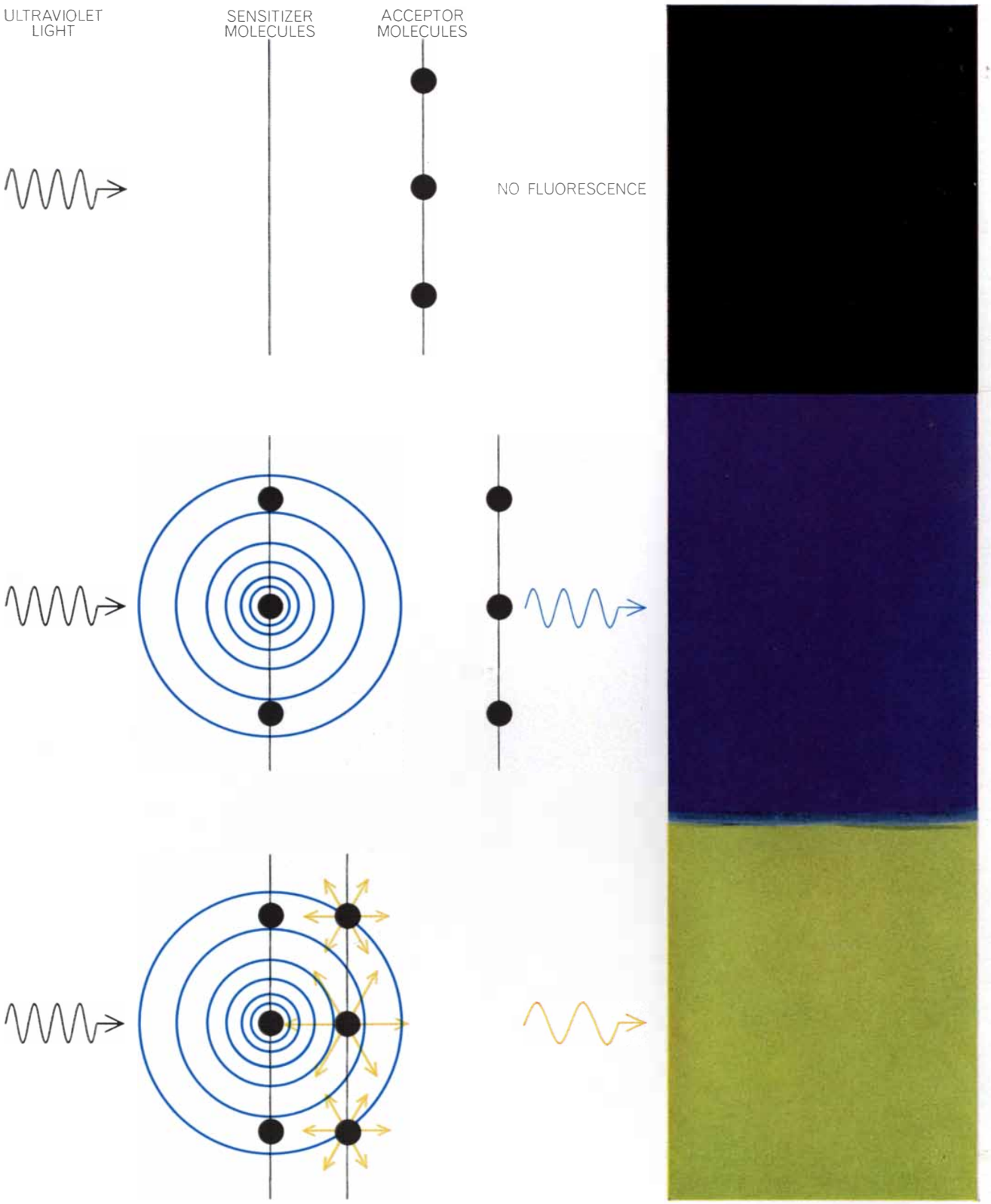
When we embarked on this line of inquiry, we adapted for our purposes an experimental procedure established more than 30 years ago by Katharine B. Blodgett and Irving Langmuir of the General Electric Research Laboratory. We have since improved on their basic method for the preparation of monomolecular-layer systems of fatty-acid molecules and have extended it to many other compounds. Before explaining how we use this technique to analyze light waves, I shall first briefly describe how such monomolecular-layer systems are built up.

If one drops a benzene solution of a long-chain fatty acid on the surface of water in a small trough, the volatile solvent will evaporate quickly, leaving the molecules of the water-insoluble fatty acid at the surface with their hydrophilic (literally "water-loving") groups sticking into the water [*see illustration on pages 112 and 113*]. By adding enough of the fatty-acid solution one eventually covers the entire water surface with a monomolecular film of the fatty acid. Although the film itself is transparent and colorless, the point of full coverage is easy to perceive: the drops no longer spread on the surface but stay unchanged in the form of small lenses. If one now enlarges the surface area (for instance by moving a floating barrier), the droplets will start spreading again, until either the new area is covered with film or all the droplets have been used up.

One then applies a small force to the float in order to exert a surface pressure on the monomolecular film. This can be done most conveniently by means of a small weight-and-pulley arrangement. The fatty-acid molecules are pushed together by the float and stand upright at the surface of the water. A highly incompressible monomolecular film now covers the area in front of the float. It is viscous enough not to be squeezed out between the float and the walls of the trough. The thickness of the monomolecular film is simply the length of the fatty-acid molecules. In most of our work we have used arachidic acid ($C_{20}H_{40}O_2$), a fatty acid made from peanut oil that has a straight chain of 20 carbon atoms. This acid is usually partly converted to its cadmium salt (CdC_{20}) by adding a small amount of cadmium chloride ($CdCl_2$) to the trough in order to improve the stability of the layers.

If one now lowers a clean glass slide through the film-covered water surface, it passes through the surface without being coated with fatty acid. As the slide is subsequently withdrawn, however, the hydrophilic carboxyl groups adhere to the glass, and a monomolecular layer of the fatty acid is attached to both sides of the slide. Under these conditions the glass emerges from the water completely dry and its surface is now hydrophobic ("water-hating"), because the terminal methyl groups of the fatty-acid molecules are pointing outward. By another immersion of the now hydrophobic slide, a second layer adheres, and by withdrawal a third layer is deposited. This procedure can be repeated again and again, so that a multilayer system is built

STANDING LIGHT WAVE in front of a highly reflecting silver mirror is probed by means of a monomolecular layer of fluorescent cyanine dye deposited on top of a stairlike succession of monomolecular fatty-acid layers in the photograph on the opposite page. The spacing between the dye layer and the mirror increases from top to bottom. The height of each step is 158 angstroms, or the thickness of six fatty-acid layers. The sample was illuminated with ultraviolet radiation with a wavelength of 3,660 angstroms, which was absorbed by the dye molecules according to the square of the electric-field amplitude at their site (*see illustration on page 116*). The marked variation of the resulting fluorescence on adjacent steps proves the absence of diffusion by the dye molecules. The varying colors are caused by the influence of the mirror on the fluorescence process (*see bottom illustration on page 117*).



NEAR ELECTRIC FIELD of a fluorescing molecule falls off with the third power of the distance from the molecule. This phenomenon can be investigated by the following technique: A monomolecular layer of a cyanine dye, which emits blue fluorescence after being excited by ultraviolet radiation, is deposited on a glass slide and is separated by means of a varying number of fatty-acid layers from a monomolecular layer of another cyanine dye, which has been chosen to absorb blue light and to emit yellow fluorescence. The molecules of the latter dye, called acceptor molecules, then act as a probe for the near field of the underlying molecules, called sensitizer molecules. On the glass slide shown in the photograph at right the distance between the dye layers in the bottom third is essentially zero; consequently complete energy transfer takes place between the two dye layers and only yellow light is emitted. When the distance between the dye layers becomes greater than about 100 angstroms, as in the middle third of the slide, the near field of the sensitizer molecules almost vanishes; consequently no energy transfer is possible and only the blue fluorescence of the sensitizer molecules is seen. The top third of the slide was covered only by the acceptor molecules, which do not absorb ultraviolet radiation.

up successively, the thickness of which is determined by the total number of deposited monolayers times the thickness of a single layer. As the film is taken away from the surface of the water, the float moves forward a distance corresponding to the covered slide area, thereby ensuring a continuous film.

The entire procedure is actually quite simple. All one needs are a few pure chemicals, a trough with a float and a dipping device [*see illustration at right*]. Most of our experiments have been done even without special protection from dust. In this manner we have been able to deposit more than 500 monomolecular fatty-acid layers of excellent optical quality.

The question arises of whether the layers are built up as smoothly and reproducibly as the preceding description suggests. We have given considerable attention to this problem and have checked the layers in several independent ways. I should like to mention two of them here, one an electrical method and the other an optical method.

If one deposits the fatty-acid layers on a slide coated with an evaporated aluminum film and evaporates on top of the fatty acid a second aluminum film, one obtains a thin-film capacitor whose capacitance is inversely proportional to the thickness of the spacer layer. Therefore a plot of the inverse capacitance versus the number of monolayers between the electrodes should yield a straight line with a slope proportional to the thickness of a single monomolecular layer. Accordingly we found that the longer the fatty-acid molecule, the steeper the slope of the experimental plot and therefore the thicker the monolayer. The values of the capacitance have been found to be reproducible within 1 percent.

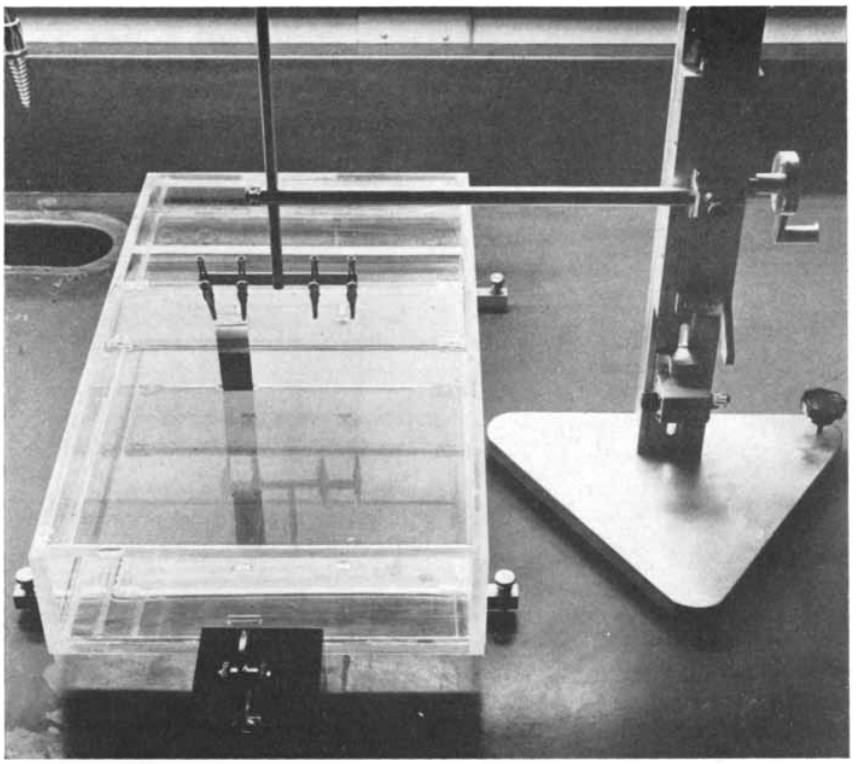
Unfortunately this method suffers from several drawbacks. First, heat developed during the evaporation of the second aluminum film can damage the fatty-acid layers. This was largely prevented by converting all the fatty acid at the water surface into its higher-melting and less volatile cadmium salt. With increasing cadmium content, however, the film becomes more viscous and tends not to attach itself properly to the slide. Another disadvantage of the method arises from the fact that the capacitance depends on the dielectric constant of the spacer layers, a quantity that is difficult to measure independently. Thus an accurate determination of the thickness of the spacer layers is not possible.

There is a far more elegant method: one that makes use of a monochromatic light wave traversing the layer system. In this experiment the layers are deposited on a glass slide coated with a semitransparent silver mirror. An incident light wave then bounces back and forth between the silver mirror and the boundary between the fatty acid and the air, each time losing part of its energy by transmission [*see top illustration on page 114*]. All the transmitted waves add up to a resultant wave, whose amplitude is determined by the phase relation between the single waves. This phase relation depends on the path each single wave has traveled within the layer system. Thus the resultant intensity of the transmitted light is dependent on the thickness of the fatty-acid layers.

Starting with just a silvered slide, we have deposited step by step more than 100 layers of CdC_{20}. After each step we have measured with high precision the intensity of the transmitted light with respect to the transmission of a silvered slide without layers [*see bottom illustration on page 114*]. Our findings show the expected variation of light transmission with the number of layers and fit a calculated curve within a few tenths of a percent, which was the limit of our measurements. This gives an idea of the excellent reproducibility of the deposition procedure.

This technique also allows us to determine the thickness of a single monolayer. The number of additional monolayers one has to deposit in order to proceed from one transmission maximum (or minimum) to the next corresponds to half the wavelength of the probe light. The wavelength inside the layer system is shortened according to the value of the refractive index, which we have determined independently. Thus from the data obtained we calculated that the thickness of a single CdC_{20} layer was 26.4 angstroms. Multilayer systems of this type accordingly provide a means of obtaining any desired spacing in the range of roughly 10 through 10,000 angstroms with an accuracy of a few tenths of a percent.

Besides the fatty acids there are a great many other substances that form monomolecular films at a water surface [see "Monomolecular Films," by Herman E. Ries, Jr.; SCIENTIFIC AMERICAN, March, 1961], and some of them have been successfully used for the preparation of multilayer systems. For the ex-

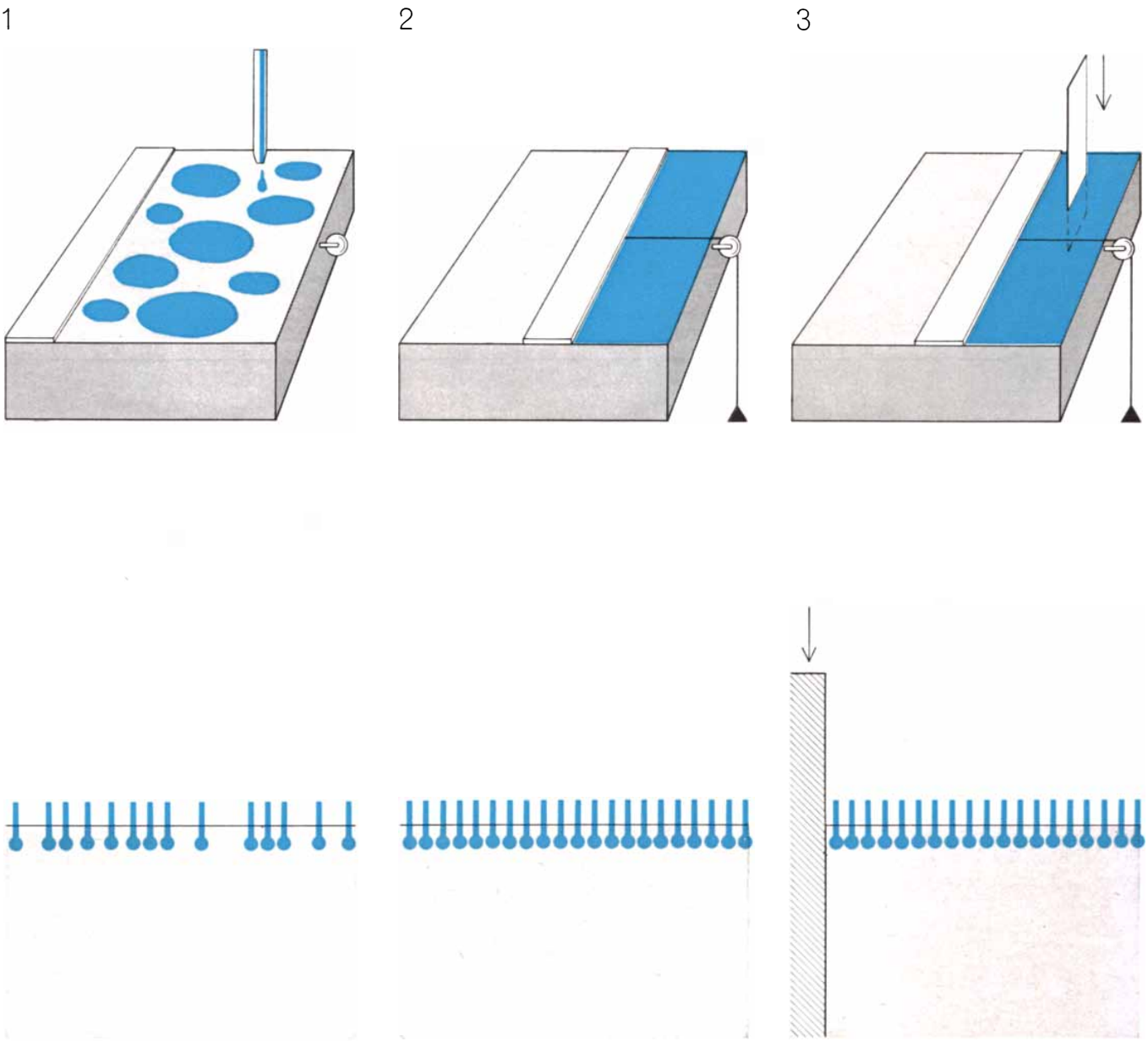


VIEW OF APPARATUS used to deposit monomolecular layers on a glass slide is provided by this photograph. The apparatus consists essentially of a water-filled Lucite trough about 12 inches wide with a floating Lucite barrier connected by means of the pulley in the foreground to a hanging weight. The chemicals to be deposited are dropped on the surface of the water. The glass slide is lowered and raised by means of the dipping device at right. A step-by-step demonstration of the experimental procedure appears on the next two pages.

periments to be described below we needed monomolecular layers of dyelike substances, that is, substances that absorb and emit visible light. To prepare such layers turned out to be a difficult task. Many attempts to work with available dyes were not satisfactory, because we were not able to prevent diffusion of the dye molecules into the layer system; even slight diffusion would have interfered with some investigations we intended to conduct.

Finally we developed suitable dye molecules by chemical synthesis, and this paved the way to the successful preparation of monomolecular dye layers. The dye molecules we synthesized consist, like the fatty-acid molecules, of a hydrophilic head (here called the chromophore) and long hydrophobic tails (hydrocarbon chains), a structure that should enable them to form a monomolecular film at the water surface. So they did, but the pure dye films turned out to be rather soft; their area depended sensitively on the pressure exerted by the float, and it was difficult to get reproducible results with them.

The reason for this behavior can be seen from the structural diagrams of the dye molecules [*see illustration on page 115*]. The area covered by the cross section of the hydrocarbon chains of the dye is considerably smaller than the area needed by the chromophore. Therefore the hydrocarbon chains cannot form a closely packed arrangement as they do in the fatty-acid films. By adding arachidic acid to the dye solution, how-

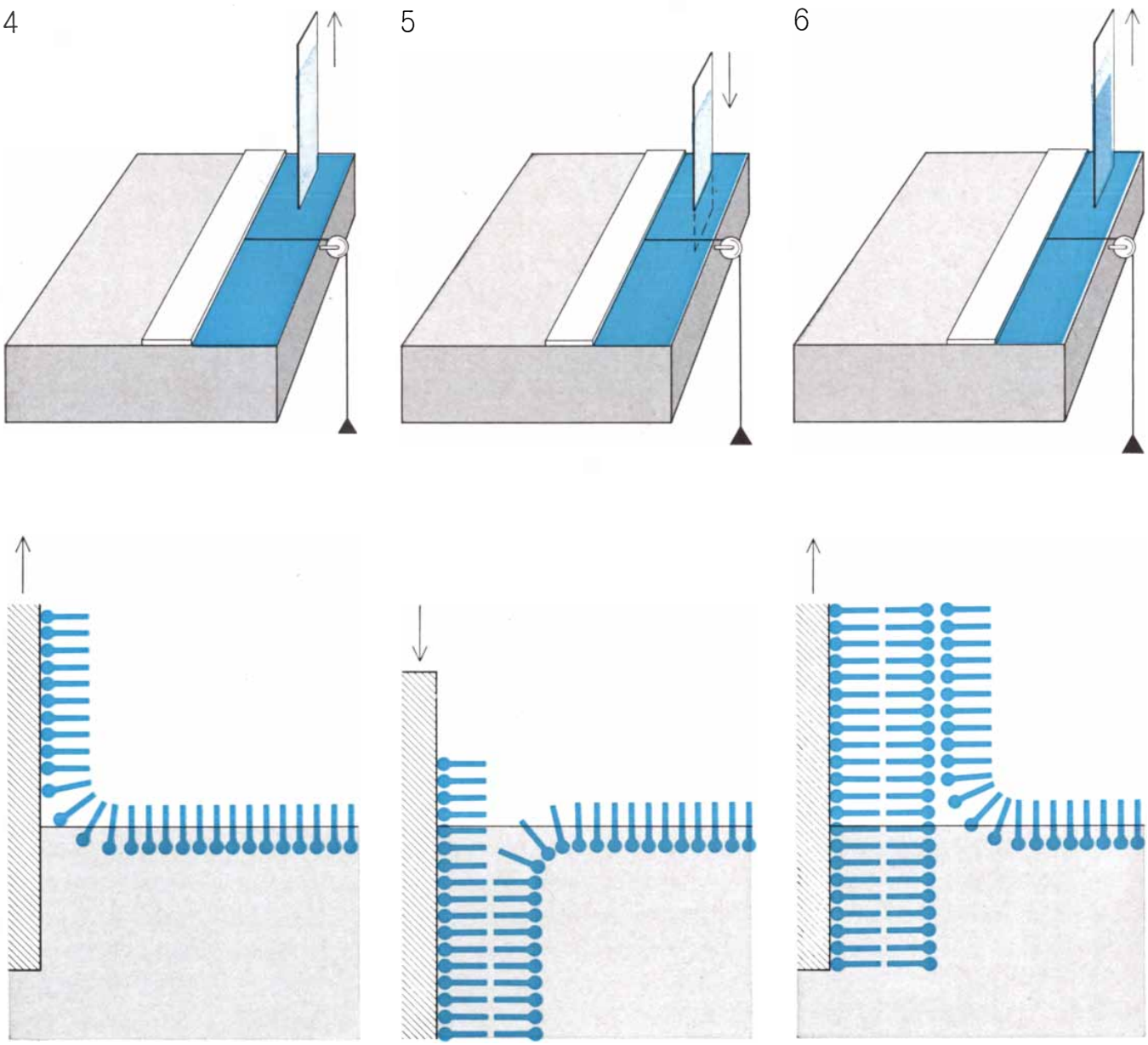


EXPERIMENTAL PROCEDURE was adapted by the author and his colleagues at the University of Marburg in Germany from a technique established more than 30 years ago by Katharine B. Blodgett and Irving Langmuir of the General Electric Research Laboratory. The successive steps are shown in the schematic drawings on these two pages both in a perspective view (*top*) and in a greatly enlarged cross-sectional view (*bottom*). One first drops a solution containing a surface-active compound such as a long-chain fatty acid on the surface of the water (*1*). The molecules of the water-insoluble fatty acid will spread out over the water surface with their hydrophilic ("water-loving") groups sticking into the water. By applying a small force to the floating barrier (*2*) the fatty-

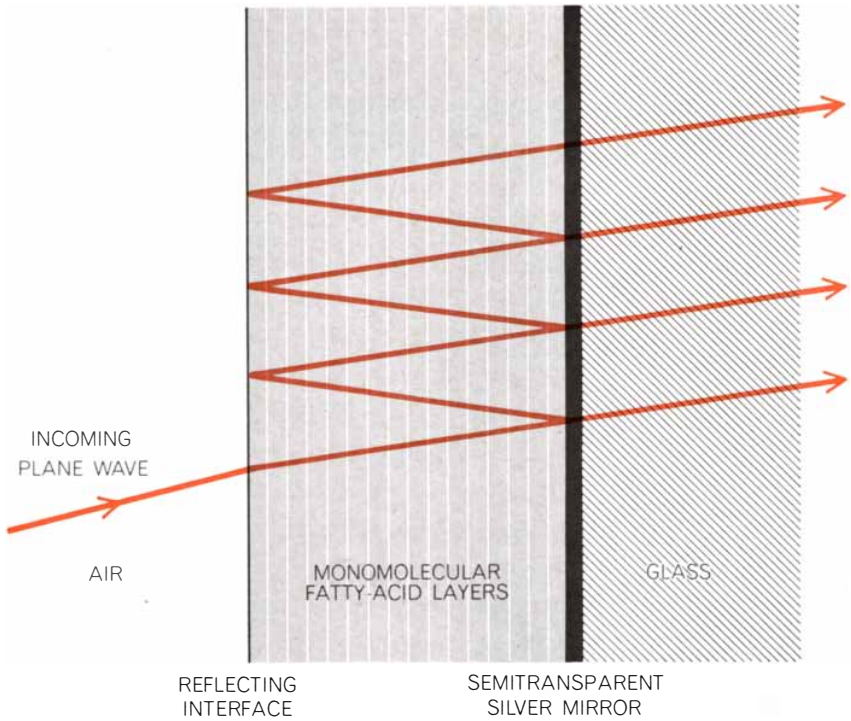
ever, we overcame this difficulty and were able to prepare dye layers as reproducible as the pure arachidic acid layers. Furthermore, by varying the amount of added arachidic acid we can easily vary the concentration of the dye in the monomolecular layer and so adjust the light absorption in the layer to the desired level. Monomolecular dye layers prepared in this way proved to be stable against diffusion for many weeks, presumably because the dye molecules are anchored in the monomolecular layer by means of their long hydrocarbon tails.

Let us now consider two specific light fields that have been investigated with our technique: the standing light wave in front of a mirror and the boundary wave accompanying total reflection. In both of these experiments a monomolecular layer of a fluorescent dye is used as a probe for the electric field of the light wave. The absorption of light by the dye layer is proportional to the square of the amplitude of the electric field of the exciting light wave; it follows that the intensity of the fluorescence emitted by the dye layer is proportional to the same quantity. (The absorption of light by such a monomolecular dye layer is small enough not to disturb the light field under investigation.)

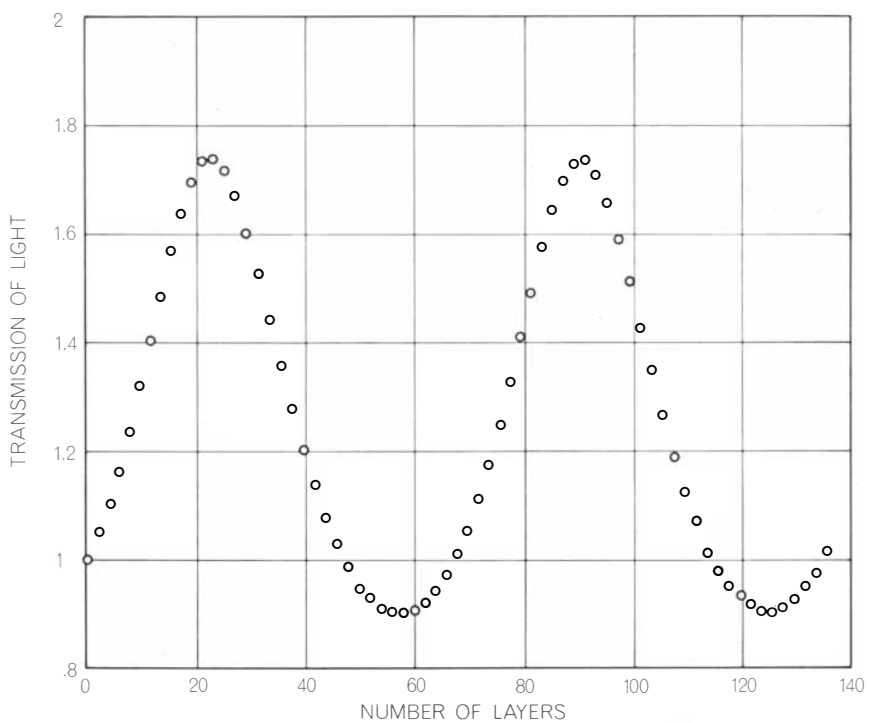
One positions the dye layer inside the field pattern by varying the number of CdC_{20} layers. Then by measuring the intensity of the fluorescence one can probe the structure of the light field



acid molecules are pushed together, forming a continuous monomolecular film. A clean glass slide is now lowered through the film-covered water surface (*3*); no film is attached to the hydrophilic glass surface in this stage, but when the slide is withdrawn (*4*), the hydrophilic carboxyl groups adhere to the wet glass and one monomolecular layer of the fatty acid is deposited. By another immersion of the now hydrophobic ("water-hating") slide (*5*) a second fatty-acid layer adheres, and by withdrawal (*6*) a third layer is deposited. The procedure can be repeated again and again to build up a multilayer system consisting of hundreds of monolayers. As the film is gradually removed from the surface of the water, the float will move forward, ensuring a continuous film.



THICKNESS OF MULTILAYER SYSTEM is most readily measured by an interference technique. The layers, deposited on a semitransparent silver mirror, are traversed by a monochromatic light wave, part of which bounces back and forth between the silver mirror and the partially reflecting interface of the layers and the air. All the transmitted waves add up to a resultant wave (*right*), whose amplitude is determined by the optical thickness of the layer system. Each arrow represents a laterally extended, plane light wave, not a light ray.



TRANSMISSION OF LIGHT through a layer system such as the one shown at top varies periodically with the number of layers constituting the system. It can be shown that the number of additional layers one has to deposit to proceed from one transmission maximum (or minimum) to the next corresponds to half the wavelength of the probe light. (In this experiment, for example, green light with a wavelength of 5,461 angstroms was used.)

quantitatively. Because the monomolecular layers are very thin compared with the wavelength of visible light, a spatial resolution difficult to obtain with other methods is readily achieved.

When a light wave impinges on a mirror, it is reflected and meets in front of the mirror the later portions of the incoming wave. The resulting phenomenon, called a standing wave, is analogous to the motion of a vibrating string that is fixed at one end; one obtains the amplitude of such a wave by adding the fields of the incoming and the reflected wave [*see illustration on page 116*]. At certain distances from the mirror the fields always cancel, creating what are called the "nodes" of the standing wave. Midway between the nodes (at the "antinodes") the fields are in phase and give rise to a maximum amplitude. The distance between two nodes (or antinodes) is accordingly half a wavelength; in the case of visible light the distance is only a few thousand angstroms. The standing light wave in front of a mirror was observed as early as 1890 by the German physicist Otto Wiener. With our technique the phenomenon can now be investigated with greatly improved resolution.

On a slide coated with a highly reflecting silver mirror we deposit CdC_{20} layers in a stairlike succession. This can easily be done by making successive dips, each of which is a few millimeters shorter than the previous one. On top of these CdC_{20} stairs a layer of a fluorescent cyanine dye is deposited like a carpet. When the sample is illuminated with an intense monochromatic light beam from a high-pressure mercury arc, a standing wave is formed in front of the silver mirror [*see illustration on page 109*]. The dye will absorb the light according to the square of the electric-field amplitude at its site. On certain steps the dye layer coincides with a node and hence experiences no net electric field; thus it does not emit any fluorescence. On the steps in between the absorption varies according to the shape of the standing wave; so does the fluorescence intensity. (The different colors of the fluorescence are caused by the influence of the mirror on the process of fluorescence, a phenomenon that will be discussed below.) The clear difference in the fluorescence from step to step proves that the dye molecules have remained in place after deposition. If they had moved by diffusion into the underlying CdC_{20} layers, the fluorescence pattern would have been washed out.

Standing light waves in front of a mirror have recently become important

in the display and measurement of the width of picosecond laser pulses [see "Laser Light," by Arthur L. Schawlow; SCIENTIFIC AMERICAN, September, 1968]. It may well be that our technique will provide a deeper insight into these fascinating ultrashort light pulses.

Now let us consider another curious optical phenomenon: the boundary wave accompanying total reflection.

When a light wave is incident on the interface between an optically denser medium and an optically rarer medium at an angle exceeding a certain critical angle, total reflection takes place. Surprisingly, even in this situation another light wave—called the boundary wave—exists beyond the interface.

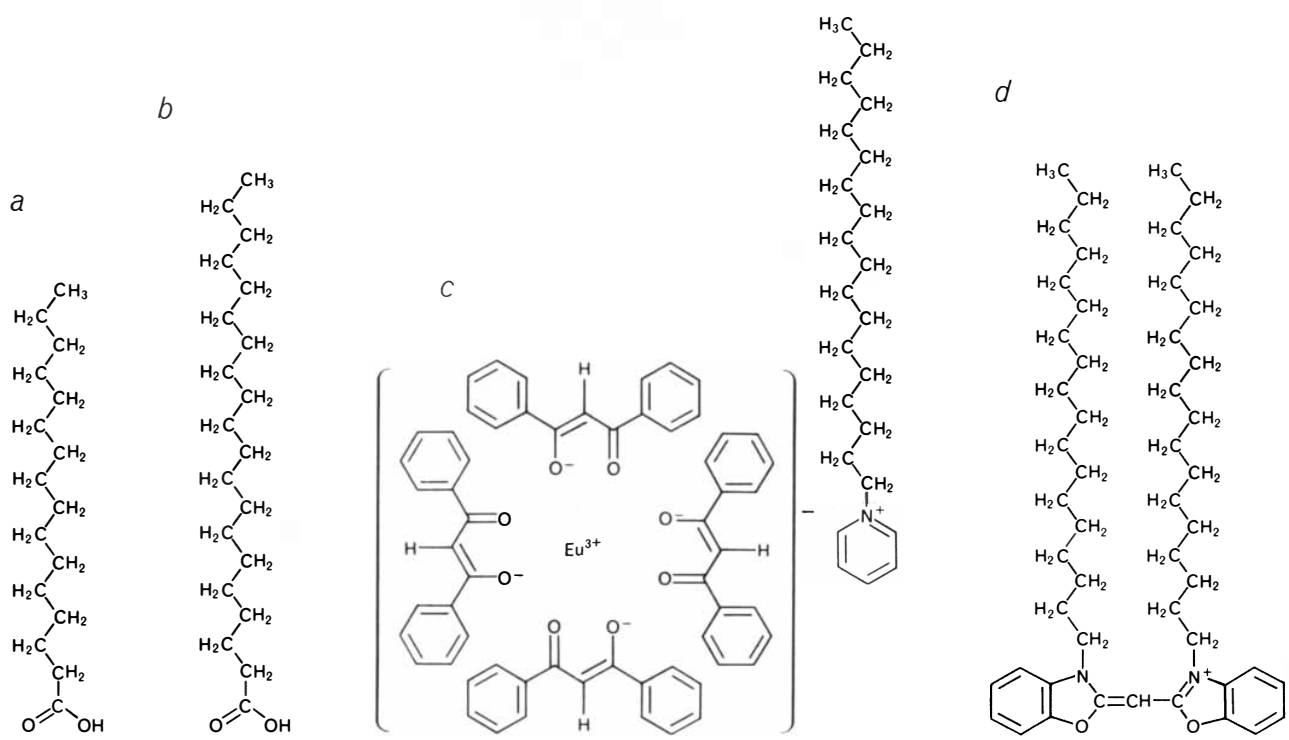
Starting with Isaac Newton, who first demonstrated the existence of such a wave, the phenomenon of a boundary wave accompanying total reflection has attracted the attention of many workers in the field of optics. Until the present investigation, however, the phenomenon has not been demonstrated in an unambiguous quantitative experiment with visible light. According to theory, the boundary wave decays exponentially with increasing distance from the interface and vanishes within a few wavelengths. Nonetheless, this region of several thousand angstroms is large compared with the thickness of our monomolecular layers, making it possible to investigate the phenomenon with high resolution.

In our experiments a monomolecular layer of a fluorescent dye is deposited on a glass plate and then covered with a varying number of CdC_{20} layers; the refractive index of the CdC_{20} layers almost matches the refractive index of the glass plate, so that the light does not "see" that interface. The slide is then dipped into a liquid of higher refractive index: the optically denser medium.

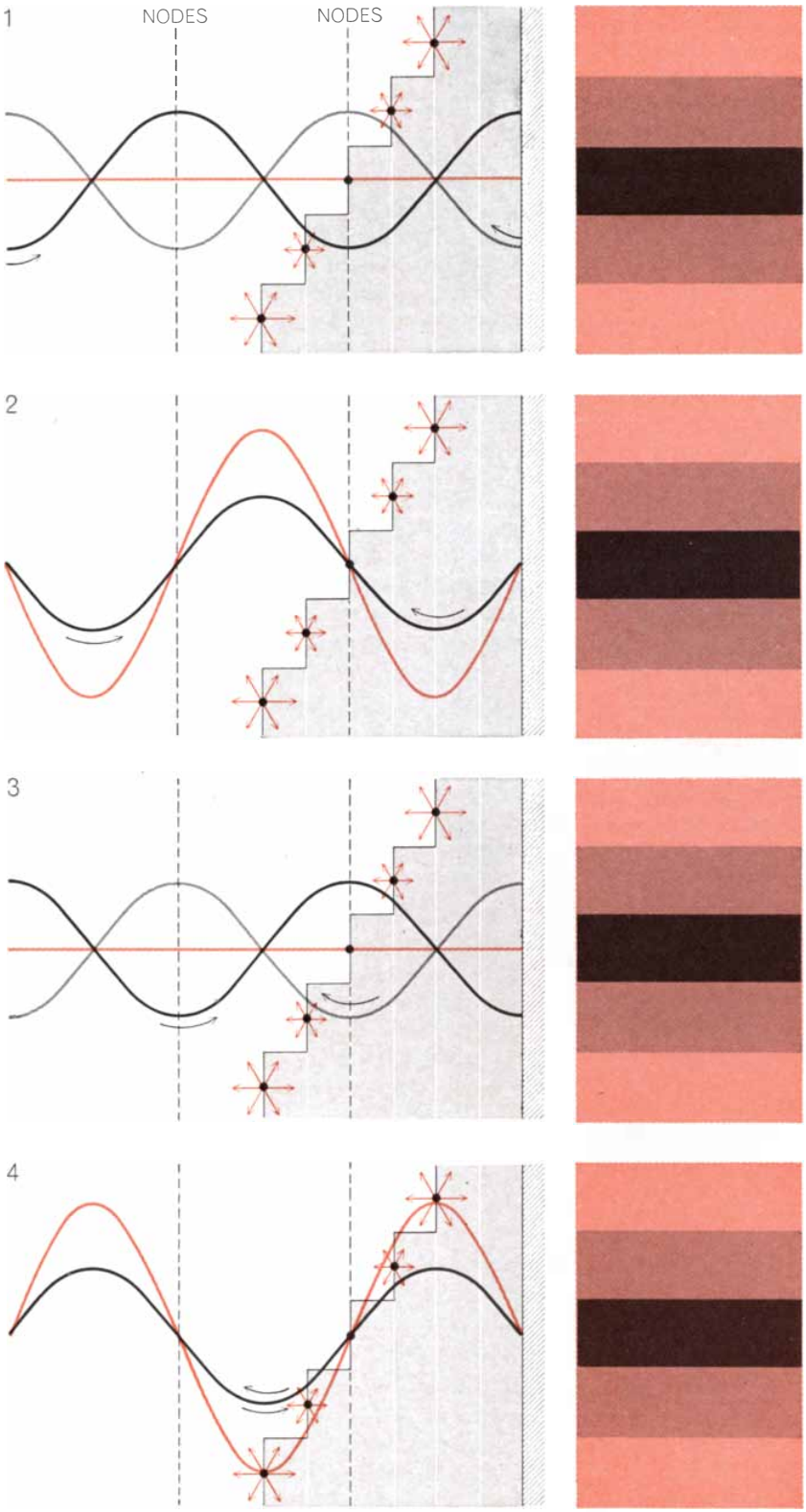
Violet light with a wavelength of 4,050 angstroms is shined from the side of the liquid onto the glass plate at an angle of incidence greater than the critical angle, so that total reflection occurs [*see top illustration on page 117*]. The CdC_{20} layers on top of the dye layer constitute the optically rare medium and also serve to keep the dye molecules at a given distance from the interface. Hence the boundary wave existing in the layer system is probed by the dye molecules, which emit yellow fluorescence with an intensity proportional to the square of the amplitude of the local electric field. From the intensity of the fluorescence we found an exponential decay of the boundary wave in agreement with the prediction of the theory. Moreover, the expected dependence of the decay length on the angle of incidence of the light has been verified quantitatively.

So far we have considered the use of dye molecules as probes for certain light fields, making use of their ability to emit fluorescence after excitation. Now let us turn to the process of light emission itself. The generation of long electromagnetic waves, such as radio waves, by antennas is treated in elementary textbooks. Since light is electromagnetic radiation too, one might ask: Is there any relation between radio-wave-emitting antennas and light-emitting antennas (the excited molecules)? The answer is yes; there is a very close relation.

The radiation from an antenna is spatially coherent, which means that the waves emitted in different directions have a phase relation that can be revealed by interference phenomena. Let us consider the radiation from a light-emitting antenna (an excited molecule) in front of a mirror [*see bottom illustration on page 117*]. The wave emitted by the molecule in a given direction interferes with a wave reflected by the mirror in the same direction. The interference can be constructive or destructive, depending on the path difference be-



SOME MOLECULAR STRUCTURES suitable for the preparation of monomolecular-layer systems are shown here. Palmitic acid (*a*) and arachidic acid (*b*) belong to the class of long-chain fatty acids. The europium complex (*c*) and the cyanine dye (*d*) were specially prepared by the author's group for their experiments; both molecules absorb ultraviolet radiation and emit intense fluorescence.



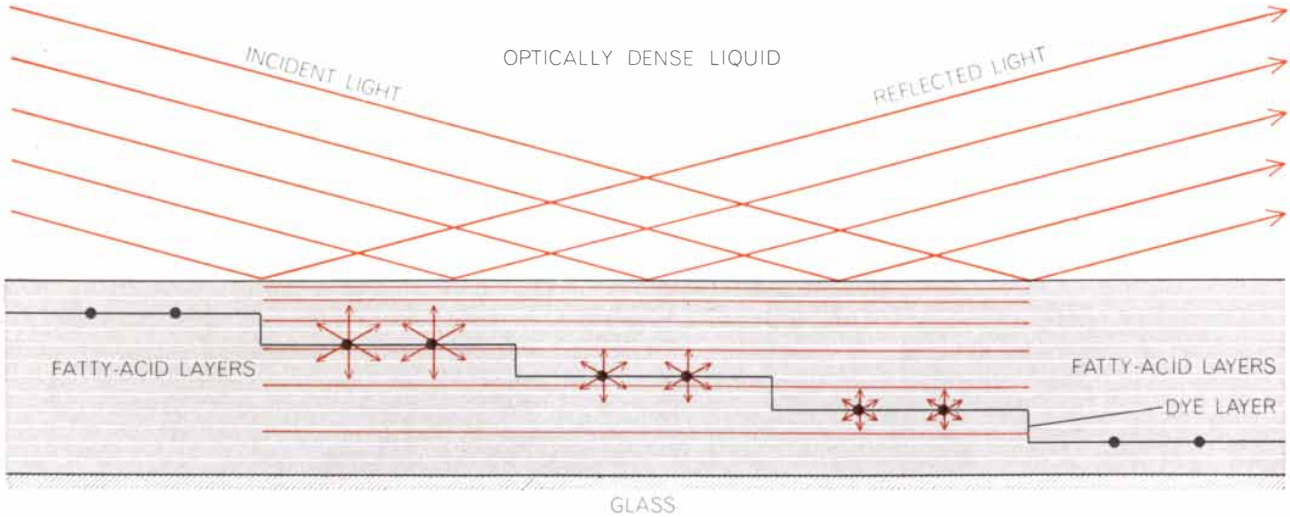
STANDING WAVE IS FORMED in front of a mirror when light impinges on the mirror. The resultant electric field (*color*), which is found by adding the electric fields of the incident wave (*black*) and the reflected wave (*gray*), is shown here for some successive instants of time. At certain distances from the mirror, which are separated by half a wavelength, there is no net electric field. Therefore a dye molecule at these "nodes" does not absorb. In between the nodes, however, it absorbs according to the square of the resultant amplitude of the electric field at its site and emits fluorescence. This explains the varying intensity of the fluorescence emitted by the stairlike dye layers in the photograph on page 109.

tween the direct and the reflected wave; the path difference varies with the angle of incidence on the mirror. Hence a molecule at a given distance from the mirror will emit in certain directions very strongly; in certain other directions, those in which the interfering waves are in counterphase, it will not emit at all. Therefore the fluorescence intensity in front of the mirror will show a pronounced angular dependence.

We have investigated this phenomenon using monomolecular layers of a europium complex. The complex strongly absorbs ultraviolet radiation at 3,660 angstroms by virtue of its peripheral organic groups, called ligands, from which the excitation energy is rapidly transferred to the europium ion in the center of the complex. The europium ion finally emits red fluorescence of 6,120 angstroms.

In our experiments glass plates coated with a gold or silver mirror were covered with CdC_{20} layers (which provided a certain distance to the mirror according to their number) and then with a fluorescent layer of the europium complex. To avoid the refraction of the fluorescence at the interface between the layers and the air, we immersed the plates during the measurements in a cylindrical container filled with a liquid having a matching refracting index. The sample inside the cylindrical cell was then irradiated with ultraviolet radiation from a high-pressure mercury arc, and the angular dependence of the red fluorescence was recorded. During this measurement the angle at which the exciting light impinges on the sample remains fixed. The angular distribution patterns of the fluorescence intensity closely resemble the corresponding patterns of a radio antenna in front of a reflector [*see illustration on page 118*].

There are of course several different types of radio antenna. The simplest type consists of an oscillating electric dipole; more complicated types include the magnetic dipole and the electric quadrupole. Each exhibits a characteristic angular distribution of the emitted radiation. Interestingly enough, the same is true for light-emitting molecules, and therefore from the angular distribution of the luminescence intensity in front of a mirror we are able to determine the nature of the antenna represented by the molecule. Such experiments were first carried out in 1911 by the Hungarian physicist Paul Selenyi; with the monolayer technique, however, greatly improved resolution is possible.

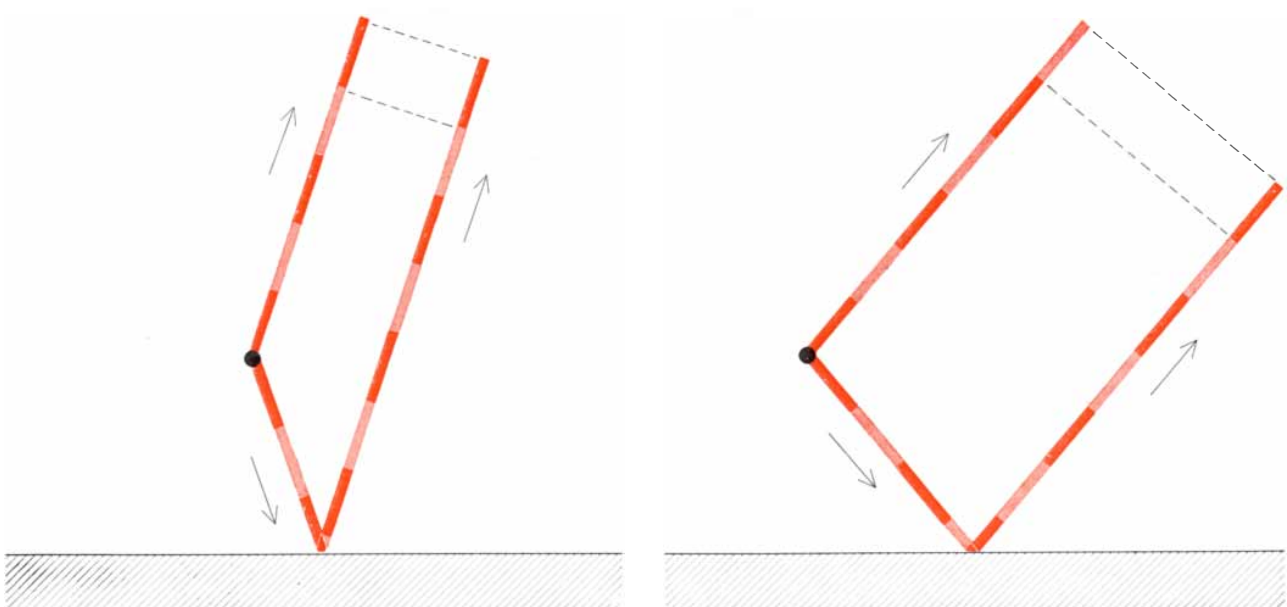


BOUNDARY WAVE accompanying total reflection decays within a few wavelengths of the reflecting interface. It can be probed easily with a monomolecular layer of a fluorescent dye deposited at suitable stairlike intervals on the other side of the reflecting interface.

We have calculated the angular patterns of the red europium fluorescence, assuming randomly oriented electric dipoles as the light source, and have found an agreement within a few percent with the measured patterns, which proves that the red fluorescence originates with an electric dipole. There is also a weak orange fluorescence (centered at 5,920 angstroms) accompanying the strong red fluorescence of the europium complex. The angular pattern of the orange fluorescence, separated by means of an interference filter, turns out to be completely different from the pattern of the red fluorescence, revealing that it is magnetic-dipole radiation, a finding that is in agreement with other investigations of europium compounds.

The angular radiation pattern of an oscillator in front of a mirror varies with the wavelength of the emitted radiation. This dependence can be demonstrated with an organic dye that is capable of emitting fluorescence throughout the visible spectrum. The molecules of such a dye, if placed in front of a mirror, will emit in a given direction light whose color varies with the distance of the molecules from the mirror; this explains the different colors visible in the illustration on page 109. If one changed one's angle of observation, a changing pattern of colors would be seen.

A mirror influences not only the angular distribution of the radiation emitted by an antenna but also the probability of the emission. To understand this rather strange phenomenon, let us consider an antenna at the center of a reflecting half-sphere [*see top illustra-*



INTERFERENCE between the wave emitted by an antenna (in this case an excited dye molecule) in front of a mirror and the reflected part of the same wave produces a pronounced angular distribution of the intensity of the resulting light field. Depending on the path difference in wavelengths between the direct and the reflected wave the interference is either constructive (*left*) or destructive (*right*).

tion on opposite page]. If the radius of curvature is such that the direct and the reflected wave are in phase, the amplitudes add up, and therefore the intensity (which is proportional to the square of the amplitude) is four times the intensity from the same antenna without the mirror. This holds for all directions in front of the mirror. Because there is no radiated power behind the mirror, the total emitted power is twice the power that would be emitted by the antenna without the mirror. If the radius of the spherical mirror is a quarter of a wavelength different from the value assumed here, however, the direct and the reflected wave are exactly out of phase and cancel in all directions. Therefore in this case the antenna does not emit radiation at all.

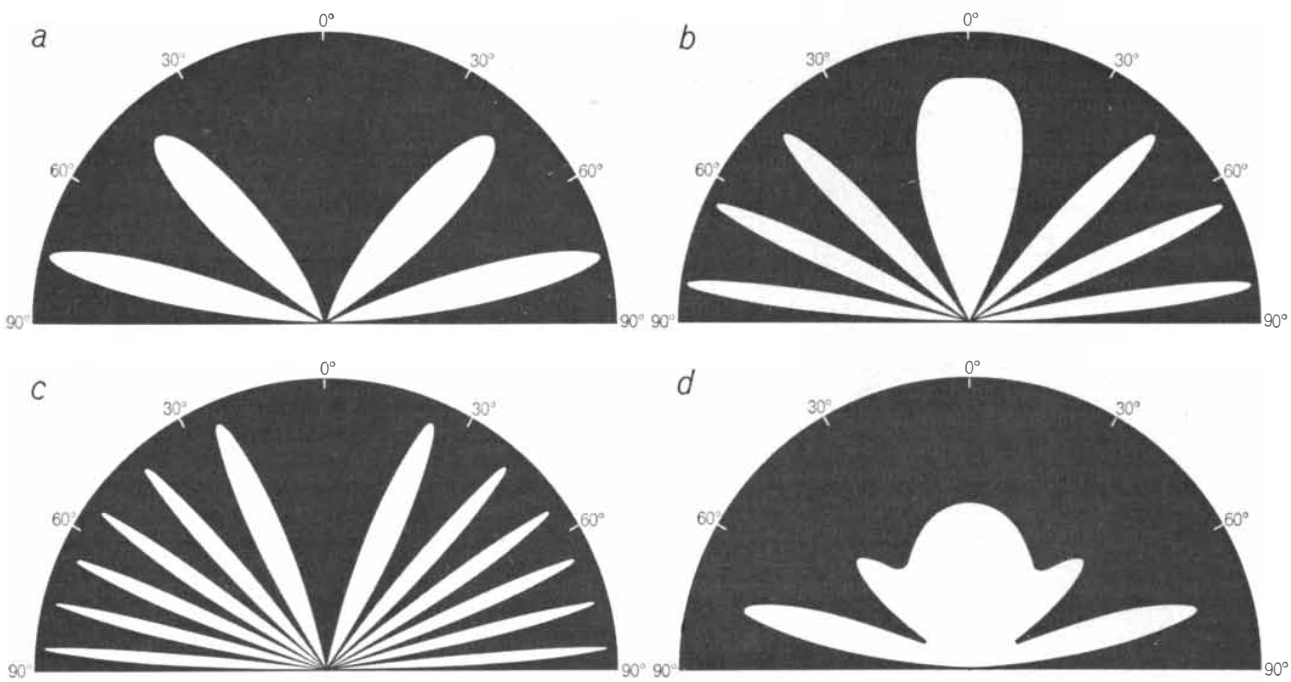
One may transfer these considerations to an excited molecule emitting fluorescence. Here the measurable quantity is the fluorescent lifetime, which is inversely proportional to the radiation probability. Hence in the first of the above cases the fluorescent lifetime should be shortened by a factor of two by the mirror. In the second case the lifetime should be infinite; the molecule should stay excited forever, because it cannot radiate at all. In practice, however, there are radiationless deactivation processes competing with the fluorescence that would not allow the molecule to keep its excitation energy for an infinite time.

For the study of this remarkable phenomenon we used a plane mirror instead of a spherical one. In applying to this case the concept I have described one expects a variation of the fluorescent lifetime with the distance of the excited molecule from such a plane mirror. The experimental arrangement of deposited monomolecular layers was quite similar to the one we used in studying the angular patterns. The europium complex is particularly suitable for these experiments because of its relatively narrow fluorescence band and its long fluorescent lifetime of about a thousandth of a second, which can be easily measured.

The results indeed show the expected influence of the mirror on the fluorescent lifetime [*see bottom illustration on opposite page*]. Because the mirror affects only the probability of radiation and generally not the competing radiationless deactivation, such plots contain information about the relative probabilities of these processes. It is to be expected that the spatial variation of the fluorescence decay time is most pronounced if there are no competing radiationless processes and tends to get washed out with an increasing probability for these processes. Thus the "fluorescence quantum yield" of the emitting state—a very difficult quantity to measure in any other way—can be determined. In the case of the europium-complex monolayers we determined the quantum yield to be 70 percent.

The influence of a mirror on the emission of radiation is independent of the kind of emitted waves. It would also apply, for instance, to the emission of gamma rays by atomic nuclei. Thus if we had a mirror for gamma rays we could change the half-life of radioactive nuclei!

Another interesting point about these experiments arises from the fact that each excited molecule can emit only a single photon. Since under the experimental conditions only a tiny fraction of the dye molecules were excited, each molecule emitted its photon independently of the other excited molecules. Nevertheless, the interference phenomena were as pronounced as expected. Thus experiments of this type also demonstrate that the smallest amount of light—a single photon—is capable of producing interference effects by means of its wave properties.



ANGULAR DISTRIBUTION PATTERNS of the fluorescence emitted by an excited dye molecule in front of a mirror closely resemble the corresponding patterns of a radio antenna. Patterns *a*, *b* and *c* were produced by the red fluorescence from a monomolecular layer of a europium complex at varying distances from a gold mirror; the fluorescent layer was separated from the mirror by 142, 256 and 446 fatty-acid layers respectively. This red fluorescence is generated by electric dipole oscillators. Pattern *d* was obtained, like pattern *a*, from a monomolecular layer of the europium complex separated from the mirror by 142 fatty-acid layers. It was measured, however, by recording a weak orange fluorescence that accompanies the red fluorescence of the europium complex. Pattern *d* appears completely different from pattern *a* because the orange fluorescence originates with magnetic-dipole oscillators.

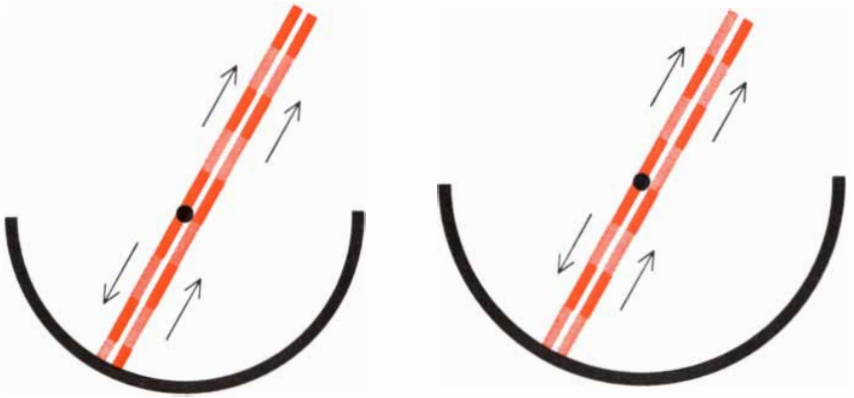
The influence of a mirror on the fluorescence of a molecule is a relatively long-range effect, inasmuch as it is still measurable when the excited molecule is separated from the mirror by many wavelengths. Hence we can understand the effect simply by considering the outgoing radiation field. Associated with an oscillating electric dipole there is also a near electric field that falls off with the third power of the distance from the oscillating dipole and therefore has appreciable values only very close to the oscillator. Within this region, however, the near field is much stronger than the far field.

We should expect to find this near field close to a fluorescing molecule, where we should be able to probe it by means of other dye molecules. To study this phenomenon we deposited on a glass slide a monomolecular layer of a cyanine dye, which emits blue fluorescence after excitation by ultraviolet light. We then deposited a monomolecular layer of another cyanine dye, separated from the first by a number of CdC_{20} layers. The dye in the second layer was chosen to absorb blue light and to emit yellow fluorescence. The molecules of the second dye therefore can act as a probe for the near field of the excited molecules in the underlying dye layer; the intensity of the yellow fluorescence is proportional to the square of the electric-field amplitude at their site [*see illustration on page 110*]. The data obtained demonstrate the existence of the near field around an excited molecule and verify quantitatively the expected decay law of the near field around an electric dipole.

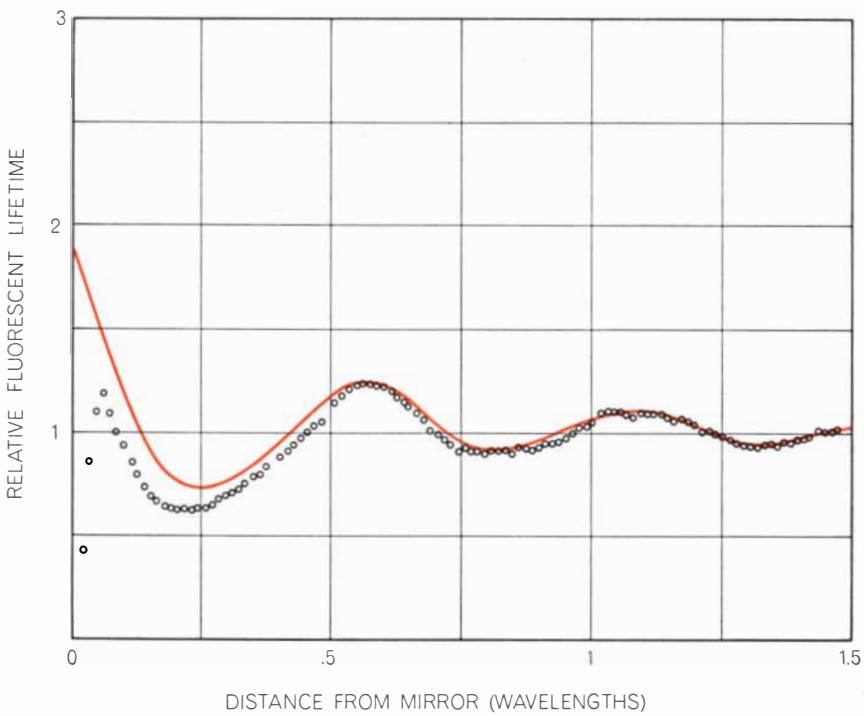
In this experiment the excitation energy is transferred from the blue-fluorescing molecules (called the sensitizer molecules) to the yellow-fluorescing molecules (the acceptor molecules). It is remarkable that the simple concept of absorption in the near field of an excited molecule accounts quantitatively for a type of energy transfer that is usually referred to as "radiationless resonance energy transfer."

The systems of built-up monomolecular layers described in this article can be regarded as artificial crystals, in which we can deliberately choose the composition within wide limits. By the deposition procedure we create a one-dimensional order in a planned manner, something that is hard to achieve by other means. Thus it is reasonable to envision numerous applications of this technique in other areas of science.

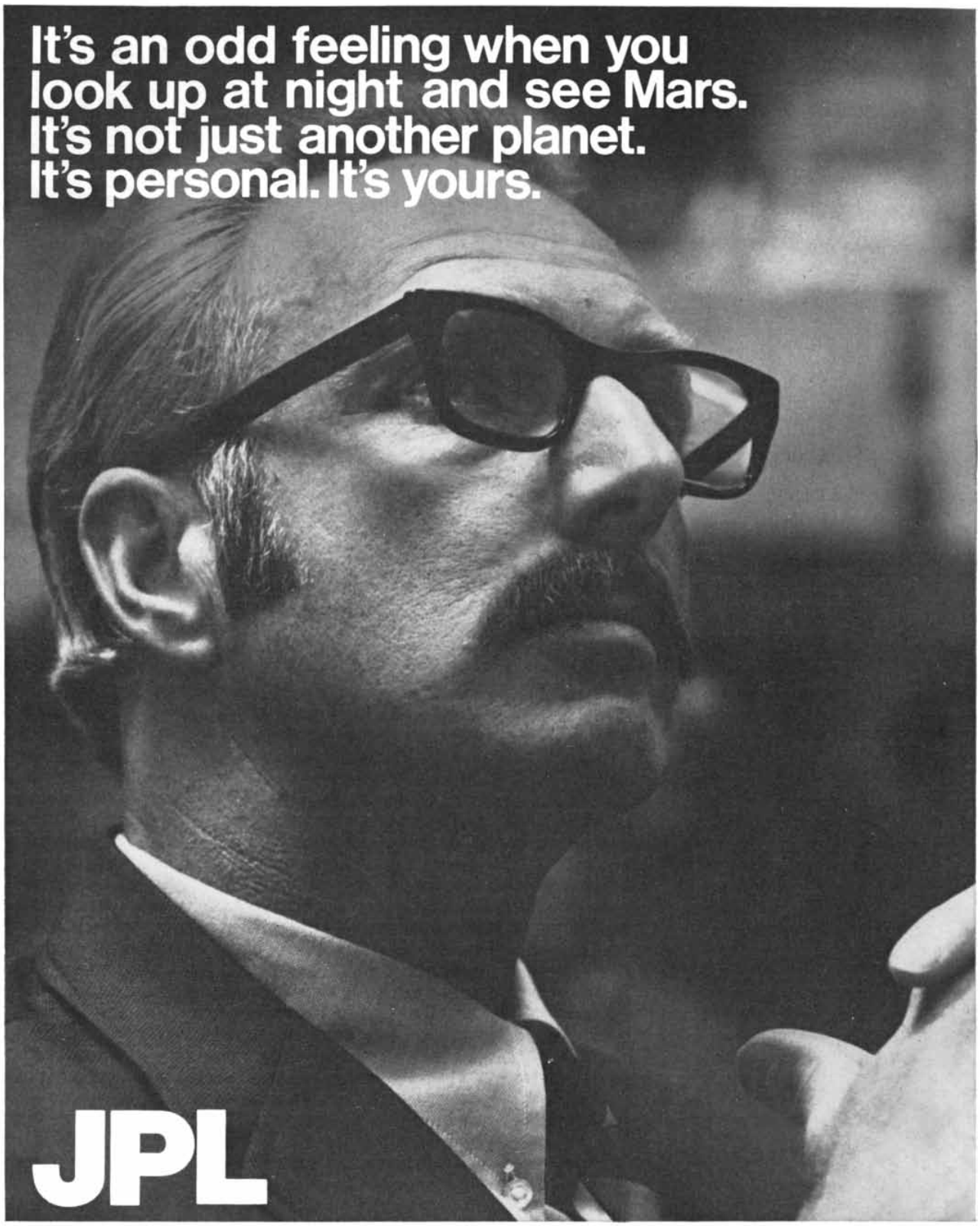
Fatty-acid-layer systems grown from a solution that contains metal ions such as barium and lead exhibit a spacing of about 50 angstroms between the planes of the heavy metal ions. Such systems have been successfully used as analyzers for soft X rays and may be useful in future X-ray lasers. Layered structures of organic molecules also play an important role in living nature, and it turns out that many natural organic compounds such as cholesterol are suitable for the preparation of layer systems. Thus artificial crystals of this type might provide a fresh insight into some life processes.



SPHERICAL MIRROR is used here to demonstrate the influence of a reflector on the radiation probability of an antenna. If the radius of curvature of the mirror is such that the direct and the reflected wave are in phase (*left*), the resultant wave has twice the amplitude and hence four times the intensity of the direct wave alone. Because this condition holds for all directions in front of the mirror and there is no radiation behind the mirror, the probability of radiation is enhanced by a factor of two. On the other hand, if the radius is such that the direct and the reflected wave are exactly out of phase (*right*), the radiation probability is zero and there will be no radiation at all. Because the fluorescent lifetime of an excited molecule is inversely proportional to the probability of radiation, the lifetime will be shortened by a factor of two in the first case and rendered infinite in the second.



FLUORESCENT LIFETIME of molecules of the europium complex was observed to depend closely on their distance from a plane silver mirror. The distance between the monomolecular dye layer and the mirror was varied in steps of two fatty-acid layers, or 52.8 angstroms. The curve shows theoretical dependence; the dots indicate experimental values.



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MATHEMATICAL GAMES

Cyclic numbers and their properties, and answers to last month's problems

by Martin Gardner

The number 142,857, which students of recreational number theory are likely to recognize at once, is one of the most remarkable of integers. Apart from the trivial case of 1, it is the smallest "cyclic number." A cyclic number is an integer of n digits with an unusual property: when multiplied by any number from 1 through n, the product contains the same n digits of the original number in the same cyclic order. Think of 142,857 as being joined end to end in a circular chain. The circle can be broken at six points and the chain can be opened to form six six-digit numbers, the six cyclic permutations of the original digits.

$$1 \times 142{,}857 = 142{,}857$$
$$2 \times 142{,}857 = 285{,}714$$
$$3 \times 142{,}857 = 428{,}571$$
$$4 \times 142{,}857 = 571{,}428$$
$$5 \times 142{,}857 = 714{,}285$$
$$6 \times 142{,}857 = 857{,}142$$

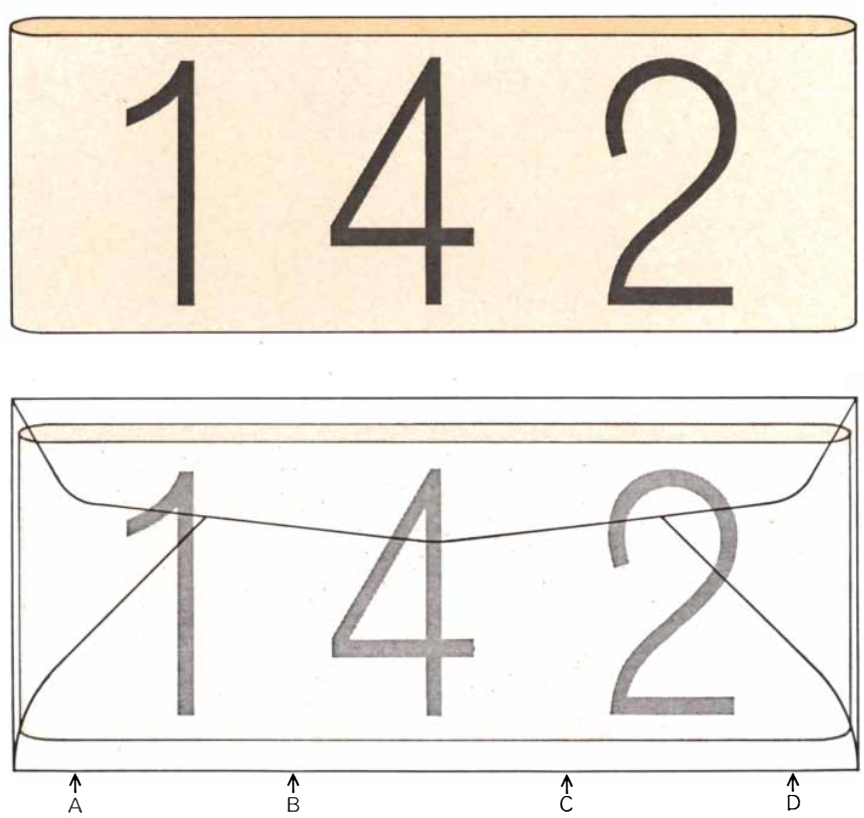
The cyclic nature of the six products has long intrigued magicians, and many clever mathematical prediction tricks are based on it. Here is one:

Prepare a deck of playing cards by removing the nine spades with digit values. Place them on the bottom of the deck so that their order from the bottom up is 1, 4, 2, 8, 5, 7, with the remaining three cards following in any order. Your prediction of the trick's outcome is the number 142,857 written in large numerals on a strip of paper twice as long as the envelope into which it will be put. Paste the ends of the strip together to make a circular band, with the numerals on the outside, then press the band flat as shown in the accompanying illustration [*at right*]. Thus flattened, the band is sealed into the envelope as shown.

You have, of course, memorized the number 142,857, recalling also that its first three digits are on the top side of the band, its last three digits on the bottom side. The envelope later is cut open by scissoring it at one of the four places marked *A, B, C, D*. If you cut at *A* or *D*, cut through the end of the band also, so that when it is pulled from the envelope, it will be a strip bearing 142,857 or 857,142. The other four permutations are obtained by cutting the envelope at *B* or *C*. Start the cut in the envelope only, below the band. As you continue cutting, make sure that the scissors snip only the upper part of the band and the upper part of the envelope. In this way you can pull from the slit a strip bearing 428,571 or 285,714. For the remaining two permutations simply turn the envelope over and follow the same procedure on the other side. This way of cutting an envelope to take from it a strip showing any of the six cyclic permutations of 142,857 is based on a procedure devised by Samuel Schwartz, a New York City attorney and amateur magician. He uses a window envelope so that spectators can see numerals on the band, and slightly different preparation and handling, but the method is essentially the same.

The sealed envelope with your prediction is given to someone at the start of the trick. Hand another person the prepared deck and ask him to give it two thorough riffle shuffles (the usual kind of shuffle in which the deck is separated into two piles and the piles are interleaved). The two shuffles will distribute the nine spades upward through the deck without disturbing their order. To obtain a random six-digit number, you explain, you will go through the shuffled deck, cards face up, and remove the first six spades that have digit values. The digits will be 1, 4, 2, 8, 5, 7. Arrange the six cards in a row on a table. A random multiplier from 1 through 6 is now obtained by rolling a die. Better still, hand someone an imaginary die and ask him to roll this invisible die and tell you what he "sees" on top. Multiply 142,857 by the digit he names. Cut open the envelope properly (in order to determine where to cut, multiply 7 by the selected digit to get the last digit of the product) and pull out the strip to prove you have correctly predicted the product.

Many centuries ago, when mathemati-



Endless strip **(top)** ***placed in envelope*** **(bottom)** ***for prediction trick***

cians first became aware of the cyclic character of 142,857, they began looking for larger numbers with the same whimsical property. Early work along such lines is summarized in the first volume of Leonard Eugene Dickson's *History of the Theory of Numbers,* Chapter 6, and dozens of papers on the topic have been written since Dickson's history first appeared in 1919. It turns out that all cyclic numbers are the periods (sometimes called repetends) in the repeating decimals (also called recurring, circulating or periodic decimals) of the reciprocals of certain prime numbers. The reciprocal of 7, or 1/7, produces the repeating decimal .142,857 142,857 142,857.... Note that the number of digits in the period is one less than 7, which generates it. This provides one way of finding higher cyclics. If $1/p$, where p is a prime, produces a repeating decimal with a period of $p - 1$ digits, the period is a cyclic number. The next-larger prime that generates such a number is 17. Its repeating period is the 16-digit cyclic 0,588,235,294,117,647. Multiplied by any number from 1 through 16, the product repeats those 16 digits in the same cyclic order. All cyclics generated by primes higher than 7 must begin with one or more 0's. If these numbers are used for prediction tricks or lightning-calculation stunts, the initial 0's can be dropped—provided, of course, that you remember to insert them at the proper place in the final product.

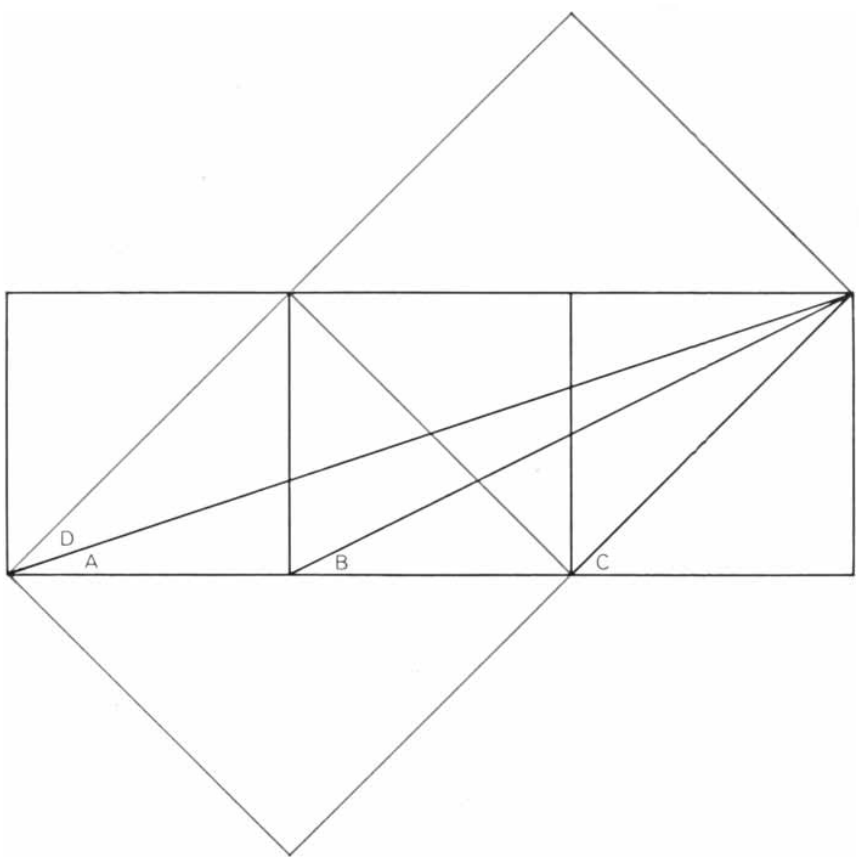
Exactly nine primes smaller than 100 generate cyclic numbers: 7, 17, 19, 23, 29, 47, 59, 61, 97. In the 19th century many larger cyclics were found. William Shanks, who is best known for his erroneous calculation of pi to 707 decimals, discovered the cyclic number generated by 1/17,389 and calculated its 17,388 digits (correctly). To this day no one has found an easier way of identifying the primes that generate cyclics than going through the tiresome process (which computers can now do very rapidly) of determining the repeating decimal of $1/p$ and counting its digits to see if their number is one less than p. There are many other ways to search for cyclics but unfortunately they are equally clumsy. C. Stanley Ogilvy, in *Tomorrow's Math* (Oxford University Press, 1962), points out that it is not even known whether the cyclics tend to increase, thin out or remain about the same as you go up the ladder of primes. For the first 1,000 primes, Ogilvy reports, the proportion that generate cyclics is about a third.

No fraction with a denominator d can have a repeating period longer than $d - 1$ digits. Since this maximum-length period is achieved only when d is a prime, it follows that cyclic numbers are equivalent to periods of maximum length for reciprocals of an integer. It is easy to see why $d - 1$ gives the longest possible period. When 1.000... is divided by d, there are only $d - 1$ possible remainders at each step of the division process. As soon as a remainder is repeated the period will start over, and therefore no fraction with a denominator d can have a period longer than $d - 1$ digits. It is also easy to see why such maximum-length periods are cyclic. Consider 8/17. Since every possible remainder appears in dividing 1 by 17, dividing 8 by 17 is merely starting the cyclic process at a different place. You are certain to get the same cyclic order of digits in the period of the repeating decimal. Multiplying the cyclic number generated by 1/17 by 8 is the same as finding the period for 8/17; consequently the product must be a cyclic permutation of the same 16 digits in the period for 1/17.

When a cyclic number is multiplied by its generating prime, the product is always a row of 9's. For instance, 142,857 times 7 is 999,999. This provides another way to search for cyclics: divide a prime, p, into a row of 9's until there is no remainder. If the quotient has $p - 1$ digits, it is a cyclic number. Even less expected is the fact that every cyclic (or any of its cyclic permutations), when split in half, gives two numbers that add to a row of 9's. For example, $142 + 857 = 999$. For another example, split the cyclic generated by 1/17 into halves and add:

05,882,352
94,117,647
99,999,999

This surprising property is a special case of "Midy's theorem," credited by Dickson to E. Midy, who published it in France in 1836. The theorem states that if the period of a repeating decimal for a/p (where p is a prime and a/p is reduced to its lowest terms) has an even number of digits, the sum of its two halves will be a string of 9's. Some primes, such as 11, have periods of even length that are not cyclic numbers and yet have the 9's property. Other primes, such as 3 and 31, have periods of odd length. All cyclic numbers are



Construction for proof of three-square theorem

even in length, however, and therefore Midy's theorem applies to them. This is good to remember because if you are doing the division to obtain a cyclic, you need only proceed halfway. You can write the remaining digits quickly by considering the digits already obtained and simply putting down their differences from nine. Of course it follows at once from Midy's theorem that all cyclics are multiples of nine, because any number whose digits add to a multiple of nine must itself be a multiple of nine. Readers interested in an elementary proof of Midy's theorem can find it in *The Enjoyment of Mathematics,* by Hans Rademacher and Otto Toeplitz (Princeton University Press, 1957), pages 158–160. Another proof is given by W. G. Leavitt in "A Theorem on Repeating Decimals" in *The American Mathematical Monthly,* June–July, 1967, pages 669–673.

There are many other strange properties of cyclic numbers, some of which the reader may have the pleasure of discovering for himself. I shall mention only one more. Every cyclic can be generated in numerous ways as the sum of an infinite arithmetic progression written diagonally. For example, start with 14 and double at each step, writing every number so that it projects two digits to the right:

```
    14
      28
        56
          112
            224
              448
                896
                  .
                    .
                      .
--------------------
142857142857...
```

The sum repeats the smallest cyclic number. Another way to obtain the same cyclic is to start with 7 and move diagonally down and left, multiplying by five at each step and keeping the diagonal uniform on the right:

```
          7
         35
        175
       875
     4375
       .
        .
         .
-----------
...142857
```

This same procedure, using the simple doubling series 1, 2, 4, 8, 16, 32, ..., will give the period of 1/19, the third cyclic number: 052,631,578,947,368,-421. The tripling series 01, 03, 09, 27, 81, ..., written diagonally down and right, each step projecting two digits rightward, has a sum that repeats the period of 1/97, the largest cyclic generated by a prime smaller than 100.

I conclude this brief discussion, which covers only a small portion of the fascinating properties of cyclics, by asking the reader what cyclic properties he can discover for the period of 1/13. This period, 076,923, is not a true cyclic. It can be called a cyclic of order-2. The answer next month will open a new field for exploration that is closely tied up with the better-known order-1 cyclics we have been considering.

Answers to last month's nine short problems follow:

1. *a*) One possible line of play:

	White	*Black*
1.	N–KB3	N–KB3
2.	N–QB3	N–QB3
3.	N–Q4	N–Q4
4.	KN takes N	QP takes N
5.	N takes N	P takes N

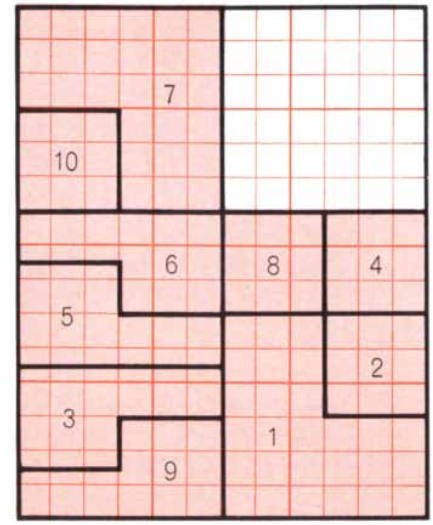
Both chess problems were reprinted in the Summer 1969 issue of a new recreational mathematics magazine called *Manifold,* published at the University of Warwick in Coventry, England. It cited a 1947 issue of *Chess Review* as its source. The above variation is credited to Larry Blustein, an American player.

b) The probability is 1. Because the discarded set of pairs must contain an equal number of black and white pieces, the all-black and the all-white pile must be equal.

2. As stated last month, to obtain the simplest fraction equal to a decimal of n repeating digits, put the repeating period over n 9's and reduce to its lowest terms. In this instance TALK/9,999, reduced to its lowest terms, must equal EVE/DID. DID, consequently, is a factor of 9,999. Only three such factors fit DID: 101, 303, 909.

If DID = 101, then EVE/101 = TALK/9,999, and EVE = TALK/99. Rearranging terms, TALK = (99) (EVE). EVE cannot be 101 (since we have assumed 101 to be DID) and anything larger than 101, when multiplied by 99, has a five-digit product. And so DID = 101 is ruled out.

If DID = 909, then EVE/909 = TALK/9,999, and EVE = TALK/11.



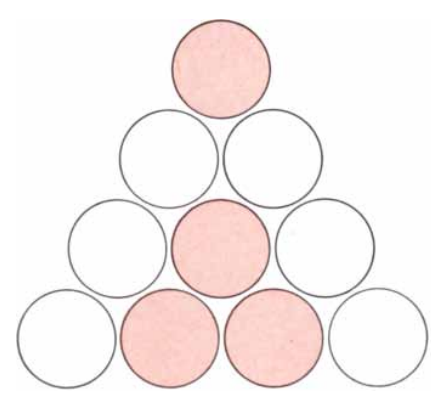
Final pattern for sliding-block puzzle

Rearranging terms, TALK = (11) (EVE). In that case the last digit of TALK would have to be *E*. Since it is not *E*, 909 also is ruled out.

Only 303 remains as a possibility for DID. Because EVE must be smaller than 303, *E* is 1 or 2. Of the 14 possibilities (121, 141, ..., 292) only 242 produces a decimal fitting .TALKTALK..., in which all the digits differ from those in EVE and DID.

The unique answer is 242/303 = .798679867986.... If EVE/DID is not assumed to be in lowest terms, there is one other solution, 212/606 = .349834-983498..., proving, as Joseph Madachy once remarked, that EVE double-talked.

3. In order to win the bet draw a 1 to the left of the tip of the thumb that is covering the row of circles. When the thumb is removed, the paper will show a binary number consisting of 1 followed by a row of 0's. Assuming the 0's to represent n coins, this binary number will be equivalent to the decimal number 2^n,



Solution for 10-penny puzzle

which is, of course, the number of ways n coins can fall heads or tails.

4. There are many ways to prove that angle C in the figure is the sum of angles A and B. Here is one [*see illustration on page 122*]. Construct the squares indicated by gray lines. Angle B equals angle D because they are corresponding angles of similar right triangles. Since angles A and D add to angle C, B can be substituted for D, and it follows immediately that C is the sum of A and B.

5. In the following 66-move solution to the sliding-block puzzle, each line (except the last) gives five moves. (Unless otherwise specified, a piece moves as far as possible in the indicated direction.)

7 up, 10 up, 9 right one-half distance, 6 up, 8 down.

10 left one-half distance, then down, 7 down, 6 right, 1 down, 5 left.

6 left, 4 down, 5 right, 2 down, 3 left.

5 up, 2 right, 6 up and left, 2 left, 4 up.

7 up, 9 right, 10 down, 1 down, 7 left.

4 down, 2 right and down, 6 right, 3 down, 5 left.

6 up and left, 2 up, 4 up, 7 right, 1 right.

3 down, 5 down, 6 left, 4 left and up, 7 up.

1 right, 8 up until its bottom edge touches at midpoint of 10, 10 up halfway, 9 left, 3 down.

1 down, 7 down, 4 down, 2 down, 6 right one-half distance.

5 up, 4 left all the way and down, 2 left and down, 5 down, 6 left.

7 up, 2 zigzags into 1, 4 right, down and right until it is over 2, 3 up, 10 up, right and up.

8 up, right, up and right, 3 down, 5 down, 6 down, 10 left.

7 left to final position [*see top illustration on preceding page*].

6. One way to solve the problem of the six weights—two red, two white and two blue—is first to balance a red and a white weight against a blue and a white weight.

If the scales balance, you know there are a heavy and a light weight on each pan. Remove both colored weights, leaving the white weights, one on each side. This establishes which white weight is the heavier. At the same time it tells you which of the other two weights used before (one red, one blue) is heavy and which is light. This in turn tells you which is heavy and which is light in the red-blue pair not yet used.

If the scales do not balance on the first weighing, you know that the white weight on the side that went down must be the heavier of the two whites, but you are still in the dark about the red and the blue weight. Rearrange the same four weights so that both whites are on one side and the red and the blue weight are on the other. There are three possible outcomes: (1) The *WW* side goes down. You know both weights on the other pan are light. (2) The *RB* side goes down. You know that both the *R* and the *B* weight are heavy. (3) The scales balance. The red or the blue weight that was on the side that went down in the first weighing is heavy. The other is light.

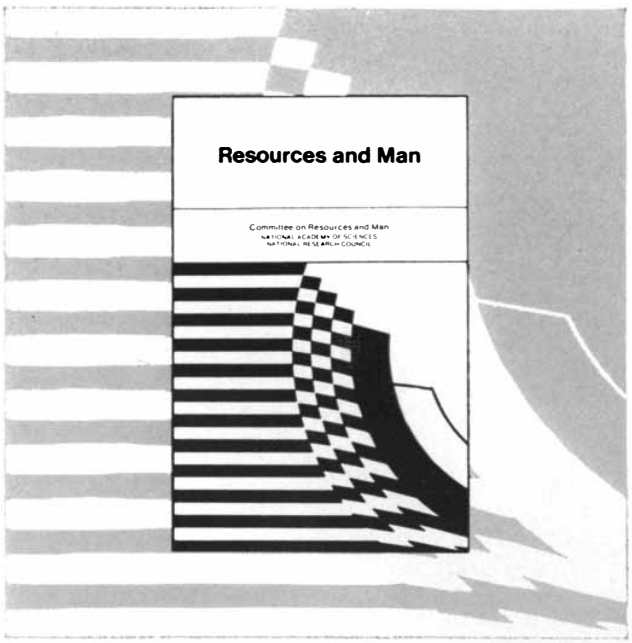
As before, in each case the result enables you to infer the nature of the red and the blue weight not yet used.

For readers who liked working on this problem, Ben Braude, a New York City dentist and amateur magician, devised the following variation. The six weights are alike in all respects (including color) except that three are heavy and three light. The heavy weights weigh the same and the light weights weigh the same. Identify each in three separate weighings on a balance scale. Braude's solution will be given next month.

7. The only answer is 6,210,001,000. I do not have the space for a detailed proof, but a good one by Edward P. DeLorenzo is in Allan J. Gottlieb's puzzle column in the Massachusetts Institute of Technology's *Technical Review* for February, 1968. The same column for June, 1968, has a proof by Kenneth W. Dritz that for fewer than 10 cells the only answers in the decimal system are 1,210; 2,020; 21,200; 3,211,000; 42,101,000, and 521,001,000.

8. The four pennies shown shaded [*see bottom illustration on preceding page*] are the fewest that must be removed from the 10 so that no three remaining coins mark the corners of an equilateral triangle. Barring rotations, the pattern is unique; it is, of course, identical with its reflection.

9. A simple way to win David Silverman's geography game is to name Tennessee. The second player can only prefix Connecticut or Vermont. Since no state begins with *E* or ends with *C* or *V*, the third player is eliminated. It is now your turn to start again. You can win with Maine or Kentucky. Maine eliminates the second player immediately because no state begins with *E* or ends with *M*. Kentucky is a quick winner, among several other possibilities. It forces him to name New York. You win by prefixing Michigan, Washington or Wisconsin.



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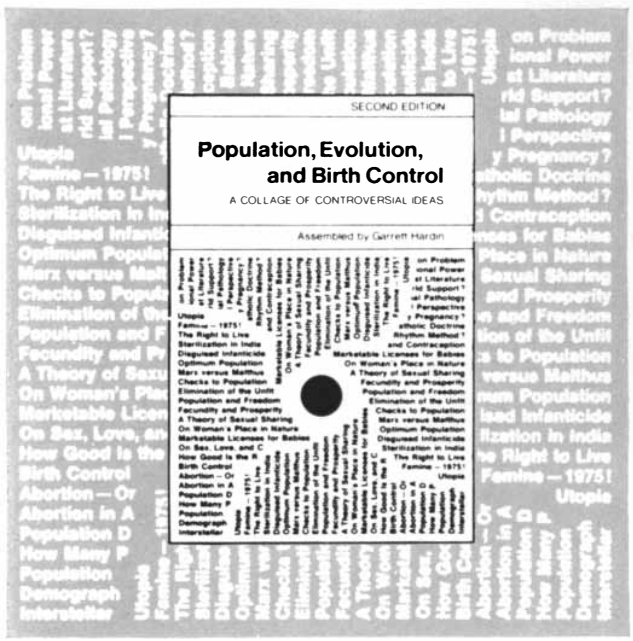

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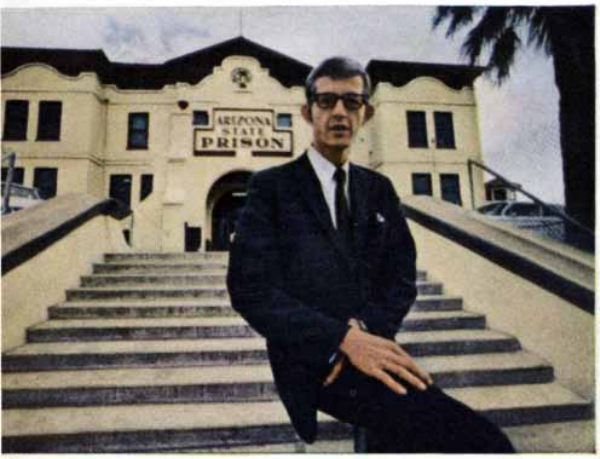
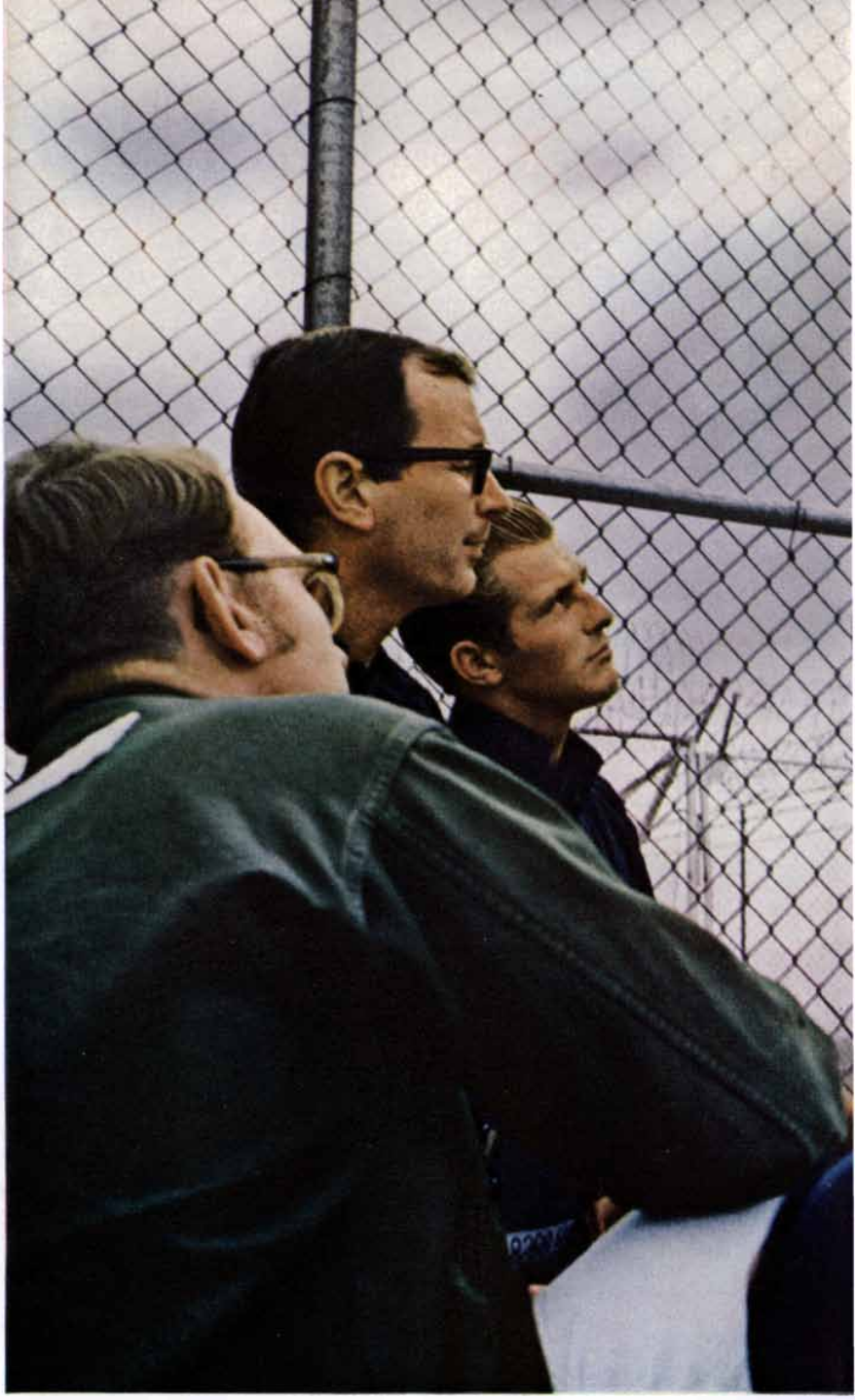
McDermed returns to the prison occasionally to keep the class informed of new programming techniques.





He offered these Arizona State Prison inmates a chance to escape from the past.

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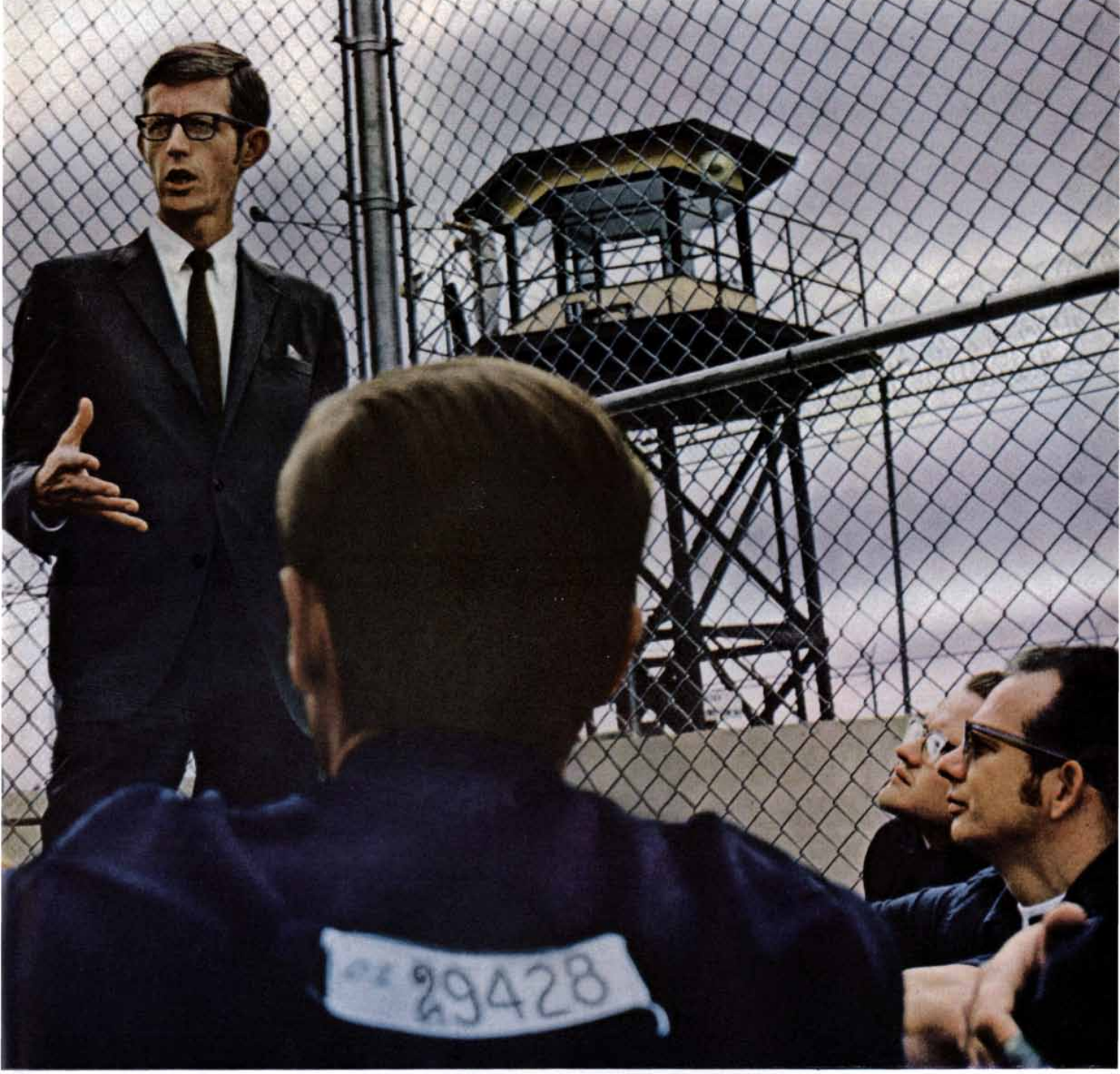

Glen McDermed and some members of his first class. Now these men are able to teach others.

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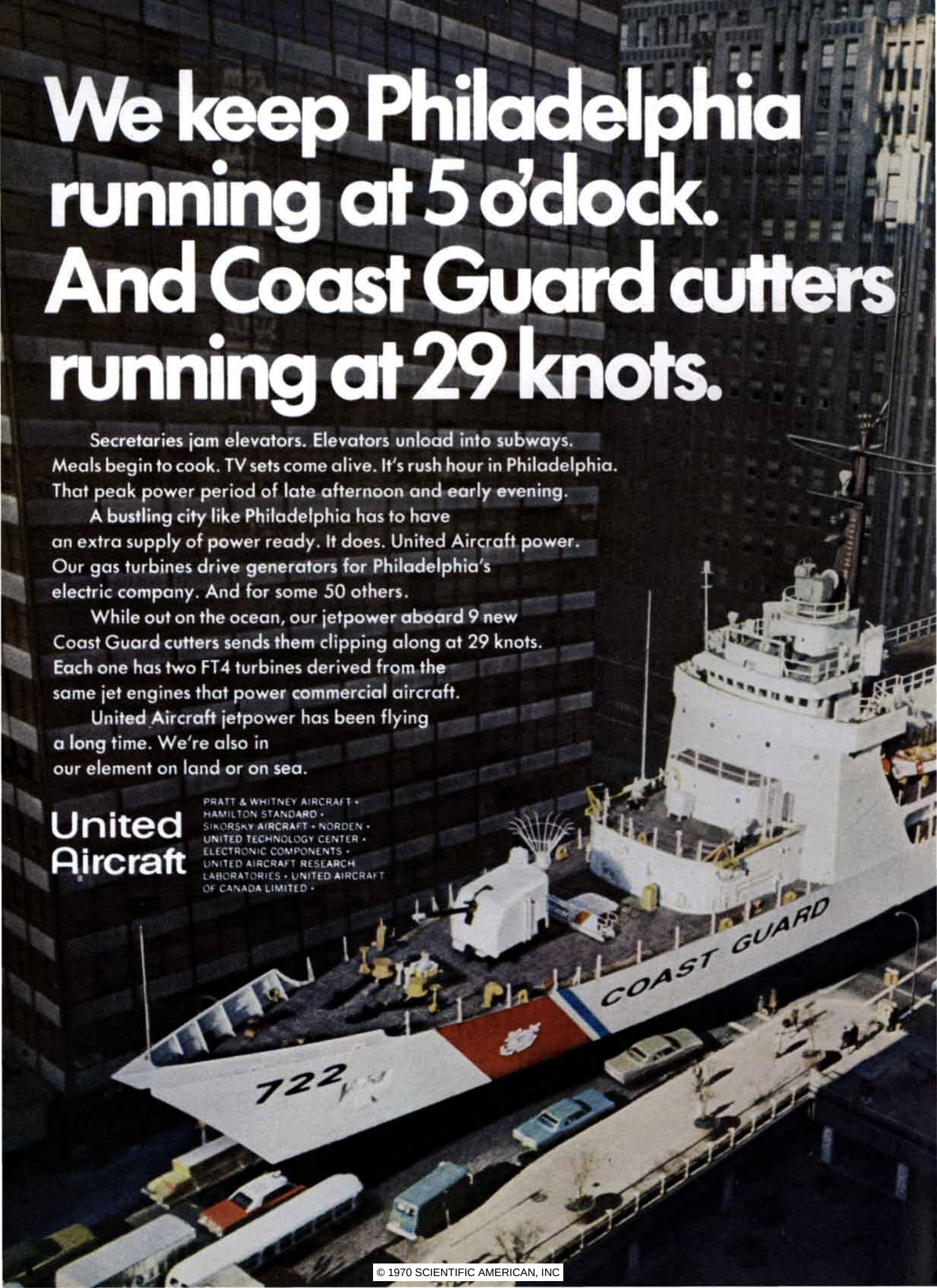

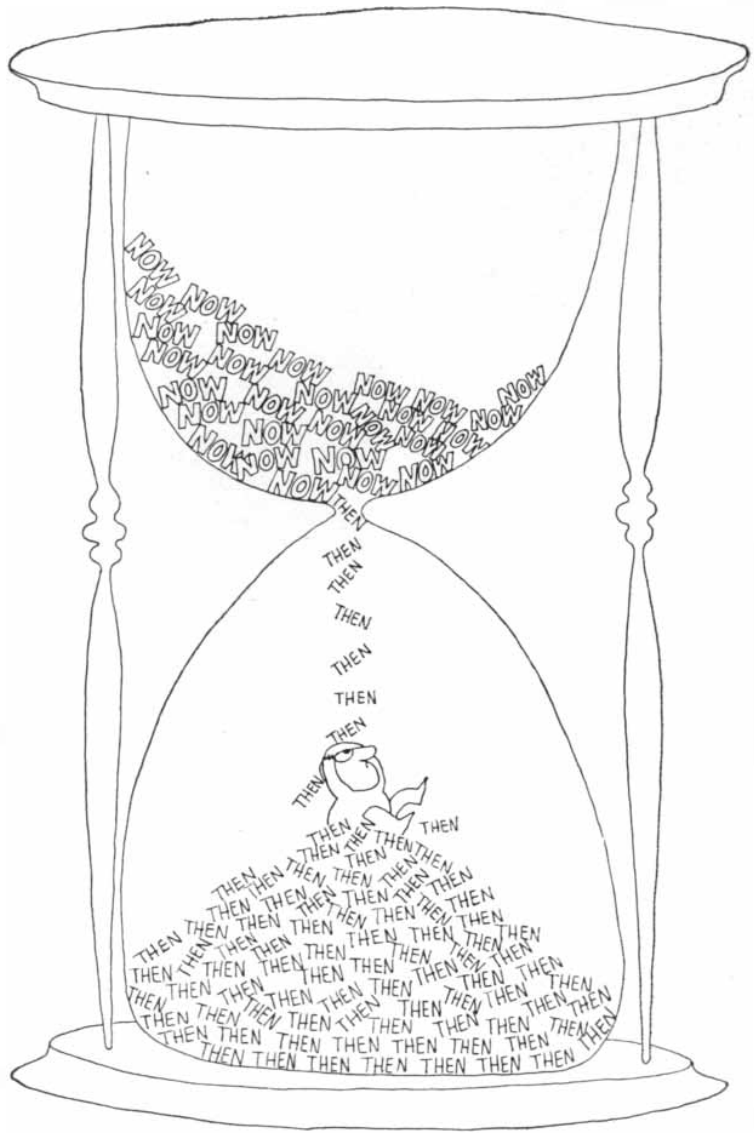

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THE AMATEUR SCIENTIST

How to study the life of a pond and to cultivate aquatic insects

Conducted by C. L. Stong

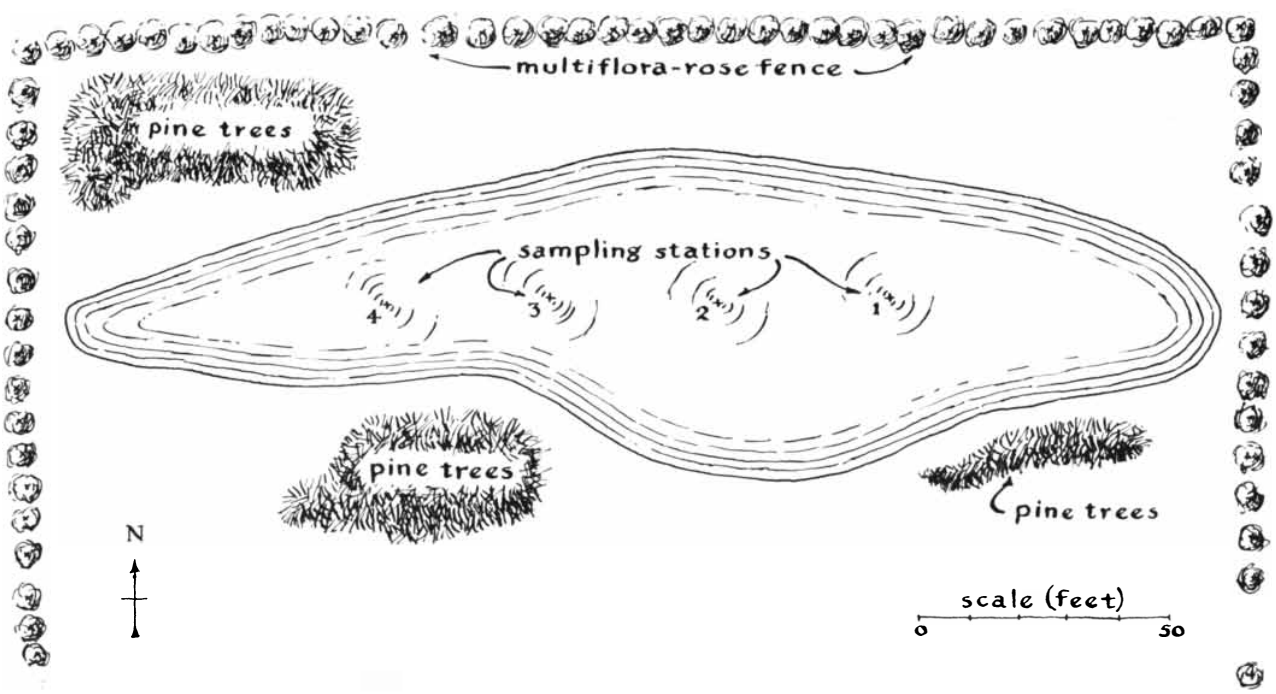
About 10,000 ponds and small lakes are created each year in the U.S. Most of them are on farms and are maintained primarily for watering livestock. Many ponds that are carefully managed, however, also become facilities for fishing, boating, swimming, ice skating, aquatic gardening and so on.

Careful management is essential if a pond is to serve these purposes, because every open body of water becomes an active universe of plants and animals. The character of a pond's population changes from day to day and year to year, not always in directions that please the human user. When the direction of the change is disappointing, the user may say that the pond has become "polluted" or "sick." In fact, every pond is a healthy environment for the organisms living in it, although they may not appeal to the owner.

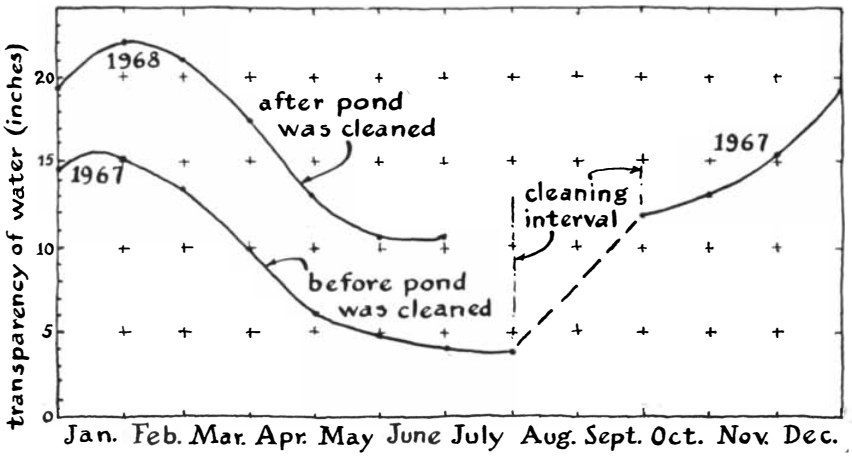
To encourage the development of a desired population, the owner must make a limnological study of the pond, which entails determining the physical, chemical and biological conditions of the water and modifying them to meet the preferences of the desired population. An example is a small pond that was created 15 years ago on a farm near Keystone, Ind., and figured in a prize-winning science-fair project undertaken by Betty Sue Settle, the daughter of a teacher and farmer who made the pond. Miss Settle, now a student at Ball State University, writes:

"Our pond was established in 1955 on the slope of a field about half a mile from our house as a water supply for cattle pastured at the back of our farm. The water was pumped to the animals so that they would not contaminate the supply. In its second year the pond was stocked in the proper proportion with prey and predator fish: fingerlings of bluegill and largemouth bass. The fingerlings developed rapidly and provided fine fishing until the extremely cold winter of 1963, when the water froze to a thickness of 18 inches. None of the fish survived, even though more than five feet of water remained under the ice. In later years all efforts to restock the pond failed. Fingerlings did not survive in the water for more than a few days. Late in 1966 I decided to find out what had gone wrong. To that end I bought a few books on basic ecology.

"Our pond is roughly oval in shape, about 250 feet long, 75 feet across at the widest point and roughly eight feet deep in the middle. Like all ponds, it consists of four more or less distinct environments or zones, each uniquely hospitable to certain groups of plants and animals. For example, large plants take root and do best in shallow water near the edge. The upper layer of water beyond these plants, which receives the



Map of the pond analyzed by Betty Sue Settle



Changes in the transparency of the water

most light, encourages the growth of plankton, including algae, protozoans, diatoms, crustaceans and rotifers. The middle layer below receives less sunlight and is cooler; it supported our fish. The bottom layer, which exists only at the deepest part of the pond and tends to merge into the middle layer when the water becomes warm in midsummer, is about a foot thick, dimly lighted, cold and low in dissolved oxygen. This zone is inhabited largely by microorganisms that feed on and thus help to decompose particles of organic debris that settle from the upper layers.

"To investigate the physical, chemical and biological conditions of the pond throughout the year I established four collection stations, equally spaced along the major axis of the ellipse. Their positions were determined by reference points on the bank, such as particular trees and nooks. Specimens were collected from these stations at the end of each month. In summer a collecting vessel could be moved to the center of the pond by a pulley that rode on a suspension rope anchored to the banks. Station No. 1 was at the east end of the pond at what was thought to be the deepest point. At Station No. 1 and Station No. 2 specimens were taken from the surface and the bottom layer, whereas at Station No. 3 and Station No. 4 they were taken from the bottom only, because of the shallowness of the water.

"Observation of the physical conditions was limited to temperature, transparency of the water and thickness of ice (when ice was present). Transparency was measured by lowering an aluminum plate on a rope until the plate could not be seen and then raising it until the plate became visible. The distance was determined by calibrations on the rope. In winter blocks of ice were cut with a large handsaw and carefully removed for measurement of the thickness with a steel tape.

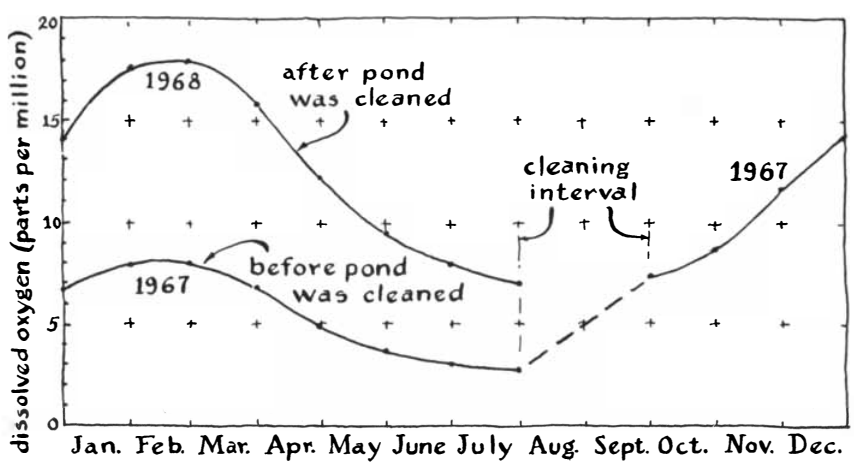
"Chemical observations included the determination of dissolved oxygen, the relative acid-alkaline balance in units of *p*H and the measurement of free carbon dioxide. The Winkler method of oxygen determination has become the most generally used means of measuring dissolved oxygen in ponds because of its convenience and the fact that it yields sufficiently accurate results. To make this measurement I put 250 milliliters of pond water in a bottle and added by pipette two milliliters of manganese (II) sulfate and two milliliters of alkaline iodide solution. The brown precipitate that formed was then dissolved by two milliliters of concentrated sulfuric acid. The resulting manganese (IV) sulfate reacted with potassium iodide in the alkaline iodide solution to form soluble iodine. The iodine was titrated with a standard solution of sodium thiosulfate, using starch as the indicator.

"Standard manganese (II) sulfate solution is prepared by dissolving 368 grams of the chemical in distilled water to make one liter. Alkaline iodide solution is prepared by dissolving 500 grams of sodium hydroxide and 150 grams of potassium iodide in distilled water to make one liter. Sodium thiosulfate is prepared as a .025 normal solution because this concentration simplifies the calculation of weight equivalents for iodine and oxygen. I prepared the solution by dissolving 6.2 grams of sodium thiosulfate in distilled water to make one liter.

"During the reaction each equivalent weight of dissolved oxygen produces an equivalent weight of iodine. Therefore the titration of iodine can serve as a direct method of determining the number of parts of oxygen in a million parts of water solution. For example, if the addition of eight milliliters of sodium thiosulfate alters the color of the solution, the specimen contains 16 parts of dissolved oxygen in a million parts of solution. The starch solution, which functions as the indicator by turning blue in the presence of iodine, is made by dissolving .5 gram of starch in 100 milliliters of hot water and cooling the liquid to room temperature for use.

"The acid-alkaline balance of the water was determined within a quarter of a *p*H unit by means of a recently developed paper for testing solutions of minimal buffer capacity and low total solids. Known as pHydrion Lo Ion test paper, the material is available from Micro Essential Laboratory Inc., 4224 Avenue H, Brooklyn, N.Y. 11210. The test is made by immersing a strip of the sensitized paper in a special test tube that comes with the kit and, after one minute, comparing the hue of the strip with a calibrated color chart that is also provided.

"Free carbon dioxide was determined



Variations in the water's content of dissolved oxygen

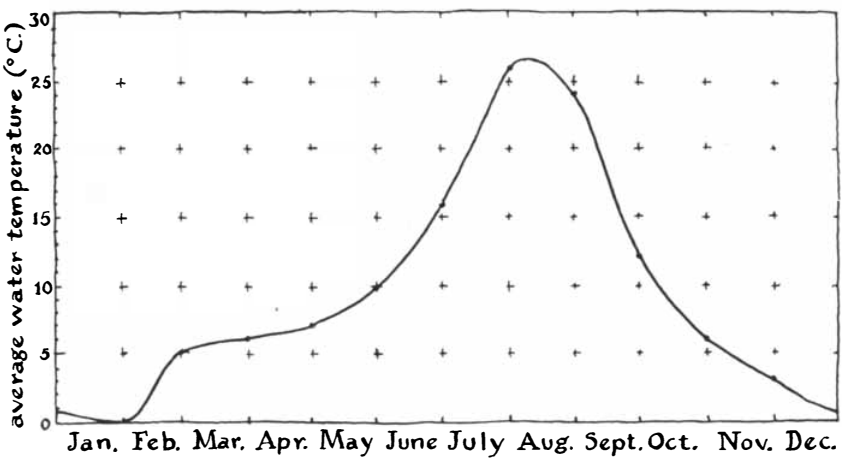
by adding 10 drops of phenolphthalein indicator solution to 100 milliliters of pond water and titrating with a .023 normal solution of sodium hydroxide until the water turned a faint but permanent shade of pink. A solution of this concentration is prepared by dissolving 910 milligrams of sodium hydroxide in distilled water to make one liter. Phenolphthalein indicator solution is prepared by dissolving .05 gram of phenolphthalein in 50 milliliters of ethyl alcohol and 50 milliliters of distilled water. The parts per million of free carbon dioxide in the specimen equal 10 times the number of milliliters of sodium hydroxide required to make the color appear.

"A monthly census of the microorganisms was taken at each of the four sampling stations. Collections were made with a four-liter aluminum pail. The four-liter specimen was filtered through a homemade plankton net of silk inside a 200-milliliter container, thus concentrating the organisms from four liters to 200 milliliters. Half of the concentrated specimen was then transferred to a clean bottle that contained five milliliters of a 5 percent solution of Formalin. The density of organisms per cubic centimeter of pond water was then determined with a 400-power microscope and a homemade counting chamber.

"In winter the ice cover reached maximum thickness in December and January, but during the 1967–1968 season it amounted to only seven inches. The temperature of the water at Station No. 1 and Station No. 2 varied from 27.2 degrees Celsius on August 15 to zero degrees C. on January 27. At Station No. 3 and Station No. 4 it ranged from 27.9 degrees to one degree. The slightly larger variation in temperature at the latter stations is explained by the shallower depth of the pond there. Four groups of plankton were identified and counted: rotifers, protozoans, diatoms and crustaceans, all of which are eaten by fish.

"All data were tabulated and subsequently plotted as graphs. The results immediately suggested that our fish had died from the lack of dissolved oxygen or a slightly acid condition of the water, or both.

"What had depleted the oxygen? The explanation became clear when I reviewed the history of the pond and the data I had collected. Dissolved oxygen in a pond comes primarily from two sources. Most of it is provided by green plants, notably those in the plankton. The gas is liberated during photosynthesis. A lesser amount diffuses into surface water from the air.



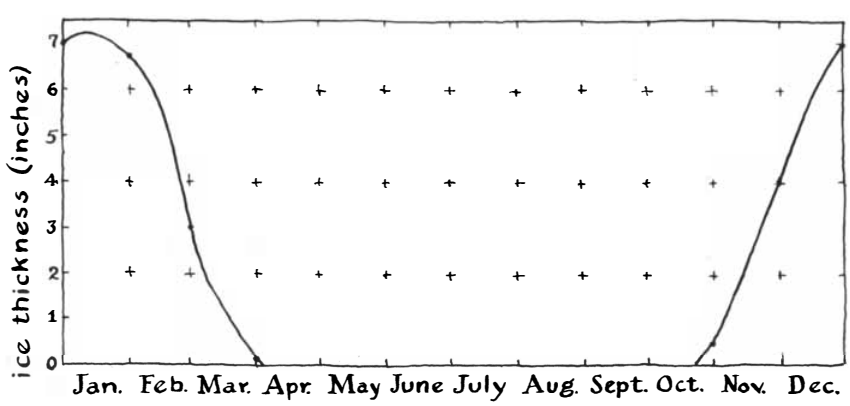
Pattern of temperature in the pond

"Two demands are made on the pond's supply of oxygen. Animals consume a substantial part of it. Hence living green plants function as essential allies of the animals. A second demand is represented by the oxidation that takes place during the decomposition of organic debris. In ponds and lakes that are deeper than about 20 feet the debris settles to the bottom, exhausts the oxygen and thereafter becomes relatively inert. In shallower water, as in our pond, convection currents carry oxygen-rich water to the bottom, where it is consumed as long as debris is available. This process lowers the concentration of oxygen in the middle layer and the upper layer, which is the oxygen reserve that sustains fish. Much of the organic debris is of plant origin. In effect, when plants die, they become aggressive competitors of the animals, at least for the available oxygen.

"Our pond developed a massive population of plants, particularly those that grow well in shallow water. Various waterweeds, including cattails and small willows, sprang up after the pond filled, and by 1963 they had covered a substantial area of the water. The debris shed by this lush growth appeared to explain why we had lost our fish. To check this supposition we undertook a cleanup operation in August, 1967. It lasted for several weeks. I then resumed the testing routine.

"The cleanup caused an abrupt shift in the data. For example, the transparency of the water in the cleaned pond averaged 16 inches in winter and spring and 11 inches in fall, whereas previously it had averaged only six inches. Seasonal variations in transparency appeared to be caused by plankton in fall, snow cover in winter and mud in spring.

"The concentration of dissolved oxygen varies inversely with the temperature of the water, rising in winter and declining in summer. Before we destroyed the weeds the oxygen concentration ranged from a maximum of 9.4 parts per million at one station to 8.3 parts at another station on the same collection date, August 15. In January the concentration was well below saturation, the theoretical limit to which oxygen can dissolve in water at a given temperature, and below the limit fish can tolerate. After the



Thickness of the ice

A view of the pond before cleaning

The pond after cleaning

cleanup it rose to 12.1 parts per million, substantially above saturation in summer and well within the limit required by fish. Ice accounted for some of the winter deficit, as indicated by the fact that the concentration rose when warm rains melted the surface.

"The *p*H was not appreciably affected by the cleanup. It ranged from 5 to 7 during the first few months and remained almost constant thereafter, somewhat on the low side for fish culture. Fish in this area cannot tolerate a *p*H below 5. It turned out that the *p*H of the water was close to that of the subsoil and was doubtless determined by the subsoil. We corrected the balance by adding pulverized limestone to the pond. The water is now almost neutral and so is suitable for fish.

"Final tests indicated that the temperature, transparency, dissolved oxygen, plankton density, *p*H and carbon dioxide concentration were all within the required limits for the culture of fingerlings. To check this conclusion I made a simple experiment. Three goldfish were placed in a small aquarium and given fresh pond water twice daily. In the beginning I added a small amount of prepared food to the water. This ration was gradually withdrawn as the fish became accustomed to eating plankton. They appeared to adjust easily to the change, and all of them thrived.

"We have not restocked the pond with fish, but we have extensive plans for it. I am away at school and will be for some time. My father, however, will retire from teaching next year. He will then drain the water and bulldoze the area to increase its size and depth. The watershed will also be increased by running more drainage ditches into the enlarged basin. When this work is completed, we

shall restock the pond. Thereafter we shall provide the maintenance that has been suggested by these experiments. Professor Eugene P. Odum of the University of Georgia has said that one of the best introductions to ecology is the study of a small pond. As an amateur who has tried it, I agree."

Not all amateurs who might otherwise enjoy ecology have access to a farm pond. Even so, they can be of good cheer. According to Harold Abernathey, a city dweller of Waterloo, Iowa, it is possible to set up a serviceable pond in one's living room—if the experimenter is willing to settle for mosquitoes instead of largemouth bass. Abernathey writes:

"Our state has acquired a measure of renown for its tall corn and fat hogs, but somehow the sheer bulk and unparalleled ferocity of our mosquitoes have received scant acclaim. I hope to correct this oversight by explaining how to grow Iowa mosquitoes anywhere. All you need is a lump of Iowa soil that contains the eggs, and an apparatus that has been designed by Ernest C. Bay, a member of the Department of Biological Control at the University of California at Riverside.

"The main part of the apparatus consists of a pair of transparent plastic containers of about one-quart capacity with close-fitting lids. I bought a pair from a local hardware dealer. Cement the lids together, top to top, and cut a big hole in the middle, one that extends to within about a quarter of an inch of the flanged edge. You now have a ring with flanges on both sides.

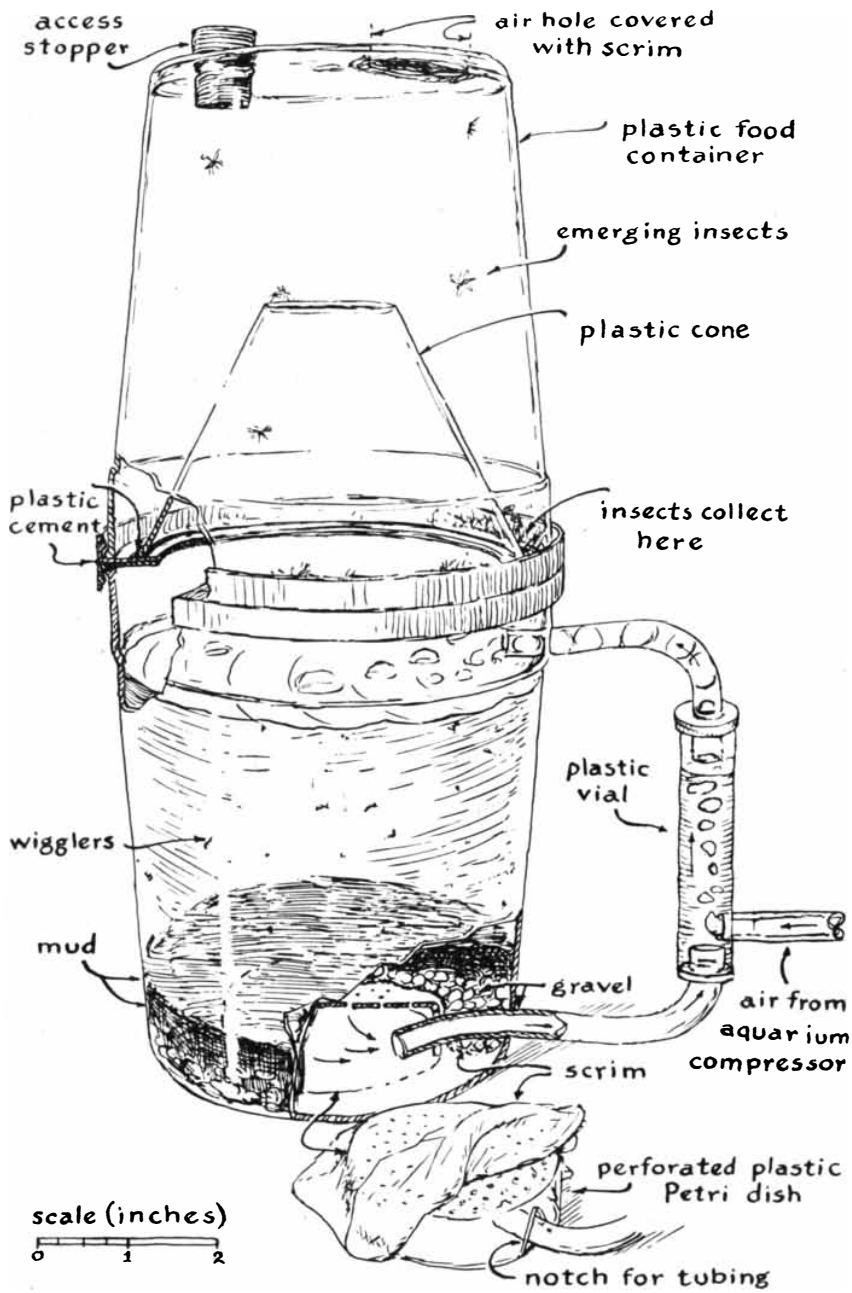
"You will also need a funnel of clear plastic with a top somewhat narrower than the lids. Cut off the spout and cement the base of the resulting cone over the hole in the ring. Assemble the containers to the ring to form a unit. The cone now extends into one of the containers. This container will function as a collection vessel. The other container, which forms the base of the apparatus, will become the pond [*see illustration at right*].

"The pond must be given a mud bottom and a filter. The filter consists of two elements: an inverted Petri dish of clear plastic that fits inside the pond, and a disk of nylon scrim. Perforate the bottom of the Petri dish with a generous number of small holes and place it upside down inside the pond. Cover the perforations with the scrim. Later you will cover the scrim with a layer of gravel and soil and fill the pond with water. First, however, you must have a way of circulating water through the pond.

"Circulation can be maintained by a novel air pump that is connected to the pond by two short lengths of Tygon tubing. Drill a pair of holes for the tubing through the side of the container-pond, one close to the bottom and one close to the top. The diameter of the holes should be slightly less than the outside diameter of the tubing. The push fit ensures a leakproof joint. Make a notch in the edge of the Petri dish for accommodating the lower hose.

"The pump consists of a small plastic vial. The lid of the vial is drilled for a snug fit with the inlet tubing of the pond, and the bottom of the vial is similarly drilled to admit the outlet tubing of the pond. A third hole is drilled in the side of the vial near the bottom. This hole accepts tubing from an air compressor of the kind designed for small aquariums.

"When the system is filled with water, bubbles of air pass up through the vial and escape through a hole that is made in the top of the collection vessel. The bubbles supply dissolved oxygen to the water and simultaneously create the desired circulation without agitating the pond, provided that the water level of the pond is at the level of the inlet tube. The water filters continuously through



Harold Abernathey's apparatus for cultivating insects

the mud bottom. Organic debris collects harmlessly under the Petri dish. The opening in the top of the collection vessel should be covered with a screen of nylon scrim to prevent the escape of mosquitoes. An access hole can be made in the top and closed with a rubber stopper.

"The apparatus can be charged with mud or soil from any location where mosquitoes breed. In our part of the country they breed in unlikely places such as animal tracks and hoofprints of almost any size that catch and hold rainwater for a few days, the inside of wooden kegs and hollow stumps, the sides of plow furrows, low places in city lawns and so on. The eggs evidently remain viable for a long time. I have hatched mosquitoes from lumps of hard clay that appear to have been dry for months and from scrapings taken inside an old rain barrel that I know had not been used for several years. (Scrapings are mixed with soil that has been sterilized in an oven.) I get good crops from lumps of frozen soil in the dead of winter.

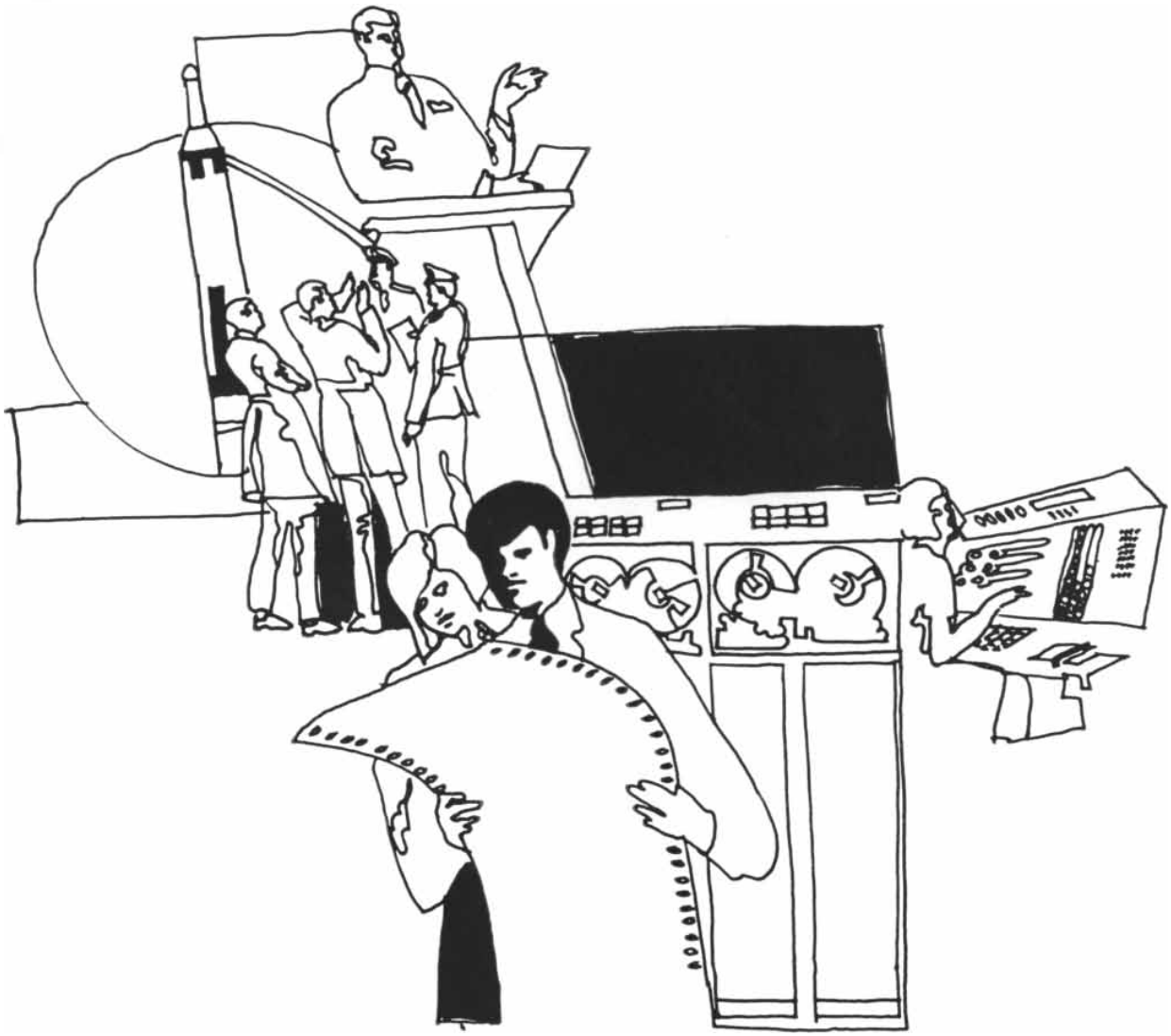
"To set up a culture I cover the scrim of the clean apparatus with a layer of soil about an inch thick and add distilled water to the level of the inlet hose. If the water is kept at room temperature, wigglers appear within a week and the adults mature a few days later. Two or three days after the adults make their way through the cone and into the collection vessel they are ready to lay eggs. I provide no special lighting, nor do I otherwise tamper with their development. When a crop hatches, I anesthetize the adults by admitting carbon dioxide to the upper chamber. The insects fall inside the ring at the base of the cone, where they can be counted, removed for weighing or otherwise manipulated.

"Mature mosquitoes feed primarily on the juices of wild plants. It is interesting to observe their preferences by giving the adults access to screened enclosures where plants of various kinds are grown. Incidentally, only the females suck blood. This behavior provides the experimenter with a reliable method of distinguishing the sexes. The females lay eggs in the absence of males, but (I am told) the eggs of some species are not fertile unless the female has partaken of animal blood at least once.

"The apparatus can be used for culturing various aquatic insects, of course, as well as other organisms that inhabit freshwater ponds. An excellent article by Bay that describes some of these experiments appears in *Turtox News,* Volume 45, Number 6, 1967."

For Scientists and Engineers

Breakthrough



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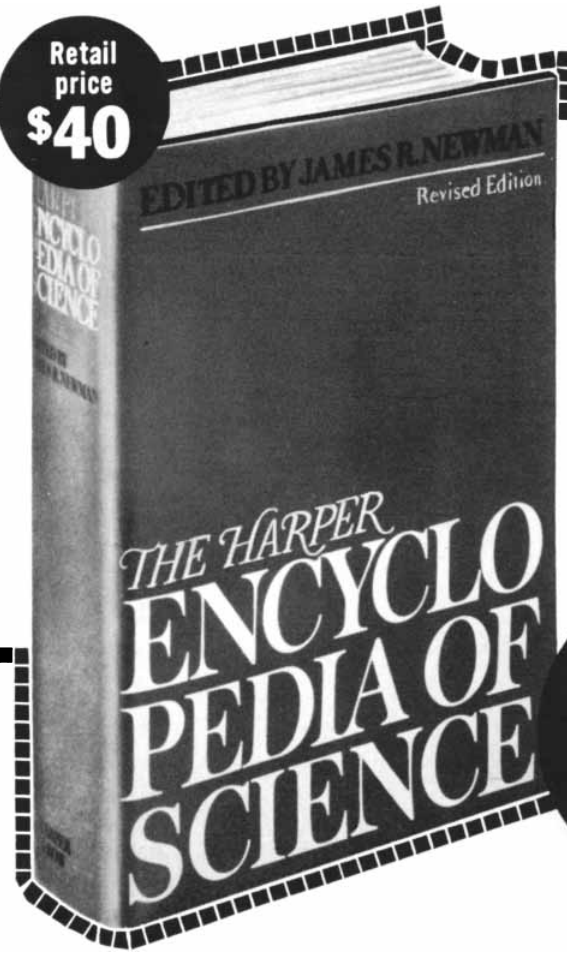

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BOOKS

The contemporary smuggler, the history of the hydrogen bomb and other matters

by Philip Morrison

THE SMUGGLERS: AN INVESTIGATION INTO THE WORLD OF THE CONTEMPORARY SMUGGLER, by Timothy Green. Walker and Company ($6.95). Cool and elegant, she sat there across the corridor of the rocking train, on her slender wrist the massy gold bracelet, with its finials of lion heads, that could have come only from the time of Troy! The young British archaeologist bound from Istanbul to Izmir could no longer contain himself; he sprang the trap. Anna Papastrati was fascinating; she took James Mellaart to her home and allowed him to sketch an archaeological treasure. It was the burial hoard of an ancient princess, and about its discovery Anna spoke excitedly but evasively. Mellaart got permission to publish his sketches, but the promised photographs never came. Anna was never seen or heard of again. The Dorak treasure also disappeared; it was never seen by the Turkish authorities. Anna's bracelet (or, as the owners say, a match to it) can be seen in a photograph reproduced in *The New York Times* on December 31, 1969, part of a 10-kilogram gold hoard datable to before 2500 B.C. The treasure has now surfaced as a gift for the Boston Museum of Fine Arts in its centennial year. Why the romance? Presumably an able group of smugglers wanted to establish the authenticity of their valuable finds, and Dr. Mellaart was an incorruptible (if susceptible) appraiser on the spot.

This volume covers art, gold, drugs, guns, people, watches and other commodities in the illicit trade of our times. Its raffish tale is well told, with much detail and documentation in the best style of the London weekly where Mellaart published his sketches, by the paper's former editor on the basis of interviews with both sides of the law around the world, and of loving study of the press and of the police dockets.

The largest single smuggling trade today is the flow of gold bars, all of them the smooth little bonbon size, to the merchants and landowners of the western states of India from the little port of Dubai. That excellent harbor is the capital of a sheikdom of the Trucial States, on the coast where the Arabian peninsula sends out a tooth to narrow the Persian Gulf. Dubai is a quiet, hot, coastal river town, but a dozen dealers there own busy teleprinters rattling with the London gold prices, and the sleepy dhows in the harbor, their deck cargo oil drums and pilgrims returning from Mecca, can waken spectacularly if Indian customs boats draw near. The dhows have modern marine engines below their lateen rigging. In 1968 smugglers brought many millions of dollars worth of gold to the seashore grounds of the Tata Institute and the Atomic Energy Establishment in the beautiful Bombay suburb of Colaba. The guards could be bribed; who would expect contraband to enter such secure government property? The trade is about $150 million a year; a few percent falls into the hands of Indian customs. It is by no means certain that this centralized and measurable trade—perhaps 95 percent of the illicit gold flow to India—is not preferred by the Republic to the universal permeation of the border that existed before the traders of Dubai became active (with much Lebanese capital).

Archaeologists and the engineers thus have a place in smuggling. So have chemists. There are currently two centers of preparative organic chemistry in the smuggling world. One is London, where the task is to prepare LSD from the intermediate ergotoxine. The base drug is supplied from Hamburg, although the manufacturers are in Hungary and Czechoslovakia, working for licit pharmaceutical industries. LSD sells wholesale (the price is falling) for some $1,500 or $2,000 a gram, a threefold markup on the materials cost. Since 1967 the London police have seized nearly 200 grams of the stuff in raids on two separate laboratories: about a million doses, intended mostly for the U.S.

The second chemical center is on the Riviera, where the Corsican operators of the high-priced heroin trade maintain their laboratories. It is the purity of the heroin that determines price: "The French stuff is the champagne of heroin." Here the chemists toil on the kilogram scale, not on the microchemical level of the LSD workers. Heroin is worth only its weight in gold—a dollar or so per gram.

This is a sad, witty, adventurous and convincing book.

A HISTORY OF THE UNITED STATES ATOMIC ENERGY COMMISSION, VOLUME II: ATOMIC SHIELD, 1947/1952, by Richard G. Hewlett and Francis Duncan. The Pennsylvania State University Press ($11.95). I. V. KURCHATOV: A SOCIALIST-REALIST BIOGRAPHY OF THE SOVIET NUCLEAR SCIENTIST, by I. N. Golovin. Translated from the Russian by William H. Dougherty. The Selbstverlag Press, Post Office Drawer 606, Bloomington, Ind. ($4). Clio, the muse of history, endures half-slave and half-free. Recent history, particularly when it deals with matters of state, requires the use of documents that are kept in secret files. Hewlett and Duncan, professional historians who have been free to use nearly all the materials under the control of the U.S. Atomic Energy Commission, present a detailed account of the years in which the arms race got under way and the first thermonuclear test was made. They have used the minutes and the laboratory reports and the letters and the oral recollections of the participants, and used them so intensively that they can characterize the record of the travail of J. Robert Oppenheimer (his hearing came after the period of this volume) as "at best the raw material of history." The participants were trying to recall the details of events long past, setting the "limitations of this fascinating document." *Atomic Shield*—marred by what seems an exaggerated concern for secrecy, and by undue, if unintended, deference to the authors' official role—is also limited, and less than fascinating. It is nonetheless full of interest; its defects are mainly those of omission.

The metaphor that gives the book its

title, repeated in two chapter headings, is symptomatic. The authors, like the rest of us, know that the hydrogen bomb is not in any sense a shield. Rather it is a six-gun at the hip. The criticism is superficial, but its implications are not; the AEC has a self-image that imprints even these able and critical historians by its mere existence. Joseph R. McCarthy appears in the 600-page book in only one sentence, and no mention is made of the lengths to which his activities led the AEC. (For example, some thousands of copies of *Scientific American* were burned on AEC orders in 1950.) The Rosenberg case gets a paragraph up to the time of the indictment; the outcome, like the role of the AEC, also goes unmentioned.

What is most important is the history of the thermonuclear weapon. The sequence of events and the stance of the participants is told in detail. The Super was first discussed in 1942—before Los Alamos. It needed a fission trigger, so that it had to be a postwar goal. It was the first Russian fission explosion late in the summer of 1949 that put Super on the crash priority list. Lewis Strauss, the influential commissioner, had been wartime assistant to the first Secretary of Defense, James Forrestal, whose mind became fixed on "a strong nuclear arm" before his resignation and suicide following "a state of deep depression." After the Russian test Strauss sought a "quantum jump" in weapons technology. He had ardent allies: Ernest Lawrence, Edward Teller, Senator Brien McMahon and McMahon's staff man William Borden (whose letter to J. Edgar Hoover was the formal cause of the Oppenheimer dismissal). By January of 1950 the tide of internal opinion, bearing the public wreckage of many private debates, had moved to the decision; the President acted, and we were set on the course to thermonuclear weapons. The Super (it had been called that for a decade) demanded tritium in quantity, which implied pounds of neutrons. The resources of the AEC were doubled. Still the Super looked far off. Its construction would cost us all the perpetual risk of thermonuclear war, but even for the hawks it cost the equivalent of many fission weapons. In a few sentences in the spring of 1951 Stanislas Ulam of Los Alamos, an ingenious and persistent analyst of the Super proposals, outlined "a couple of thoughts (ideas).... Edward is full of enthusiasm about these possibilities." By late summer it was clear that the new Super might be tested in the fall of 1952. On November 1, 1952, the "Mike" test, equivalent in energy to 10 megatons of TNT, vaporized the island of Elugelab. (There are air views before and after.) The thermonuclear age had dawned. The new Super was not unique. The Russians tested an even more workable device only nine months later. The thermonuclear race was on, and it is still joined.

There is no official word here on Supers without cryogenic liquids, nor on Supers without tritium. The lore of common rumor suggests that the Elugelab shot was "wet" and the Russian shot was "dry," but this history does not confirm such lore. Indeed, it is rather a surprise to read officially that the Mike shot was a form of the new Super, even though there is reason to believe—beyond the scope of this volume—that only the giant test in the spring of 1954 brought the U.S. to a demonstrated thermonuclear parity.

The second book is a paperback translation of an amateur, devoted, personal and curiously stereotyped biography of the Russian equivalent of Ernest Lawrence and Arthur Compton: Igor' Vasil'evich Kurchatov, who died in 1960. The author is a younger associate. The book is slight but genuinely warm. It is strongest in the years of study and research in the 1930's and weakest in the climatic period when Kurchatov headed the Russian race to become a nuclear and a thermonuclear power. The Russian edition appeared in 1967; the few pages here and there that speak to the point are still the most complete published counterpart of the voluminous histories of American atomic energy work. The feeling is clear: as the Germans were to the Anglo-American wartime nuclear effort, so the Americans were to postwar Russian physicists. There are recognizable roles shared in both countries; the Russian counterpart of Leo Szilard was G. N. Flerov. Serving in the Red Army on the Voronezh front in the terrible year of 1942, this "possessed" physicist organized the nuclear project by mail, writing to his physicist friends and to the leaders of the state alike. He made his point—aided, we are told, by the information that "top-security work was in progress in Germany and the United States."

The same story remains to be told for the world's most populous nation and newest nuclear power.

GYROSCOPIC THEORY, DESIGN, AND INSTRUMENTATION, by Walter Wrigley, Walter M. Hollister and William G. Denhard. The M.I.T. Press ($21). About as costly and as numerous as Rolls-Royces, there spin all over the earth and the seas, at 10,000 or 20,000 turns per minute, the two-inch beryllium rotors that are the heart of the elegant navigational gyroscopes built in clusters into every guided missile the great powers have, into their space vehicles and—in less elite versions—into the instrument panels of aircraft. This engineering text, complete with explicit problems but a little lacking in candor about performance and dimensions, is intended as a one-term course for senior or early graduate students. It does not have much to say about the navigational system as a whole, the electronics of servomechanisms and computers that makes the gyroscope sensors useful, but it presents the theory of the gyroscope (and the simpler accelerometer) from the general equations, through the linearized approximations that describe the useful case, the choices taken now and in the past by a generation of designers, and the intricate testing procedures. The familiar aircraft instruments are included, as is the ship's gyrocompass, mainly for their theory; the center of interest is the modern strapped-down single-degree-of-freedom floated integrating gyroscope—the working state of this high art until lasers or electrostatically suspended grains or something else proves acceptable. In this device the rotor is driven magnetically on a superb ball-bearing axis. (The tolerances are specified to five or 10 microinches.) The rotor is housed in a float also made of the light, strong metal beryllium. That float is buoyed up by a bath of a syrupy fluorocarbon liquid, which takes the weight and inertial load off the transverse output axis on which the floating rotor housing can so delicately turn. That axis, whose remarkably small motions represent the output of the gyroscope, is damped by the fluid, which kills the oscillations dear to gyroscopic theory. In some ways this is the key idea. There are no bearings on the output axis. Alternating-current magnetic suspensions center the output axis fully, so that in normal operation it does not even touch. The axis direction is servo-controlled by the computing circuits, which step by step, every fraction of a millisecond, pulse torque into the gyroscope to compensate for its tiny deviations, and keep algebraic count of what they do. Thus the device integrates motion and leads the vehicle to the target, given six separate integrators, a known starting point and a built-in gravity model. The output axis is not likely to turn through more than a fraction of a minute of arc at any time; such motions are submicroscopic. The power leads are carefully designed linear spring

devices. The entire can is temperature-controlled for exact buoyancy and fixed sizes; it is magnetically shielded, made with press fits designed in advance to 20 microinches or less and sealed with special adhesives. The top spins in helium in its precise way for the few years of its working life, provided that it has been put together in an ultraclean atmosphere, checked for dust specks with a microscope (a few micrograms of extra weight is too much) and designed and built by a team whose experience is reflected in the curves showing the steady evolution of lifetime and performance over the past 20 years.

Such virtuosity in the paths of Newton, Maxwell, Whitworth and the metallurgists is genuinely remarkable. No matching wisdom in saving these gems of gyroscopes from being vaporized someday, along with our cities, is to be found in any current text.

THE OXFORD BOOK OF FOOD PLANTS. Illustrations by B. E. Nicholson. Text by S. G. Harrison, G. B. Masefield and Michael Wallis. Oxford University Press ($11). THE DOMESTICATION AND EXPLOITATION OF PLANTS AND ANIMALS, edited by Peter J. Ucko and Geoffrey W. Dimbleby. Aldine Publishing Company ($17.50). In *The Oxford Book of Food Plants* are 95 color plates, all done by Barbara Nicholson from the real plants of necessity, pleasure and indulgence. Each plate bears half a dozen convincing and attractive paintings of the plants men eat—details of fruit or seed as well as views of the tall growing plant. They are as useful and entertaining for children and students as they are for the general reader curious to learn what mango and mangosteen look like.

For each plant shown, and for others not illustrated, the artist's colleagues have provided a few paragraphs of readable text, giving a brief history and an account of use. Here is the beautiful heavy cluster of the deep red kernels of the oil palm, there the ugli fruit (a grapefruit-tangerine hybrid) and the West Indian akee (whose daring admirers scrupulously remove the pink tissue that joins the creamy white flesh to the dark seed "as it is highly poisonous"). The staples are here: yams, millets, wheats, oats, peas, beans and barleys. The stock of the local greengrocer (the book shows many signs of its true English heart) is not forgotten; his turnips, potatoes and cabbages are all befittingly represented. Spices and flavorings from all the world are marshaled; there is a page of Chinese greens, including the yellow chrysanthemum, whose young plants go so well with crab ("to the Western palate, their flavour may seem rather strong"). No tobacco, hemp or poppy appears.

The second book is the report of a rich—might one say meaty?—London conference of a year or so ago, bringing geneticists, archaeologists and historians together to examine the great questions of the mutual domestication of *Homo sapiens* and his crop and herd species. The cereals, being self-pollinators, seem to favor genetic change and the isolation of strains under man's unconscious selection, compared with other families of useful plants. It seems certain that men first reaped without sowing. Even today in a wet year stands of wild wheat and barley covering thousands of acres yield fully half as much per acre as what the Turkish peasant gets from his best field. "Armed with a flint-bladed sickle, he [Jack R. Harlan] harvested enough wild wheat in an hour to produce one kilo of cleaned grain... twice as rich in protein as domestic wheat."

It was at the margins of such lands, the argument goes, that the settled cereal gatherers first felt impelled to sow, extending their range, pressing out more and more, committing posterity to support the new hamlets by the sweat of the brow. Thus the plant-breeding began, thus the cultivation, the new tools, the social division of lands, the fruit of the tree of knowledge. Root crops, such as yam or cassava, reproducing vegetatively, give no such genetic control; the tropical peoples who used them found less challenge. "It was the industrious and prudent grain farmer whose expansion created the peasant communities... on which the great civilizations seem to have been based.... Easy cultivation does not select for either foresight or industry." This tale is somewhat forced; it holds a familiar social Darwinism rather too close to the surface, and one expects truth to arise more from the input-output studies, annual rain-variation data, animal age-distribution censuses and other new techniques than from the brilliant but brittle hypotheses of the reflective expert.

The domestication of animals—mainly the ungulates—depends on achieving control of their breeding, a phenomenon much more complex than the parallel in plants. A sudden increase in the number of bones of young animals at a site has been taken as a sign of domestication. Yet it may represent only some technique of the hunter. Looking for real changes in the morphology of beasts is also chancy. The progeny of 36 Norway rats caught in the wild have been studied since 1919—more than 50 generations of domestication. The descendants of these captive grays remain much wilder than the white laboratory rat. They are bigger than their wild kin, but they are not very different. On the other side, there are people in the New Hebrides whose pigs have changed drastically. Ten or 20 percent of the males are hermaphrodite intersexuals: they have tusks but are sterile. The pigs are used only for sacrifices, and those with the proper reentrant tusks are almost a form of currency. The breeding sows have little value. This is a complex hard to predict from genetics.

The llama is a splendid animal—strong, hardy, thirst-tolerant, load-bearing and giving fuel, wool, hides and meat. (It is never milked.) The Inca armies moved with llamas supplying rations on the hoof. The lovely vicuña still remains wild. "Before mating it goes through an elaborate courtship ritual [that is] inhibited by captivity." Only the Romans seem to have achieved the controlled breeding of any mollusk. They reared big land snails for size, color and yield, says Pliny. The stock has not been maintained.

POWELL OF THE COLORADO, by William Culp Darrah. Princeton University Press ($2.95). It is just 100 years since the dynamo of a one-armed veteran was swept with his party through the rapids of the Grand Canyon of the Colorado. Then he returned to spend the winter season lecturing and seeking backers (he got $10,000 by Act of Congress in July, 1870) for a second and better-planned trip. This biography, close to the source materials and aided by many interviews with supporting players in Powell's drama, is reprinted for the centenary from the first edition of two decades ago. Powell is a proper hero for his times: he was national mapper, geologist, reformer, political spokesman before Congress for his science and founder of the great Bureau of American Ethnology. He traveled unarmed and unescorted as friend and equal among Hopi, Zuñi and Ute. He set the 100th meridian as the western bound of secure farming, and he preached irrigation, power and "local self-government by hydrographic basins." He knew that there was more land than water, and he sometimes diverted funds meant for irrigation surveys into topographic mapping.

This is a meaty and honest book, with excellent photographs, although it is not handsomely made. There are a couple of beautiful new books on Powell, but none is so matched to the breadth of his legacy for scientific Americans.

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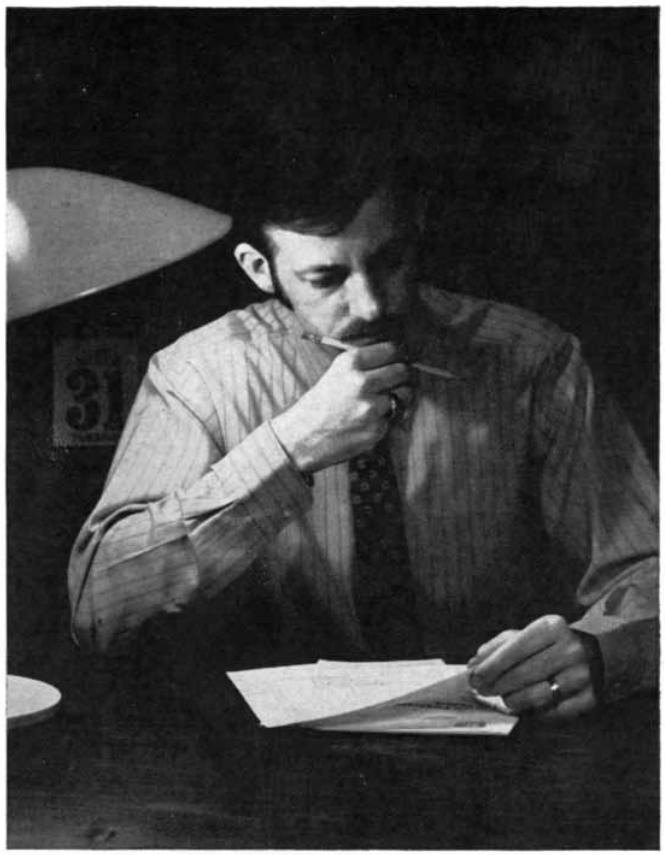

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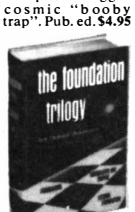

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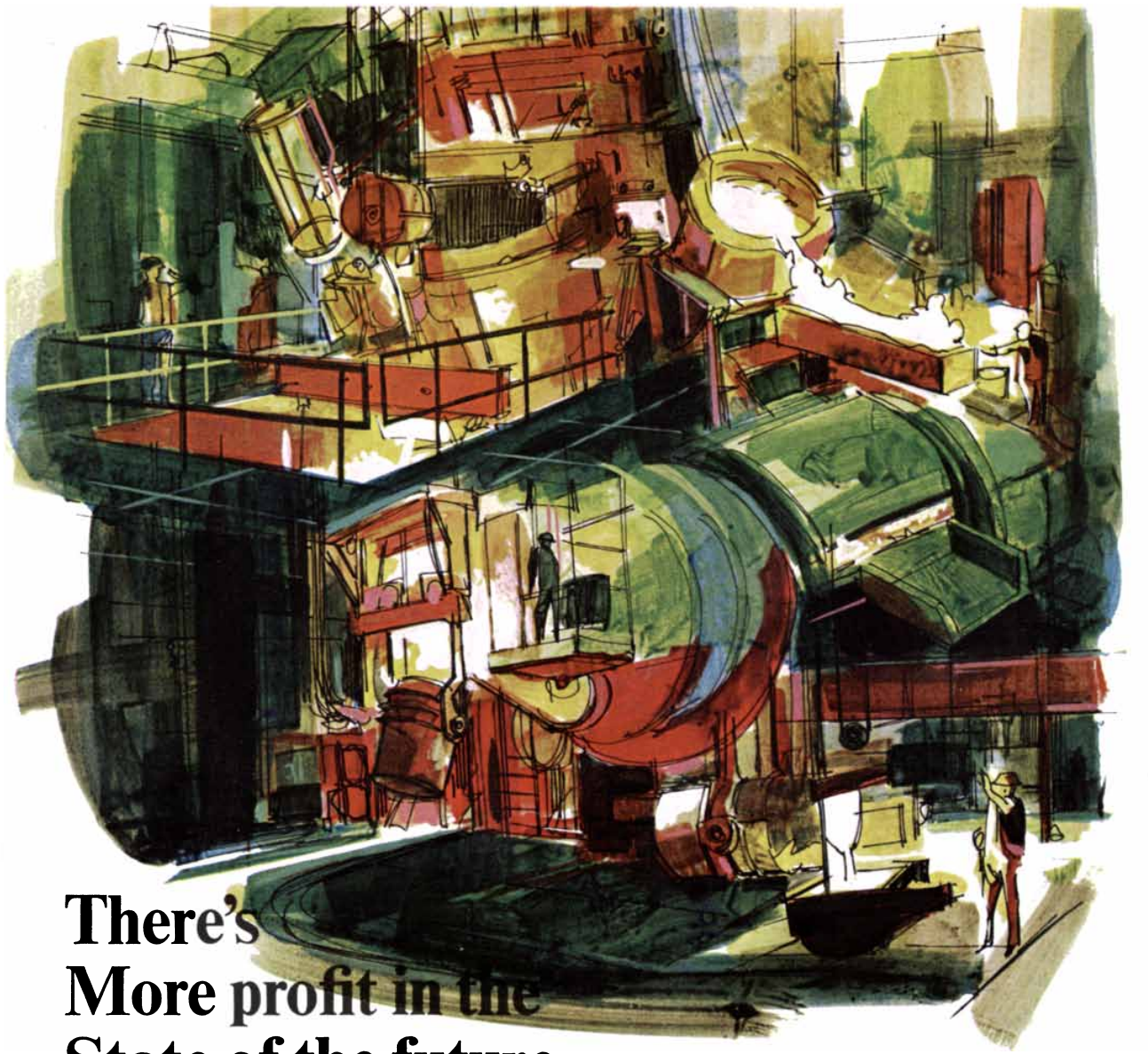

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