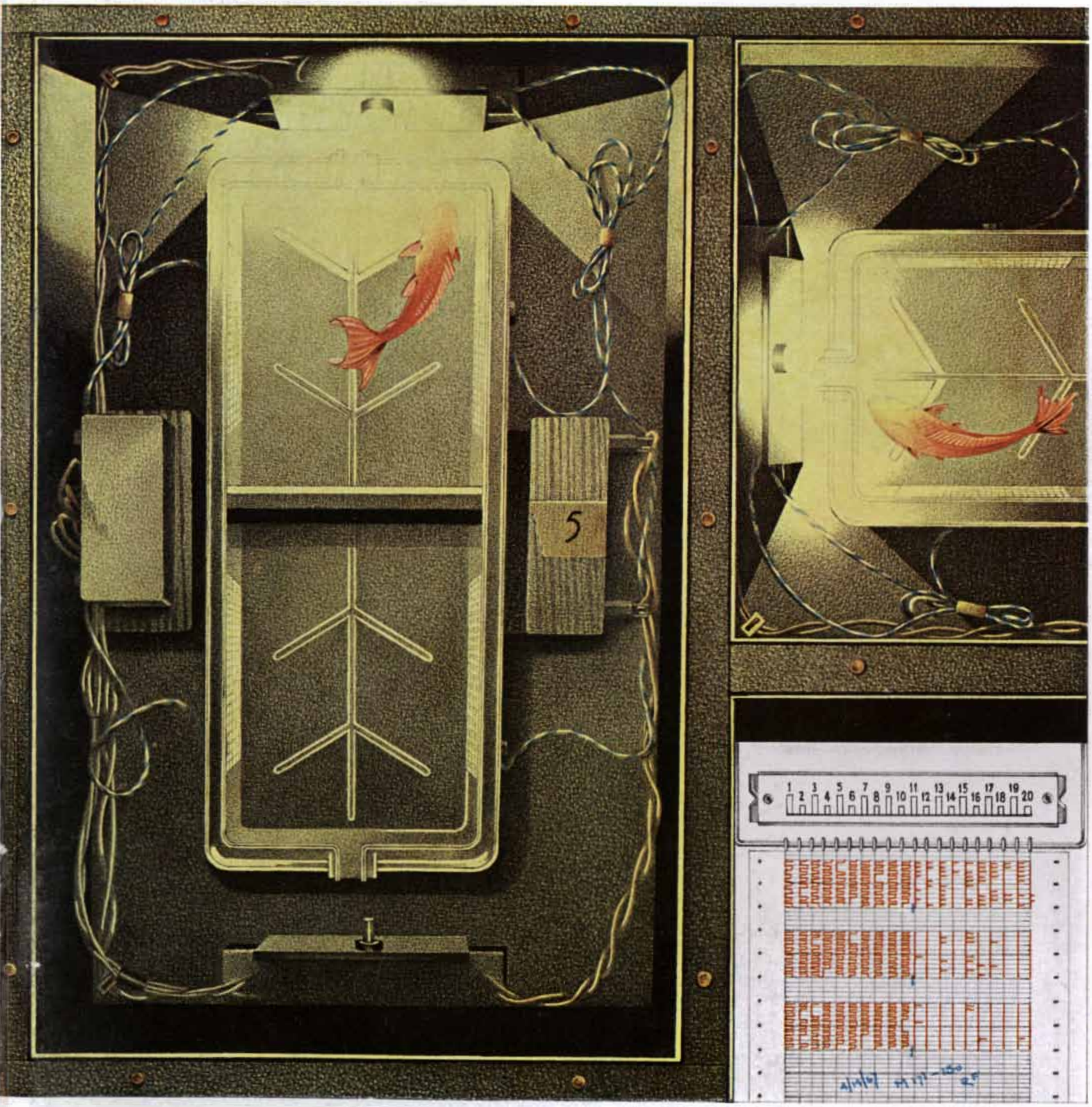
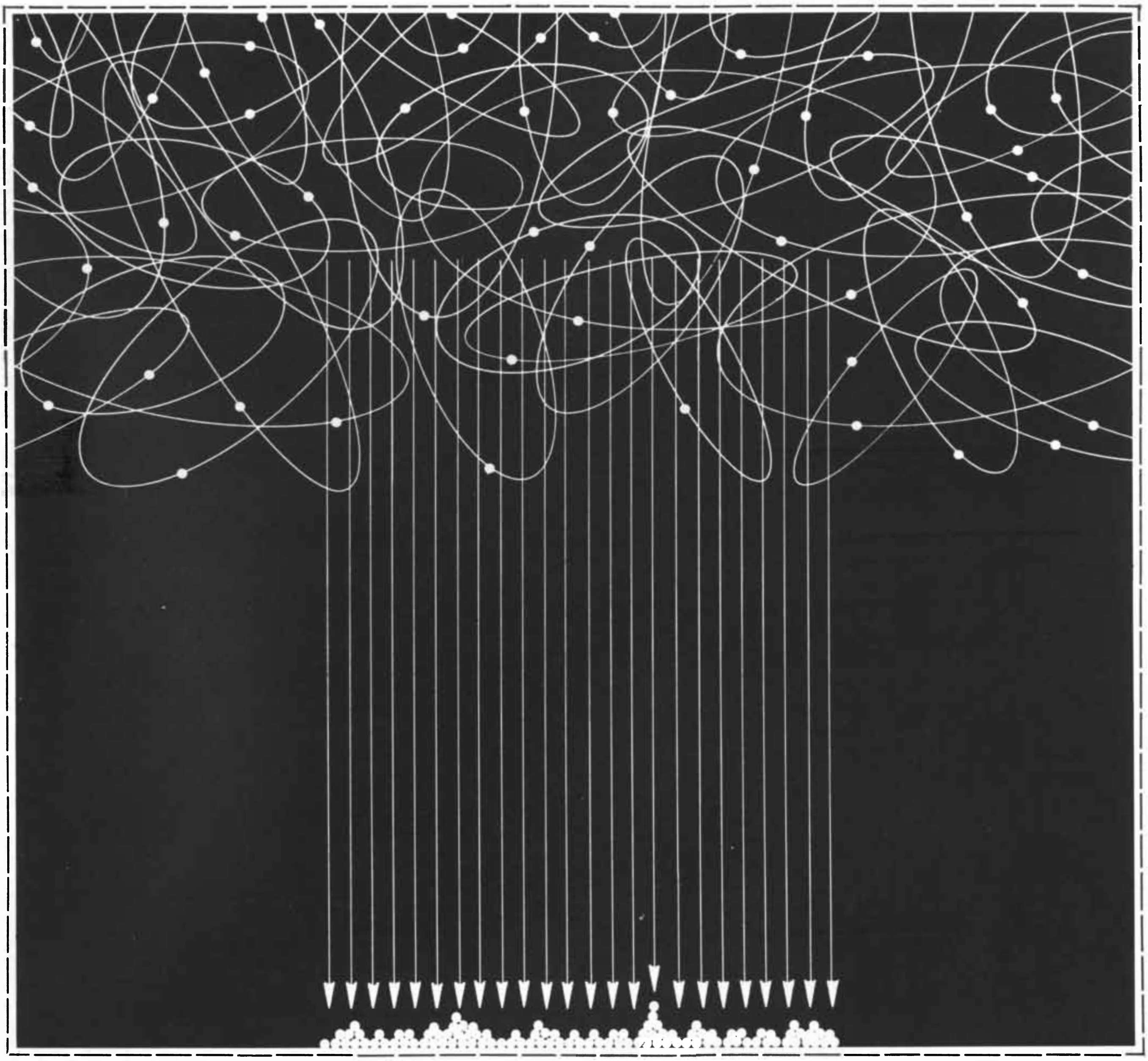
SCIENTIFIC AMERICAN



GOLDFISH IN TRAINING BOXES

SIXTY CENTS

June 1967



Scientists develop new Fourier analysis algorithm and test it with an earthquake.

Ever encounter a calculation that takes a long time to perform even on a large computer?

Richard Garwin of the IBM Watson Laboratory at Columbia University did when he decided to carry out a large Fourier transform problem in a spin calculation for solid helium 3 (He^3). With the programs then available he estimated at least four hours of high-speed computer time.

Garwin had a hunch there might be a better way. He discussed it with John Tukey of Princeton University and Bell Telephone Laboratories who proceeded to outline a computer algorithm which he thought would handle Fourier transforms far faster than existing programs.

Recognizing the potential and importance of the algorithm, Dr. Garwin took his notes to IBM's James W. Cooley at the IBM Thomas J. Watson Research Center at Yorktown Heights. A program development project was started, and in April, 1965 *Mathematics of Computation* published the Cooley-Tukey paper, "An Algorithm for the Machine Calculation of Complex Fourier Series."

For large N (where N is the number of terms in each Fourier series), conventional techniques of computation require a number of complex multiply-add operations proportional to N^2. With the fast Fourier transform (FFT) the number of operations is proportional to only $N\log_2 N$. The fast Fourier transform, therefore, increases the speed of calculation by a factor proportional to $kN/\log_2 N$, k ranging roughly between ½ and 2, depending on programming efficiency. On paper, it looked good. With the new algorithm much less computer time would be required to solve the large Fourier transform problem.

Then came the test to prove it.

Lee Alsop, an IBM scientist at Lamont Geological Observatory, decided on a direct comparison of the new algorithm with a conventional Fourier transform program.

For the test, he chose an earthquake that shook Rat Island, Alaska in 1965. Its seismograph record consisted of 2048 numbers representing longitudinal displacements at instants equally spaced over a 13.5 hour period.

To solve the problem, the conventional program took 1567.8 seconds.

The new Fourier analysis algorithm took only 2.4 seconds. But the test didn't stop there.

Having verified the greater speed of FFT, Dr. Alsop together with Dr. Ali Nowroozi then ran an accuracy check, using a time series generated from a sum of seven sines and cosines of harmonics of a base frequency. (This time, computer analysis took 464.4 seconds with the original program and just 1.2 seconds for FFT.) Then, by computing back again from the transform, the results of each program were compared to the original series.

FFT was both faster and more accurate. Even though this conventional program had been developed specifically for accuracy at a sacrifice of speed, the new FFT beat it. For scientists and mathematicians, it is a new, faster way to handle Fourier analysis. It can cut computer time by a factor of approximately $(\log_2 N)/N$. That's why the new algorithm is now part of IBM SYSTEM/360's Scientific Subroutine Package, a library of more than 200 mathematical and statistical subroutines available to IBM customers.

An interesting sidelight to this story is the fact that it was later discovered that the basic method had been proposed years before in a paper by Runge and König, published in Germany in 1924, and that its application was described in 1942 by Danielson and Lanczos who were working with X-ray scattering problems. Unfortunately the technique lay buried, and modern computers have been working at only a fraction of their potential speed on Fourier transform problems.

Like to know more about these programs? Write to Director, Scientific Development, IBM Corporation, Department 805-051, 112 East Post Road, White Plains, New York 10601. While you're at it, ask for a copy of the paper that gives the derivation of the algorithm. It's titled "An Algorithm for the Machine Calculation of Complex Fourier Series." We'll gladly send a copy.

IBM®

Established 1845 SCIENTIFIC AMERICAN June 1967 Volume 216 Number 6

ARTICLES

DEPARTMENTS

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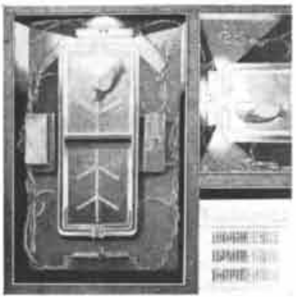

THE COVER

The painting on the cover shows two goldfish learning a simple task in the course of experiments on the mechanism of memory (see "Memory and Protein Synthesis," page 115). Two training tanks appear in the picture, one at left and the other at upper right. The training routine is controlled automatically; at lower right is a record of the results. Each training tank is divided into two compartments by the barrier visible in the middle of the tank at left. At each end of the tank is a light, and at the sides of each compartment are grids that can administer a mild electric shock to the fish through the water. The task to be learned by the fish is that when it is at one end of the tank and the light at that end goes on, it should swim over the barrier into the other compartment. If it does not, it receives a shock. The fish learn the task readily. This makes it possible to observe the effects of certain chemical substances on the fish's memory by injecting the substances into their skulls at various times before, during and after the training.

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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All About Abaca or The Truth About Teabags

Just about 63 years ago, a New York wholesale tea merchant named Thomas Sullivan accidentally invented the teabag. He was putting some tea samples into silk bags when one of his tea-loving customers tried dunking a bag into a pot of hot water . . . the rest is history.

After that chancy beginning, the teabag went through some lean days before its general acceptance by housewives. By the mid '40s, however, it had come into everyday use. Today, over 65% of all the tea consumed in the United States and Canada is sold in bags.

Until Dexter invented modern teabag paper in 1933, all sorts of substitutes were tried for Sullivan's original (and expensive) silk teabags. Cheesecloth, gauze and cellophane proved unsatisfactory. One manufacturer even tried punched paper formed into various shapes. The trouble was in the punchings. Either they were improperly cut and fell into the tea cup or they refused to drop out and therefore didn't allow the necessary infusion. Not to mention the annoying problem of tiny tea leaves that kept falling through even the smallest holes and would leave an unappetizing residue in the bottom of the cup.

The Long and Short of It

The problem, of course, was in the length of fibers in the paper being used. Short-fibered paper just wouldn't provide the necessary wet and dry strength, the porosity, the foldability or the ruggedness to stand up under steeping in boiling water.

Luckily for tea lovers (and Dexter) the knowledge of how to make a long fiber paper that met pretty near all these requirements had long existed. It had been uncovered by our ancient forebears centuries ago. But it had always had to be made by hand, sheet by sheet.

In 1933, after years of experimentation, Dexter solved the problem of machine-made long fiber paper. To do so called for a new type of papermaking machinery (all of which Dexter people designed or modified or made by hand) and for a very special type of basic fibrous material. This turned out to be Philippine abaca (you'd probably call it hemp). Actually the two are not at all the same, hemp being "cannabis sativa," while abaca is a product of the Philippine banana plant, commonly known as "musa textilis" and sometimes mistakenly confused with sisal, cantala, jute or sunn. Abaca is classified as a hard fiber.

Napoleon actually played a part in the availability of abaca as a prime fibrous material from which to make teabags. By shutting off supplies of Russian hemp (primarily used for cordage), the Napoleonic Wars (1789–1815) brought other substitute fibers like sunn into usage. Then, shortly after the war's end, an American Naval Lieutenant named John White brought a fibrous material called "abaca" home from the Philippines. Eventually, it replaced Russian hemp as a basic material for cordage manufacture.

The so-called hemp that Dexter used, and still uses, to make fine quality teabag paper has fibers typically ¼″ long with a diameter of 18 microns and a tenacity of 6 to 8 grams per denier, wet or dry. It is the strongest of all natural fibers and exceeds in strength all man-made fibers except ceramic and metal.

But Enough About Abaca

In short, with its perfection of machine-made long fiber teabag paper, Dexter pioneered a whole new industry (today it makes more than 60% of all the teabag paper used in the world).

If you ever really thought about teabag paper (most people don't), you'd realize that its manufacture requires some very sophisticated technologies. Because what a teabag really is, is not a paper but a complex filter which must not only keep the tea in . . . but let the flavor out.

And like the Swiss and the Swedes, a good teabag paper must adhere to a policy of strict neutrality. In other words, it can have no flavor of its own that would in any way affect the delicate nuances of a fine tea brew.

THE UNIQUE PROPERTIES OF TEABAG PAPER

	Non Heat-seal	Heat-seal	Benefits
BASIS WEIGHT (lbs./2880 sq. ft.)	7.25	9.75	Lightweight
CALIPER (inches)	.0017	.0036	Thin
AIR POROSITY (cfm/sq. ft. @ 0.5″ H_2O $\triangle P$)	550	350	High infusion rate
DRY TENSILE STRENGTH (grams/inch)			
Machine Direction	2825	2675	Excellent machin-ability
Cross Machine Direction	970	690	
WET TENSILE STRENGTH (grams/inch)			
Machine Direction	580	900	High wet strength
Cross Machine Direction	200	260	
MULLEN-BURST STRENGTH (psi)	6.0	5.7	Won't rupture
COST/Sq. Yd. (cents)	2.6	3.5	Inexpensive

AVAILABLE IN ROLLS FROM 1 TO 130 INCHES WIDE.

Today, the tea packing industry uses two high speed packaging methods for producing teabags from Dexter paper. In the oldest method, the bag is formed by folding the paper several times in several different directions and finally securing the top with a staple or staples. This must be done without the paper splitting or tearing. In addition, extreme care must be taken that the edges of the paper are perfectly square and do not weave. Otherwise, there would be difficulties during the folding machine's operation.

A more recent Dexter accomplishment was the development of heat-sealable teabag paper. This means that the bags are formed by heat-sealing the paper to itself along the edges of the desired pouch at a bag-per-minute rate of up to 350.

Another Breakthrough by Capable Dexter

In perfecting this paper, the trick was that the necessary heat-sealability could not just be applied to the paper . . . it had to be an intrinsic part of the paper itself.

The breakthrough came in 1945 when a technique for laying thermoplastic fibers onto an existing web was discovered. Again, this necessitated non-existent equipment which had to be invented and, at first, built by Dexter people.

Let's Hear It For Sullivan!

Back in 1904, Tom Sullivan did more than invent a neater way of making a good cup of tea. He not only revolutionized the entire tea industry, he also (we're happy to say) put Dexter into a very special kind of business . . . with a unique possession of some very special technologies.

"What's in it for me?" you say. Frankly, we don't know. Because if we do have a major problem as a company, it's this: telling people exactly what we can do for them. This is because we have a whole galaxy of capabilities that cannot be described briefly. And because we are constantly experimenting in new parameters that produce newer techniques and materials that keep broadening our know-how.

Another is that we don't have a lot of people available for following up dead-end inquiries relating to applications that don't have even a one-in-a-million chance of succeeding. What we do have is a small group of highly trained sales engineers who can bring our technologies to bear on genuine materials-in-design problems.

If you're interested, write to Glenn Werly, Vice President-Marketing, C. H. Dexter & Sons, One Elm Street, Windsor Locks, Connecticut 06096. If you can't remember the street address, that's okay. People around here know us . . . we've been in business for 200 years.

1767 – Bicentennial – 1967

C. H. DEXTER & SONS COMPANY
ONE ELM STREET, WINDSOR LOCKS, CONNECTICUT
DIVISION OF THE DEXTER CORPORATION

LETTERS

Sirs:

The article "Toxic Substances and Ecological Cycles" by George M. Woodwell in your March issue deals first with the distribution and lethal effects of radioactive fallout from the testing of hydrogen bombs. The author then states that "if it is difficult to estimate the nature and extent of the hazards from radioactive fallout ... we are in a poor position indeed to estimate the hazards from pesticides.... Our chief tool in the pesticide inquiry is DDT.... It is toxic to a broad spectrum of animals, including man." At this point the reader may well be prepared to equate DDT with strontium 90.

The toxicology of DDT and other pesticides is reviewed in a recent article (*Proceedings of the Royal Society*, Series B, Vol. 167, No. 101; February 21, 1967) by W. J. Hayes, who has studied the subject in depth for a number of years. He states that DDT has been consumed by human subjects at the rate of .5 milligram per kilogram of body weight per day for more than 600 days without any clinical effect. The largest nonfatal single dose was 285 milligrams per kilogram, part of which was vomited, and the median single dose with a clinical effect was 16 milligrams per kilogram. Of considerable interest is the observation that "workers who have been employed in the formulation of DDT since 1945 or even earlier... remain well while absorbing doses that for some are equivalent to 35 mg" per man per day. Hayes states that this is a dosage that is between 200 and 1,000 times as great as the exposure of people who eat "ordinary restaurant meals." Clearly the statement that DDT is toxic to man needs quantitative explanation.

What does the term "toxic to man" mean? Is it the effect of DDT on an isolated experimental subject or on human beings as a species? How does the term apply to human beings in India, where the use of DDT has been the principal factor in reducing the incidence of malaria from 100 million cases a year to less than 100,000 (P. C. C. Garnham, *loc. cit.* p. 134)? The main effect of pesticides is to increase the number of human beings; this increase exceeds all other factors in producing changes in ecology.

THOMAS H. JUKES

University of California
Berkeley, Calif.

Sirs:

As a manufacturer of DDT, I read George M. Woodwell's article "Toxic Substances and Ecological Cycles" with great interest and, I admit, some bias. While I have no quarrel with the mass of data he presents on the concentration of DDT in various organisms in the ecological cycle, I feel exception should be taken to his statement that DDT "is toxic to a broad spectrum of animals, including man." Indeed, his very next sentence, recalling DDT's "spectacularly successful [use] during World War II in controlling body lice and therefore typhus," offers evidence to the contrary, since hundreds of thousands of soldiers and civilians were dusted with large quantities of DDT without ill effect....

In view of the widespread public "belief" that DDT is toxic to humans, which Dr. Woodwell apparently shares, the paucity of supporting clinical evidence can only be considered surprising. During 1966 the Toxicology Laboratory of the Pesticides Program of the U.S. Public Health Service in Atlanta, Ga., undertook a clinical study of men with intensive occupational exposure to DDT. The group studied consisted of employees at the Torrance, Calif., plant of the Montrose Chemical Corporation of California. This plant has manufactured DDT continuously and exclusively since it was built in 1947, during which time it has produced almost 900 million pounds of DDT technical, as well as converting much of this to DDT dusts and liquid formulations.

From a group of more than 60 volunteers with over five years of heavy exposure to DDT, 35 were chosen who had been employed between 11 and 19 years and ranged in age from 30 to 63. In addition to analysis of their blood, urine and fatty tissue for pesticides (DDT, DDE, DDD, BHC and Heptachlor) they underwent complete physical examinations, routine clinical laboratory tests and chest X rays. High concentrations of isomers and metabolites of DDT were found in their fat (ranging from 30 to 647 parts per million) as well as in their urine and blood. Based on their storage of DDT in fat and excretion of DDA in urine, the average daily intake of DDT is estimated at 17 to 18 milligrams per man per day compared with an average of .04 milligram per man per day for the general population. In spite of these high levels of DDT, the overall clinical findings did not reveal any ill effects attributable to DDT and did "not differ significantly from those one might expect from a group of similar age and socioeconomic status with no occupational exposure to DDT."

During the 20 years our plant has operated we have not had a single case of occupational disease attributable to DDT, our employee turnover rate is well below that for the chemical industry in Southern California as a whole and our industrial accident rate is likewise below that for the State of California.

While no one would propose that DDT be sprayed indiscriminately or be prescribed as an elixir to assure a long healthy life, there is substantial clinical evidence that man can ingest considerable quantities over a long period of time without ill effects.

I have made no mention of the beneficial effects of DDT: lives saved, countless millions once debilitated by malaria enabled to perform useful work, forests preserved, crops protected, and so on. These facts are sometimes forgotten. True, the ecological process is changed, but change is part of life. The very fact that man's life-span has been extended by chlorination of his water supply, by vaccination and by chemicals such as DDT has resulted in a changed ecology. As Dr. Woodwell points out, we face a problem with many facets and all factors must be weighed before charting a course. It does not help to have scare

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words such as "toxic to man" thrown into the reasoning process.

SAMUEL ROTROSEN

Montrose Chemical Corporation
of California
Newark, N.J.

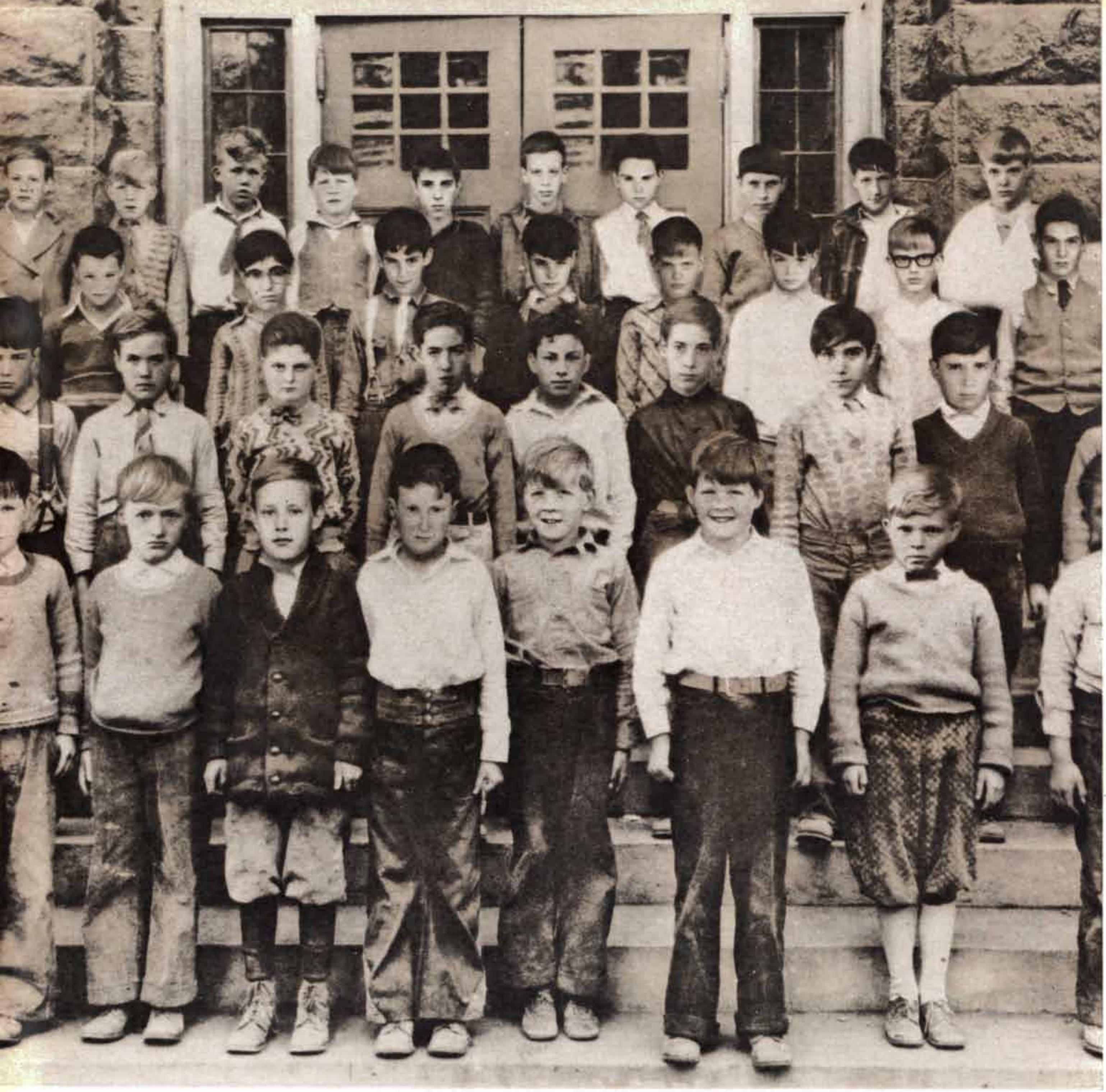
Sirs:

Messrs. Jukes and Rotrosen are correct in their contention that DDT's toxicity to man is low relative to other pesticides. It is, nonetheless, "toxic" not only to insects but, as I wrote, "to a broad spectrum of animals, including man." Its toxicology is far from simple and a discussion of it was beyond the scope of my article. DDT is a nerve toxin and clinical symptoms are correlated most closely with residues in the brain, not with those in fat. Residues may be stored in the fat of mammals for long periods and at comparatively high concentrations without obvious harm, as Mr. Rotrosen has indicated, but there is good reason to believe residues stored in fat are released when fat is mobilized during starvation or illness, increasing the danger of toxicity. DDT can be used safely in clothing against lice because in crystalline or powdered form it is not readily absorbed, either through the skin or the gut. Dissolved in oil, it is absorbed much more readily and the hazards of exposure are greater.

The point of the article, however, was not that current levels of DDT in human fat are toxic (there is reason for intensive interest in this, but no evidence that current levels are dangerous) but that the persistence of biologically active substances such as DDT that are distributed freely and in large quantities in the environment adds another important dimension to the hazards, including direct hazards both to man and to other organisms that are important to man. Messrs. Jukes and Rotrosen reflect what has become the classical approach to hazards from toxic substances, perpetuated by agencies treating public health, namely that the only important consideration is a direct, acute hazard to man. If man is protected, the rest of the environment will take care of itself. This attractively simple assumption breaks down when we find residues of substances such as DDT accumulating to levels that steadily degrade the environment....

G. M. WOODWELL

Brookhaven National Laboratory
Upton, N.Y.



Remember back in 1935? Just to get out of that stuffy classroom you'd even stand still for your class picture.

Remember that "sleepy" classroom air—air that was stagnant, humid and overheated much of the time?

On spring days, it was all you could do to keep awake after lunch.

And in the winter! Remember those iron monsters by the windows that hissed and gave off the steamy-wool smell of drying mittens? If you sat near one you broiled, and if you sat across the room from one you nearly froze.

But times have certainly changed. Today, ITT makes Nesbitt equipment for schools—for classrooms, offices, dormitory rooms, labs—that heats, cools or air conditions. When preset to a particular level, it "locks on" and maintains that level, no matter how much room conditions change.

This also goes for the Nesbitt rooftop multizone unit which is designed to take care of a number of areas at once—particularly areas where room size may be varied by using sliding wall panels or modular wall construction.

Now you know why Nesbitt components and systems are installed in more U.S. schools than any other climate conditioning equipment made today. (And we're doing quite well in hospitals and large buildings, too.)

International Telephone and Telegraph Corporation, New York, N.Y.

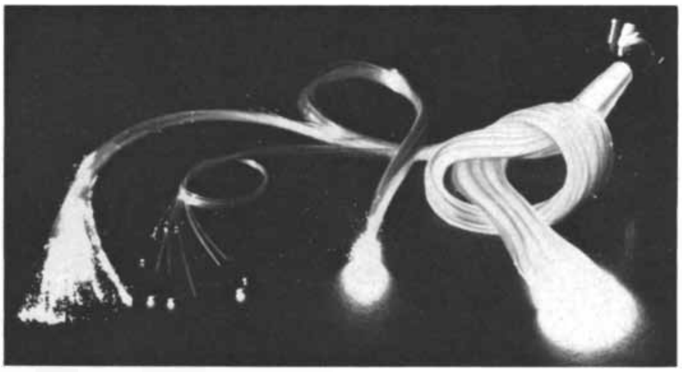
ITT

Photo: Hughes Aircraft Co.

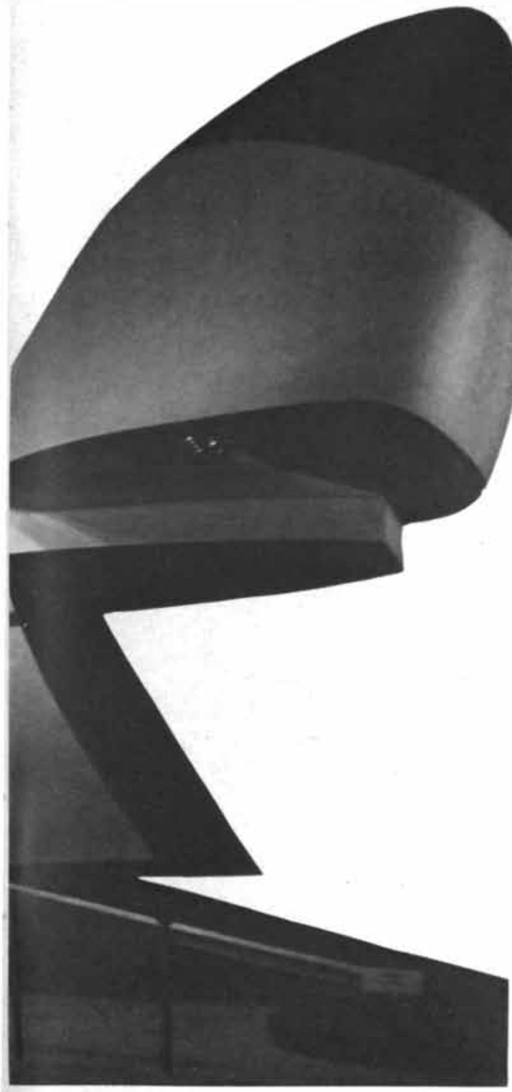
In electronics. With the help of a satellite and Bendix, the days of radio silence are numbered for transoceanic airliners. Recent large-scale tests using the NASA Goddard Space Flight Center ATS-1 satellite and jetliners equipped with Bendix systems demonstrated the feasibility of two-way, ground-to-airliner VHF communications via satellite relay.

In oceanics. Now we can tell you why the boat is rocking. The diver, for example, is positioning an ocean current measuring system developed in connection with our work on beach planning, pollution control and other aspects of ocean engineering.

In automation. This Bendix technician is holding a new kind of circuit that utilizes fluids instead of electricity. Bendix pioneering efforts in the new field of fluidics hold special promise for propulsion control, air data computers, automotive controls and automation equipment.



In automotive. Glass fibers that "pipe" light around corners form the heart of a new Bendix system that can tell a driver if each of his car's lights is working. A "pipe of light" visually connects each bulb to the dashboard.



The Bendix Corporation/Fisher Bldg./Detroit, Michigan 48202

Bendix

Where ideas unlock the future

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1917: "The last annual report of the Mount Wilson Observatory contains the interesting news that the mirror of the 100-inch reflector is now completed and silvered. The dome for the giant telescope is finished and painted, and the mounting was in course of erection at the end of the year."

"Another monarch has ridden to a fall, and a great stumbling block to the progress of the Allies on the Saloniki front has been removed by the abdication of the Greek king, Constantine, brother-in-law of the German Emperor. None can deny that Constantine was a man of capacity and political management. He was able to hold the greater part of the Greek nation and a good portion of the Greek army against the Allies, despite the fact that it was generally known that he had ordered the surrender of Greek troops, forts and military material to the Bulgars, that he had instigated the attack some time ago on French troops in Athens, and that he had encouraged, if he had not organized, guerrilla warfare in the rear of the Allies' army. His abdication has finally brought to an end what was an impossible military and political situation."

"Anthony Fokker's views of the future of aviation were recently published in the *Vossische Zeitung* in the form of an interview. The inventor and constructor of the famous fighting machine that bears his name said in part: 'Passenger traffic on flying machines will assume great importance after the war. Flying machines will have preference because they are the speediest means of traveling great distances. It is my belief that they will become the most successful rivals of American liners, being able to fly across the ocean within a day and a half or two days.'"

"The one great problem that is now most disturbing to the Allies' cause—and particularly to the United States, now that our country has entered the war financially as the creditor nation to all the others as well as an armed participant—is the present and future attitude of Russia, the unformed and apparently uncontrollable giant of the north. The revolution resulting in the deposition of the Czar Nicholas came as a surprise to many but in reality was in no way unexpected by those well informed. It was only the end of what has been in process of formation for the past 12 or 15 years. The first chapter was the outbreak of 1905 after the Japanese war, resulting finally in the first Duma, or representative assembly. This Duma was dissolved in view of its demands, although these were quite moderate in comparison with what has since been granted or assumed. Following these happenings with varying success, the popular movement culminated when it became evident in the present war that the Czar's government was either incapable of governing and defending the country, or was in secret alliance with the Central Powers. When it became evident that Russian defeat was inevitable, the Russian people took the government into their own hands and with this also they took the fate of the country. So far as law and order are concerned, conditions have shown little or no ability on the part of the leaders to cope with the present surroundings, although the latest happenings seem to indicate that one or more strong men have come to the front to direct affairs."

SCIENTIFIC AMERICAN

JUNE, 1867: "The prospects for a speedy completion of the Suez canal are not flattering. The original plan contemplated the running of a canal 260 feet in surface width and 26 feet deep, connecting Port Said on the Mediterranean with Suez at the head of the Red Sea, a course of about 96 miles. From recent and trustworthy reports it appears that the maritime canal has been partially excavated as far as Ismaileh, a distance of 48 miles, or just half the total length. For the first nine miles north of Ismaileh the canal is only dug to half its future complete width. Beyond this, for the remaining distance to Port Said, there are two channels, each one-third of the complete width, the center portion being left so that traffic may be carried on in the one channel while work is progressing in the other. The average depth throughout is only seven feet. Although interested parties have persistently published the most encouraging prospects, actually the main Suez canal, after seven years of labor and millions of money have been spent upon it, is now but about one-third completed, and at the present rate of progress fully five years must pass before it, as a commercial highway, begins to repay the funds which its protracted construction has absorbed."

"M. Berthelot pursues the new and wonderful line of achievement opened in the chemical creation of the products of organic life with unflagging zeal and steady progress. Having heretofore succeeded in forming acetylene by the direct union of carbon (4) and hydrogen (2), he has lately built upon this structure by the addition of oxygen (8), which makes the exact constitution of oxalic acid. Other carbides of hydrogen are oxidized with the same success, giving a variety of appropriate products. M. Berthelot's latest success has been the synthesis of toluene (carbon 14, hydrogen 8), produced by the addition of marsh gas (carbon 2, hydrogen 4) to benzine (carbon 12, hydrogen 6) with the elimination of two parts of hydrogen."

"A new gas engine, exhibited by Otto and Langen, has some interesting and perhaps valuable peculiarities. The piston is shot upward through the length of the cylinder by the explosion at its foot but does no work on this stroke, moving freely. The elastic pressure of the air against the vacuum thus formed stops the piston gracefully and sends it back with the whole force of the atmospheric pressure added to the weight of the piston, this time gearing into a pinion and doing good service."

"There have been numerous theories proposed to account for the production of mineral oils, among which the following is advanced by Professor Wilbur. He believes that oil has been formed from marine vegetation, just as coal has been formed from land vegetation. Seaweed has a large proportion of oily carbonaceous matter, and few persons have any adequate conception of the immense growth and deposit of this product in the ocean bottom every year. Each crop, after fulfilling its term of growth, becomes detached and sinks to the bottom, naturally accumulating in the hollows or pockets. As it is a received opinion among geologists that the eastern portion of the North American continent was once the bed of a salt-water ocean, the accumulated masses of seaweed, after being covered with deposits of stratified rock, might with probability be supposed to have eventually the form of a hydro-carbon oil."

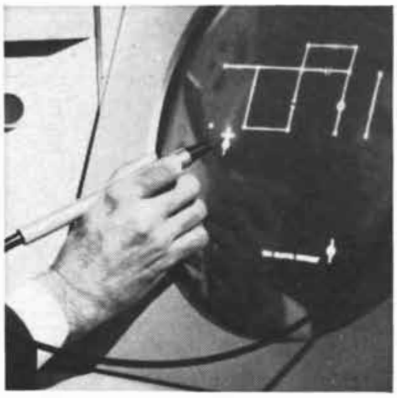
Report from

BELL LABORATORIES

Programming Complex Problems Simply

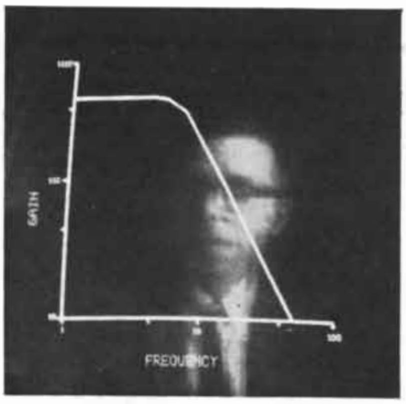
1. A program for GRAPHIC I lets engineer W. H. Ninke draw a circuit diagram on a cathode ray tube, using familiar component symbols.

2. In describing a circuit problem to the computer, he guides nodes (circuit junction points) into place with a light pen.



3. He next guides components into place. Where necessary, he can mark certain ones "variable" by placing a slant arrow across each.

4. With a keyboard, which resembles a typewriter, he inserts the values of the various components and the operating conditions of the circuit.



5. He asks the central computer to use this information to calculate and display a curve of gain vs. frequency response for the circuit.

6. Seeing the curve, he may modify the circuit, insert new values for variable components, request the computer to recalculate performance.

Scientists at Bell Telephone Laboratories have improved communications between engineers studying circuits and the computer that helps them. The key is an experimental console on which the engineer works with familiar graphics: component symbols, performance curves, and so on.

The engineer composes a circuit on a cathode-ray tube, inserts component values, makes certain components variable, as required. The display equipment responds immediately to his commands. As he proceeds, the console displays appropriate operating instructions. At his request, the computer calculates and displays circuit performance. He may adjust the variable components or revise the circuit and call for performance calculation again.

This sophisticated tool is not needed in routine circuit design. Its principal use will be where well established, highly automated design procedures do not exist—for example, when investigating effects of temperature, component tolerances, and stray coupling. The "conversational" ability promises to make this hardware-software system a valuable laboratory tool.

The console itself is GRAPHIC I, a man/machine computer terminal developed at Bell Laboratories. It includes a cathode-ray display, a keyboard for inserting letters or numbers, a light pen for selecting and positioning symbols on the tube, and a small display-control computer. Network analysis is handled by a separate large digital computer on a shared-time basis.

The circuit-analysis program is only one of several compiled for GRAPHIC I at Bell Laboratories. Others help generate integrated-circuit masks, design wiring patterns for magnetic-core logic devices, or retrieve documents. A special compiler (program for making programs) has been developed for GRAPHIC I. It is GRIN—for GRaphic INput.

Based on GRAPHIC I, a new generation of graphic terminals will be installed as part of an overall computer facility at Bell Laboratories.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

THE AUTHORS

J. HERBERT HOLLOMON ("The U.S. Patent System") is Acting Under Secretary of Commerce. He is an alumnus of the Massachusetts Institute of Technology, from which he received a bachelor's degree in 1940 and a doctorate in 1946. From 1946 to 1962 he was with the General Electric Company, progressing from metallurgist to manager of metallurgy to general manager of the general engineering laboratory. In 1962 he became the first to hold the post of Assistant Secretary of Commerce for Science and Technology, where his responsibilities include supervision of the U.S. Patent Office. Early this year President Johnson assigned to Hollomon the additional duties of Acting Under Secretary of Commerce. Hollomon organized and is chairman of the Commerce Technical Advisory Board, which he describes as a "significant but little known instrument for achieving good public policy."

P. J. E. PEEBLES and DAVID T. WILKINSON ("The Primeval Fireball") are assistant professors of physics at Princeton University. Peebles was graduated from the University of Manitoba and obtained a Ph.D. at Princeton in 1961. Wilkinson received bachelor's, master's and doctor's degrees from the University of Michigan. At Princeton their major concern is achieving a better understanding of gravity. They write: "Since gravity is such a miserably weak force in the laboratory, we have turned more and more to clues that might be uncovered on the much larger scale provided by geophysics, astrophysics and even cosmology." In their collaboration Peebles is the theorist, Wilkinson the experimentalist. They write that for outside activities Peebles "raises tropical fish and weird plants," Wilkinson "is active in the Unitarian Church and is a jazz fan" and "both enjoy beachcombing along the New Jersey shoreline."

RENÉ MILLON ("Teotihuacán") is professor of anthropology at the University of Rochester. He took all his degrees at Columbia University, beginning with a baccalaureate in 1948 and ending with a Ph.D. in 1955. His doctoral dissertation, "When Money Grew on Trees," dealt with the use of the cacao bean as money in Middle America before the arrival of the Spanish colonizers. Millon taught at the University of California at Berkeley from 1957 to 1961 and was a fellow of the Center for Advanced Study in the Behavioral Sciences in Stanford, Calif., in 1962–1963. Millon's work at Teotihuacán is supported by the National Science Foundation. His colleagues in the work include Bruce Drewitt of the University of Toronto, who is assistant director; George Cowgill of Brandeis University, who has done computer analyses, and Michael Spence of the University of Southern Illinois, who has analyzed obsidian. Ceramic chronology was developed by James Bennyhoff of the University of California at Berkeley.

RUTH HUBBARD and ALLEN KROPF ("Molecular Isomers in Vision") are respectively resident associate in biology at Harvard University and associate professor of chemistry at Amherst College. Miss Hubbard, who was born in Vienna, took a Ph.D. in biology at Radcliffe College in 1950 and since then, except for a year as a Guggenheim fellow in Copenhagen, has worked with George Wald (to whom she was married in 1958) in his laboratory at Harvard. Kropf, who was graduated from Queens College in 1951 and obtained a Ph.D. at the University of Utah in 1954, became interested in the chemistry of vision after hearing Wald lecture on the subject at the University of Utah. From 1956 to 1958 Kropf worked with Wald at Harvard, going to Amherst in 1958.

ALEXANDER LEMPICKI and HAROLD SAMELSON ("Liquid Lasers") are with the General Telephone & Electronics Laboratories, Lempicki as manager of the quantum physics group and Samelson as senior scientist. Lempicki, a native of Poland, was active in the Polish underground movement during World War II. After the war he studied at the Jagiellonian University in Cracow, the University of Rome and the Imperial College of Science and Technology in London. He received a Ph.D. from the University of London in 1960, based on work he had done in his present laboratory since arriving in the U.S. in 1955. Samelson, who was graduated from Columbia College in 1947, went on to graduate school at Columbia and obtained a Ph.D. in 1952. He was at the Bell Telephone Laboratories for two years before joining General Telephone.

SULLIVAN S. MARSDEN, JR., and STANLEY N. DAVIS ("Geological Subsidence") work at Stanford University; Marsden is professor of petroleum engineering and Davis is professor of geology. Marsden was graduated from Stanford in 1944 and received a Ph.D. in physical chemistry there in 1948. Before joining the Stanford faculty in 1957 he was with the Stanford Research Institute in California, the National Chemical Laboratory of India and Pennsylvania State University. During the academic year 1963–1964 he was visiting professor of petroleum engineering at the University of Tokyo. Davis was graduated from the University of Nevada in 1949 and obtained master's and doctor's degrees at the University of Kansas and Yale University respectively. He has been at Stanford since 1954, except for a year at the University of Chile. He writes that his outside interests include the growing of trees and "study of the interaction of science and pseudoscience."

PAUL R. EHRLICH and PETER H. RAVEN ("Butterflies and Plants") are respectively professor and associate professor of biological sciences at Stanford University. Ehrlich, who was graduated from the University of Pennsylvania in 1953 and received a doctorate in entomology from the University of Kansas in 1957, has been at Stanford since 1959. His primary interest is in the structure, dynamics and genetics of natural populations of animals. Raven, who was graduated from the University of California at Berkeley in 1957 and obtained a Ph.D. in botany from the University of California at Los Angeles in 1960, went to Stanford in 1962. His principal concerns are the biosystematics and evolution of the higher plants and their pollination systems.

BERNARD W. AGRANOFF ("Memory and Protein Synthesis") is coordinator of biological science in the Mental Health Research Institute at the University of Michigan. He holds a medical degree, which he received at Wayne State University in 1950, but he has worked mainly as a research biochemist. From 1954 to 1960 he was a research biochemist at the National Institute of Neurological Diseases and Blindness; he went to Michigan in 1960. For the past three years he has been engaged in research on biochemical aspects of the formation of memory in the goldfish.

O. R. FRISCH, who in this issue reviews *Niels Bohr: His Life and Work as Seen by His Friends and Colleagues,* edited by S. Rozental, and *Niels Bohr: The Man, His Science, and the World They Changed,* by Ruth Moore, is professor of physics at the University of Cambridge.

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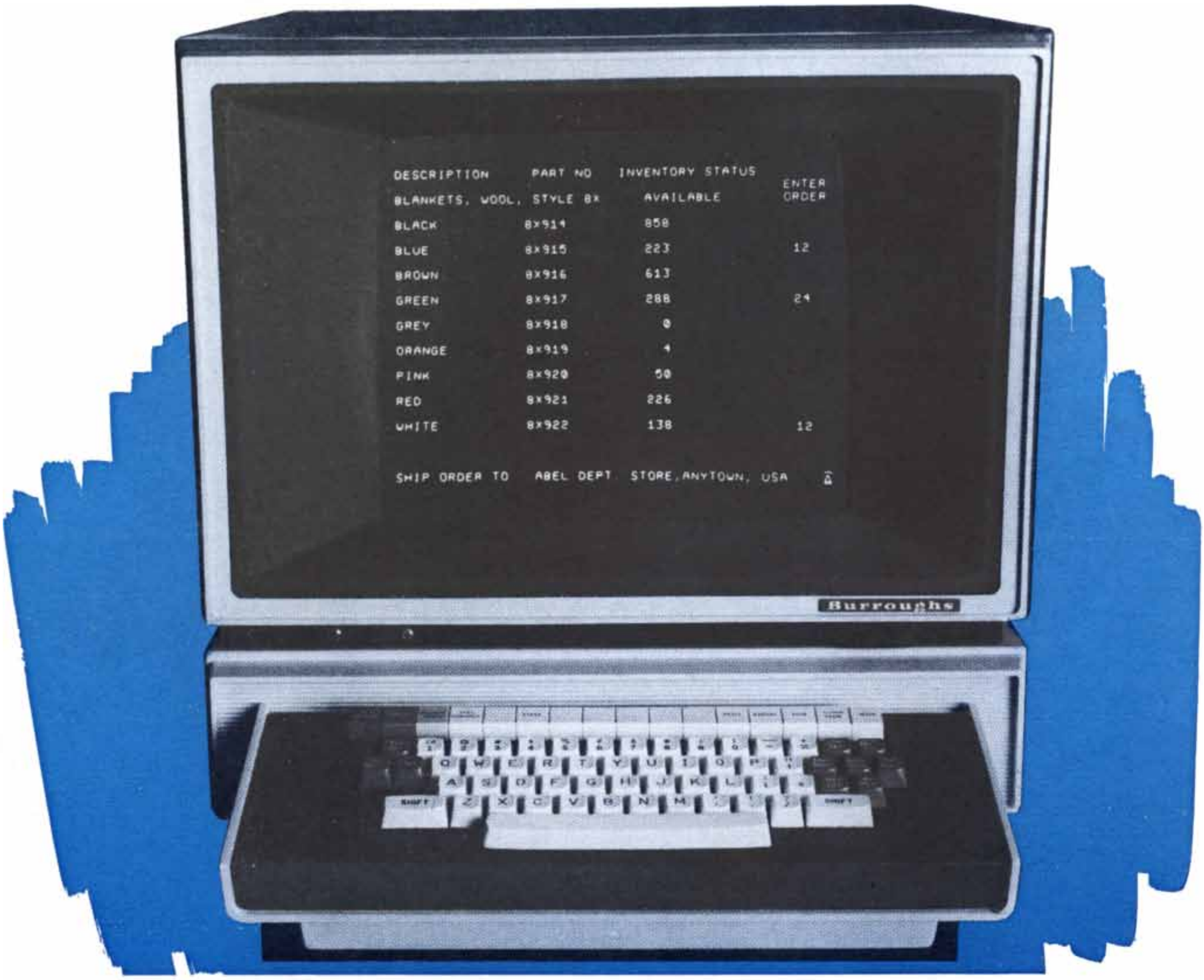

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Burroughs

Submarines at Work: A report from General Dynamics

For sale: Choice 400-acre plot west of Bermuda. Lat. 32° 06′N., long. 64° 04′ W. 250 fathoms *down*. Ideal for algae farming, fish grazing. Includes all water rights to surface and bottom mineral rights.

A *farm* at the bottom of the ocean?

Before this century is over, man will undoubtedly be farming, mining and manufacturing under the sea. With the world population growing and our natural resources shrinking, we will *have* to exploit the oceans for necessary food supplies and raw materials.

But before it happens, we must learn how to live and work in the strange and hostile marine environment.

Blue collar submarines:

A new breed of fish—the research submarine—has already begun the job of exploring and working in the depths of the ocean.

Unlike World War II submarines, which could dive to only a few hundred feet, research submarines will have to descend *thousands* of feet. And unlike bathyscaphs, which are essentially underwater elevators, research submarines move and maneuver under their own power and can perform a variety of jobs. In fact, "research" is a misnomer; they are really *working* submarines.

General Dynamics, which delivered the first submarine to the United States Navy in 1900, has already built five operational research submarines and is currently building three more. One of them, *Aluminaut*, an aluminum-hulled submarine built for Reynolds International, went mineral prospecting in 1966.

The boat searched for deposits of ore along the Blake Plateau, a section of the Continental Shelf stretching from Virginia to Florida. As *Aluminaut* travelled along the bottom, it scooped up samples of sediment and brought them up to the surface escort ship.

Doing the impossible:

Last year, two other research submarines built by General Dynamics—*Star II* and *Asherah*—performed jobs that had not been possible before. They inspected underwater cables, diving to depths and carrying photographic equipment that puts the job well beyond the capabilities of skin divers.

A cable does not always lie undisturbed on the bottom once it has been laid. It can be dragged by fishing nets and tidal currents; abraded and strained by rocks or sunken wreckage; and corroded by salt water and chewed on by sea life.

Star II, diving to depths of 1,050 feet, inspected and took more than 3,000 still photographs of 42 miles of underwater cable.

Asherah's assignment was to inspect a six-inch power cable that ran for seven miles along the bottom of Rosario Strait in the state of Washington. Before throwing the switch that would send electricity through the cable, officials of the Bonneville Power Administration wanted to know how the cable was oriented on the bottom.

Fitted with externally mounted strobe lights and floodlights, a 35mm. still camera and a television camera, *Asherah* followed the seven miles of cable, making a complete record of it on video tape and in still photographs.

Hunting the aku:

The aku, or skipjack tuna, is one of the mainstays of Hawaii's fishing industry. The annual catch of tuna in Hawaiian waters averages 5,000 tons—largely from netting fish near the surface. Some experts believe the yield could be as high as 200,000 tons a year if a key question could be answered: how deep do schools of tuna live?

In 1965, the research submarine *Asherah*, on loan to the Bureau of Commercial Fisheries, found the answer. In the course of diving to depths of 600 feet off Oahu, *Asherah's* observers discovered tuna much further down than anyone had expected. On the basis of this evidence, the Bureau outfitted a surface ship with sonar to locate and track deep-swimming schools of tuna. A General Dynamics study showed the feasibility of a research submarine fast enough and with sufficient endurance to follow oceanic fish and to discover their migratory habits and spawning and feeding grounds.

Fish talk:

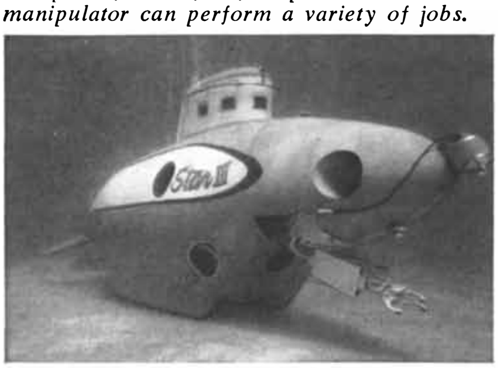
Research submarines have already extended our knowledge of rock and coral formations, the marine phenomenon known as plankton, and the habits—even the conversation—of fish.

Far from being silent, fish talk a great deal. During its dives off Hawaii, *Asherah* was able to record fish conversing in their cave homes. Fish talk has an immediate application to underwater telephone communication; the "chattering" of fish can be picked up, and distort human conversation.

In the summer of 1966, General Dynamics' *Star III*, diving off Bermuda, investigated an ocean phenomenon that sometimes plays havoc with sonar listening results: the deep scattering layer. This is a layer of plankton—organic and plant particles that small fish feed on.

Research submarines have also inspected the understructures and footings of offshore oil wells. There is a

STAR III can carry its two-man crew and 1,500-pound payload, including scientific equipment, to depths of 2,000 feet for up to 12 hours. Its manipulator can perform a variety of jobs.



ASHERAH was designed and built by General Dynamics for the use of the University of Pennsylvania Museum.

ALUMINAUT, built by General Dynamics for Reynolds International, has first all-aluminum hull and is the deepest diving submarine.

large market for submersibles capable of this kind of work.

And in 1964, *Asherah,* diving in the Aegean Sea off the coast of Turkey, photographed the hull and cargo of a sunken 5th century Byzantine galley on the sea floor. The submarine accomplished in one hour what would have taken skin divers weeks to do.

Ambidexterity:

Many first-generation research submarines have a single external manipulator, or "arm," enabling them to scoop up sediment or pick up objects from the ocean floor.

Second-generation submarines now under construction at General Dynamics will have considerably greater work and repair capacities.

These new submarines will have two manipulators, rather than one—each analogous to the human arm. That is, it has shoulder, elbow and wrist joints (see illustration at right). Fully extended, the manipulators have an 82-inch reach; when not in use they can be folded back against the hull of the submarine to improve its hydrodynamic motion through the water.

Interchangeable claw "hands" will allow new submarines to pick up objects as heavy as 100 pounds—or as delicate as an egg. Clamshell scoops enable them to collect mineral and marine specimens.

But their greatest advance over present manipulators is their power tool capacity. Detachable snap-on tools will enable them to cut cables, drill holes, install or remove nuts on equipment—and do a variety of other deep-sea construction and repair work.

Manipulators may be operated independently of each other or together, depending on the nature of the job.

With manipulators that approach the human arm in dexterity and control—and exceed it in reach, strength and versatility—the ability of research submarines to perform meaningful work will be dramatically advanced.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic, and communications systems; machinery; building supplies; coal, gases.

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The U.S. Patent System

The patent law both protects inventors and encourages the diffusion of inventions. The present law has not basically changed since 1836, and it is now proposed that new circumstances call for its revision

by J. Herbert Hollomon

Patents are widely regarded as being a means of protecting inventors. A patent gives an inventor exclusive rights to something he has invented and thereby enables him to share in whatever rewards the invention may bring. That is certainly one of the functions of a patent, but it is only a secondary one. The primary function is social: the society that issues the patent gains access to the invention. If there were no patents, the inventor would benefit most if he could exploit his invention while keeping it secret.

The correct order of priorities is reflected in the language of the Constitution, which gives Congress power to "promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." Congress implemented that provision in 1790 with the first U.S. patent law: "An Act to Promote the Progress of Useful Arts." The patent system that was thereby established, together with the patent systems of other nations, has contributed profoundly to the advance of technology.

Two years ago President Johnson appointed a commission (consisting of 14 leading businessmen, scientists, engineers, inventors and lawyers) to review the U.S. patent system, which had remained basically unchanged since a revision of the original system by Congress in 1836. Reporting last December, the commission said it had agreed unanimously that "a patent system today is capable of continuing to provide an incentive to research, development and innovation." The commissioners added that they had "discovered no practical substitute for the unique service" rendered by the system.

They were less satisfied with the procedures of the U.S. system, and they recommended a number of changes. On the basis of the recommendations the President has sent to Congress the Patent Reform Act of 1967. The act would make several fundamental and far-reaching changes in the U.S. patent system.

Patents originally applied to much more than inventions. The term comes from the Latin *litterae patentes,* meaning "letters patent" or "open letters." For 1,000 years sovereigns and other constituted authorities issued letters patent to proclaim the granting of a special privilege, franchise, monopoly, office, title or honor. Letters patent were used to pay off royal debts and to award court favors. They were also used to encourage voyages of exploration and to give grants of land; the Penn Charter issued by King Charles II to William Penn is an example. Letters patent were bestowed on towns and other groups in order to stimulate the expansion of finance and trade.

By the 16th century several nations were issuing patents that granted exclusive privileges of manufacture and sale to citizens who had invented new devices or processes. Two developments in England during the 17th century resulted in the establishment of principles that still apply to the issuance of patents for inventions. The first was the enunciation by Sir Edward Coke, the lord chief justice, of the principle that a patent on an invention was beneficial to society even though it gave exclusive rights to an inventor. Coke pointed out that since an invention is by definition something new, there was nothing for society to lose by granting a monopoly to the inventor; in that way the public would gain the use of the new invention.

The second principle arose because of patent abuses. Royal patents had given some court favorites and creditors monopolies over products that were not new. The fortunes made by people who had patent-based monopolies on such products as salt and paper caused public indignation and resulted in the establishment of the principle that a patent should be awarded only for a uniquely new device or process.

In the American colonies the colonial legislatures undertook to control patents. Most of the legislatures were quite restrictive in their patent practices. No exclusive rights were given unless they would be profitable to the colony; even when issued, the rights remained in effect for only a short time. An inventor seeking a patent had to obtain a special act of his legislature, which based its decisions more on service to the public than on reward to the inventor.

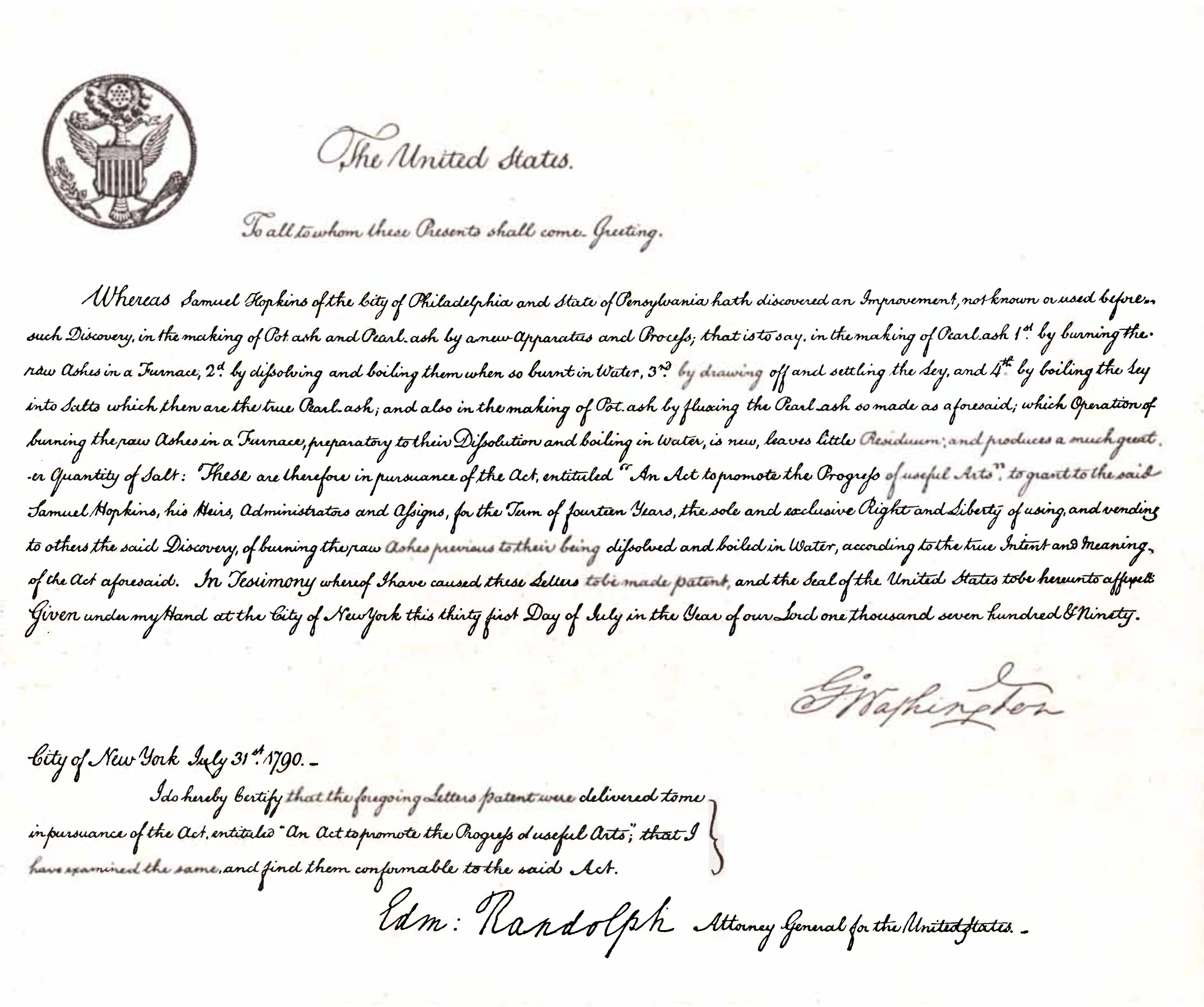
With the adoption of the Constitution the control of patents passed into the hands of Congress. The patent law of 1790 stipulated that patents would be granted for "any useful art, manufacture, engine, machine or device or any improvement thereon not before known or used." In the same year the first U.S. patent was issued to Samuel Hopkins of Philadelphia for "the making of Pot-ash and Pearl-ash by a new Apparatus and Process." Hopkins' patent was signed by President Washington, Attorney General Edmund Randolph and Secretary of State Thomas Jefferson.

In the beginning the requirements for obtaining a U.S. patent were rather simple. The inventor filed a written description of his invention, accompanied by drawings and a model, and paid the fee, which was about $5. For a brief period the Government undertook to establish the validity of inventions by examining each application before granting a patent, but such examinations were abandoned in 1793.

Eventually the lack of examination led to a multitude of conflicting claims. In 1836 Senator John Ruggles of Maine, chairman of a Senate committee appointed to investigate the patent situation, reported: "Many patents granted are worthless and void and conflict upon one another, and a great many law suits arise from this condition. Frauds develop. People copy existing patents, make slight changes and are granted patents. Patents have become of little value, and the object of the patent laws is in great measure defeated."

The result of the investigation was the patent law of 1836, which required that all patent applications be examined to determine the novelty of the claimed invention. That rule still prevails. So does the authority of the patent commissioner to require the submission of a model with a patent application, although the authority is seldom invoked because it became apparent years ago that the Government would be inundated with models. Patent models used to be a major tourist attraction in Washington; noteworthy models are still on display at the Smithsonian Institution.

Today the patent system is again laboring under difficulties, although they differ entirely from those of 1836.



The United States.

To all to whom these Presents shall come. Greeting.

Whereas Samuel Hopkins of the City of Philadelphia and State of Pensylvania hath discovered an Improvement, not known or used before, such Discovery, in the making of Pot ash and Pearl ash by a new Apparatus and Process; that is to say. in the making of Pearl ash 1st. by burning the raw Ashes in a Furnace, 2d. by dissolving and boiling them when so burnt in Water, 3d. by drawing off and settling the Ley, and 4th. by boiling the Ley into Salts which then are the true Pearl ash; and also in the making of Pot ash by fluxing the Pearl ash so made as aforesaid; which Operation of burning the raw Ashes in a Furnace, preparatory to their Dissolution and boiling in Water, is new, leaves little Residuum, and produces a much greater Quantity of Salt: These are therefore in pursuance of the Act, entituled "An Act to promote the Progress of useful Arts", to grant to the said Samuel Hopkins, his Heirs, Administrators and Assigns, for the Term of fourteen Years, the sole and exclusive Right and Liberty of using, and vending to others the said Discovery, of burning the raw Ashes previous to their being dissolved and boiled in Water, according to the true Intent and Meaning of the Act aforesaid. In Testimony whereof I have caused these Letters to be made patent, and the Seal of the United States to be hereunto affixed. Given under my Hand at the City of New York this thirty first Day of July in the Year of our Lord one thousand seven hundred & Ninety.

G Washington

City of New York July 31st. 1790.–

I do hereby Certify that the foregoing Letters patent were delivered to me in pursuance of the Act, entituled "An Act to promote the Progress of useful Arts"; that I have examined the same, and find them conformable to the said Act.

Edm: Randolph Attorney General for the United States.–

FIRST U.S. PATENT was issued in 1790 to Samuel Hopkins of Philadelphia. It said that he "hath discovered an Improvement, not known or used before," involving "the making of Pot-ash and Pearl-ash by a new Apparatus and Process." The patent was signed by President Washington and Edmund Randolph, Attorney General, and on the back by Thomas Jefferson, the Secretary of State.

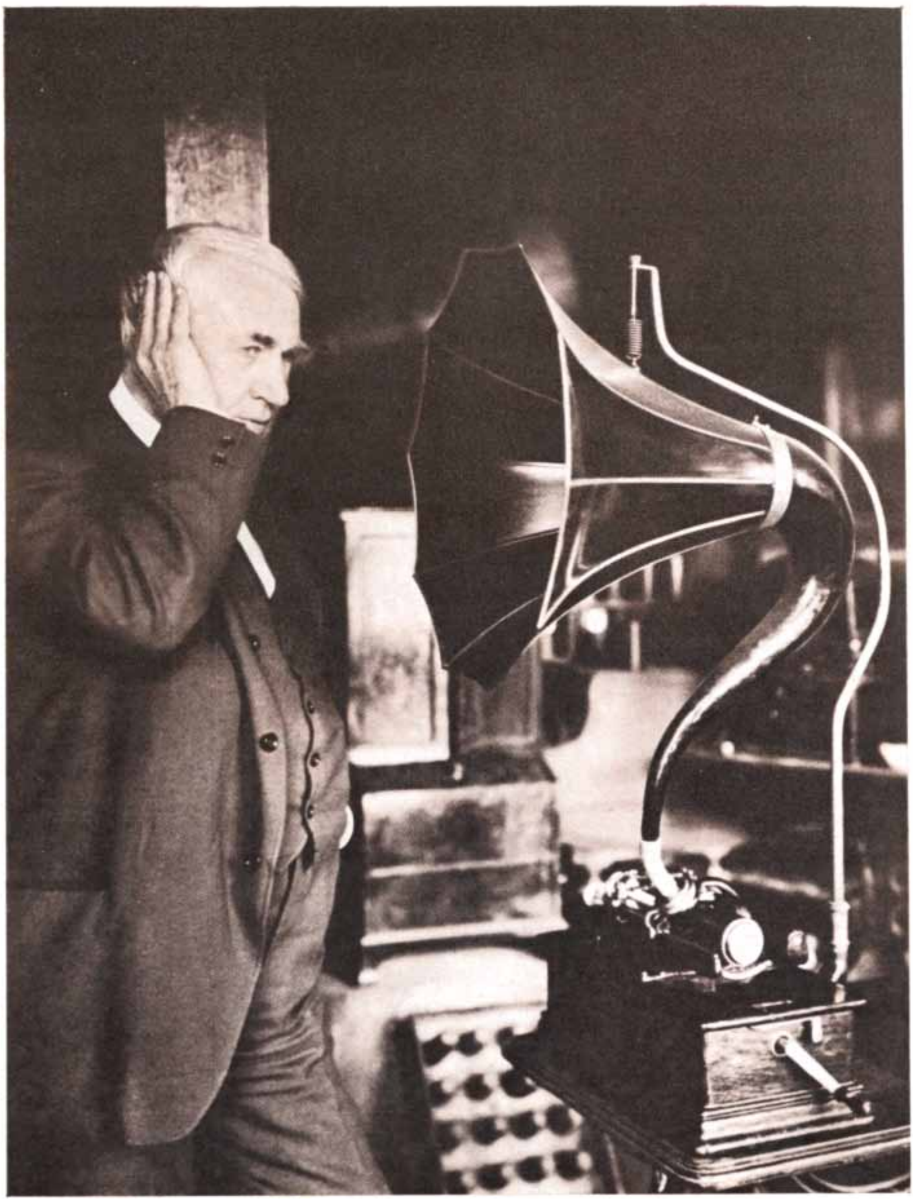
The present problems arise from the volume of patent applications, the expense an inventor frequently must incur to obtain a patent and the impairment of international trade that results from inconsistent patent practices among nations. In order to see these problems in perspective one needs to consider some of the philosophical and economic aspects of patent systems.

In this country a patent is defined by the Patent Office, which is part of the Department of Commerce, as a "grant issued by the United States Government giving an inventor the right to exclude all others from making, using, or selling his invention within the United States, its territories and possessions" for a specified number of years. A patent, then, does not give its holder the absolute right to do something; it gives him the right to prevent other people from doing something. The distinction is significant for two reasons. First, a patent does not provide immunity from other laws if in the process of putting an invention into practice the patent-holder comes into conflict with those laws. Like real property, intellectual property can be owned, used exclusively and protected, but it cannot be used to harm others or to deprive them of their rights.

Second, the issuance of a patent does not automatically mean that the state of the art in a particular field will be advanced or that the invention will be used or that someone will benefit by the new knowledge disclosed in the patent. Achievement of these objectives is the function of the process of innovation, which is quite different from and in some ways independent of the process of invention. The definition of the two terms is important. Invention involves the conception of an idea; innovation is the process by which an invention or idea is translated into actual use.

What a patent system provides, in the form of a patent, is a *quid pro quo* between the inventor and society. He receives a limited monopoly, which gives him an opportunity for financial reward if the invention is translated into commercial reality; hence the patent system provides him with an incentive to invent. Society receives the benefit of the inventor's insight. If one takes the long view, it is evident that the financial rewards obtained by inventors are more than offset by the society's gains from the enrichment of knowledge, the stimulation of technology and the growth of the economy.

These ideas were foremost in the minds of the men who wrote the patent provision of the Constitution. The same ideas provide the rationale of the U.S. patent system today. If technological progress was essential to the nation's expansion across the continent in the 19th century, it is clearly essential to the fulfillment of our aspirations today.

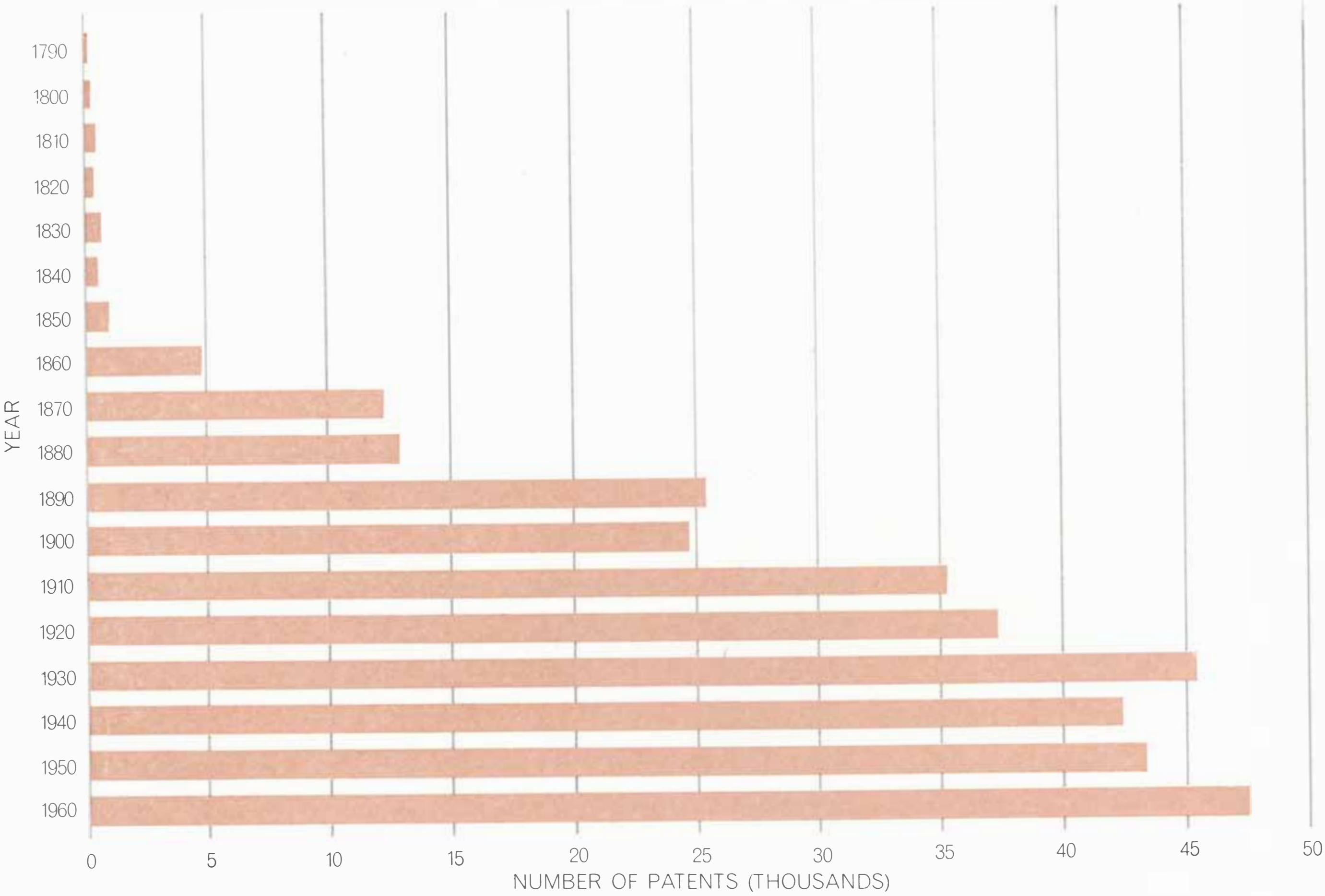


THOMAS ALVA EDISON obtained 1,093 U.S. patents, the largest number awarded to any single inventor. One of his inventions was the phonograph, to which he is shown listening.

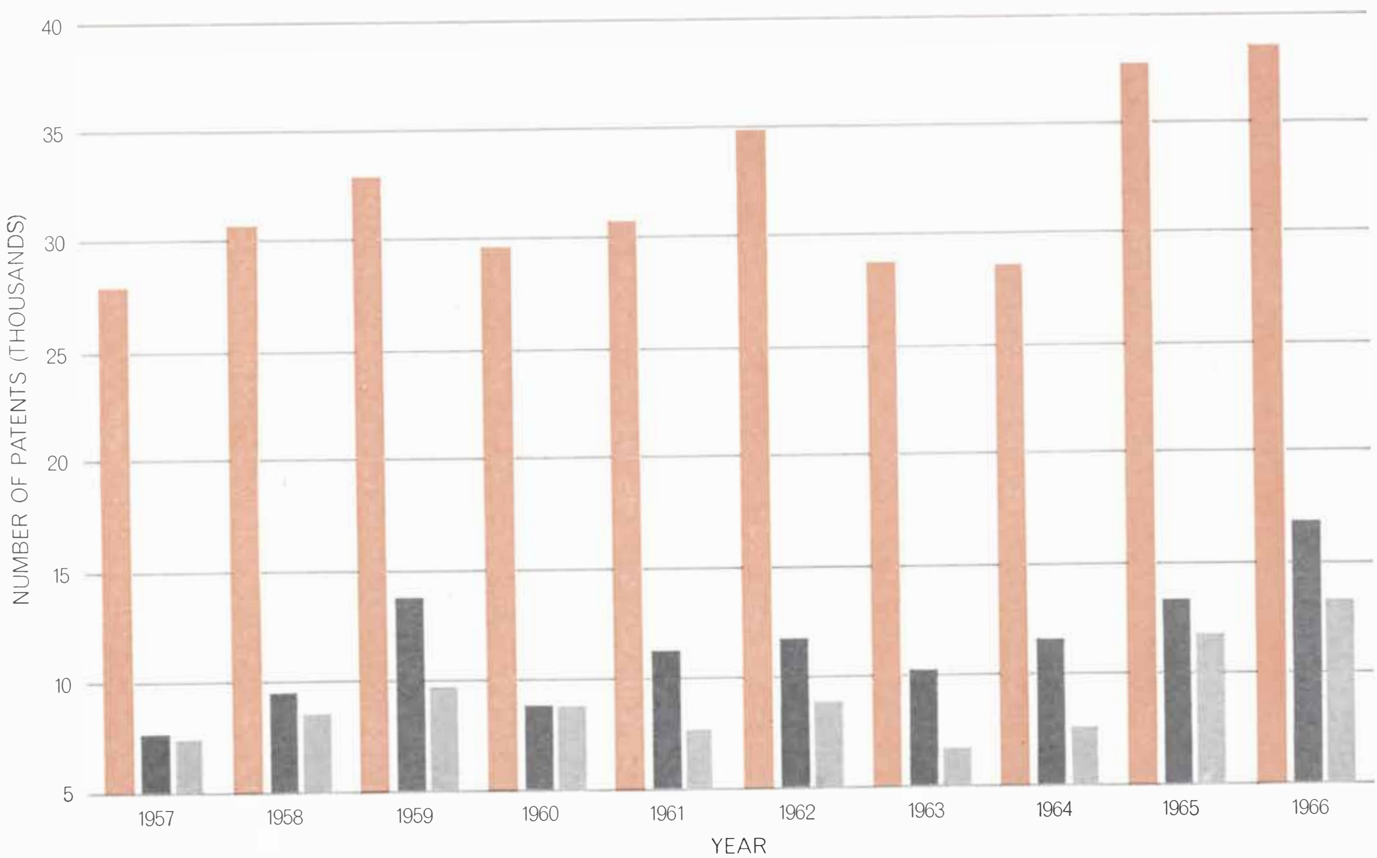
Let us consider another aspect of patents: the role of patents in the economy. Patents have an obvious importance to companies that have any degree of technological base. Beyond that three particularly intriguing questions present themselves. How effective are the processes of invention and innovation in commerce today? Are there significant differences related to the size of companies? Are there advantages or disadvantages for companies in certain geographical areas?

Billions of dollars are spent annually in the U.S. for research and development and for innovation. Nevertheless, the amount of detailed knowledge about the processes of technological change and economic growth is limited. For example, it is widely believed that the lone inventor, tinkering away in a garret or a garage, has become an anachronism. It is also thought that large companies, which conduct most of the private research and development in the country, obtain most of the patents.

The facts are that about 25 percent of the U.S. patents issued annually go to individuals and that half of the patents issued to private industry go to small companies. (Private industry receives about 70 percent of the patents issued; the Government and nonprofit institutions receive about 5 percent.) In this



NUMBER OF PATENTS ISSUED in the U.S. has grown rapidly since the establishment of the patent system in 1790 and reflects the rapid expansion of technology. Three patents were issued in 1790; in fiscal 1966 the Patent Office set a record by issuing 66,243.

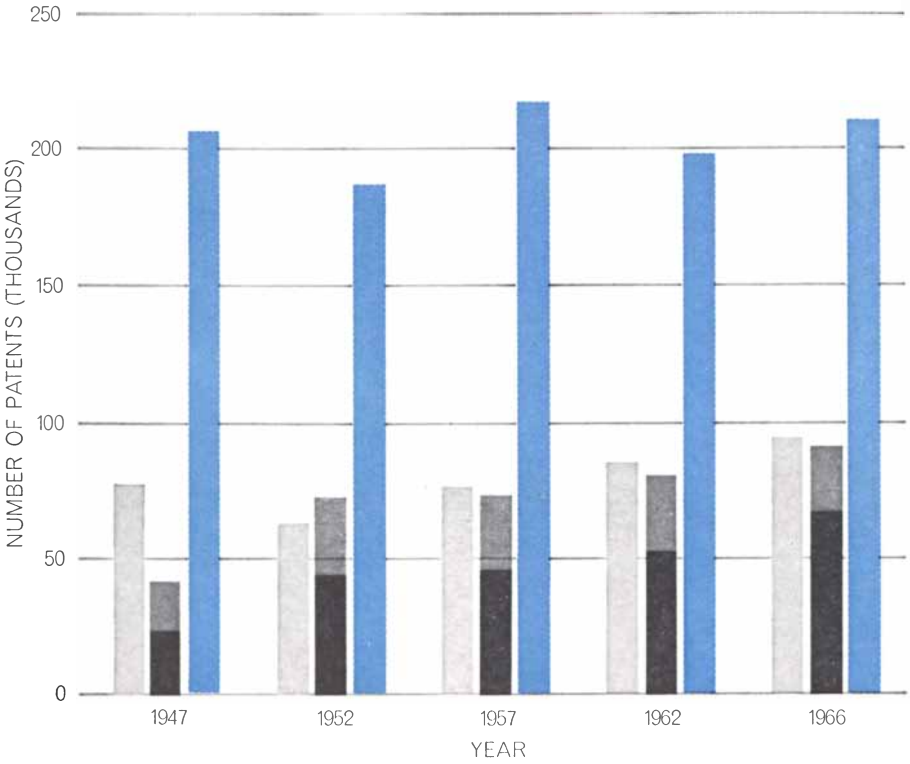


CATEGORIES OF PATENTS reflect changes in technology. Since 1957 the number of patents issued for chemical inventions (*dark gray*) and electrical inventions (*light gray*) has been rising in proportion to those in the category of mechanical inventions (*color*).

century alone individual inventors and small companies have made such outstanding inventive contributions as the vacuum tube, xerography, DDT, metallic titanium, the zipper, automatic transmissions, the gyrocompass, frequency-modulation radio, the self-winding wristwatch, the helicopter, power steering, air conditioning and the Polaroid camera.

John Enos of the Massachusetts Institute of Technology studied seven major inventions dealing with the refining of petroleum. He found that all seven were made by independent inventors. Merton Peck of Harvard University studied 149 inventions in the aluminum industry. Of the seven regarded as the most important, only one had come from a major producer of aluminum.

It seems evident that the record of individuals and small companies challenges large companies to make a better showing for their substantial investment in research and development. There are two ways in which the large companies might meet the challenge. They could explore new ways of working with small, technologically based companies. Alternatively, they could develop internal subgroups that would seek to develop the entrepreneurial spirit found in small companies while benefiting from the resources of the large company.



BACKLOG OF PATENTS pending in the Patent Office has been difficult to reduce because of growing work load. Backlog (*color*) is compared with patent applications (*light gray*) and finished cases, meaning patents issued (*black*) and applications abandoned (*dark gray*).

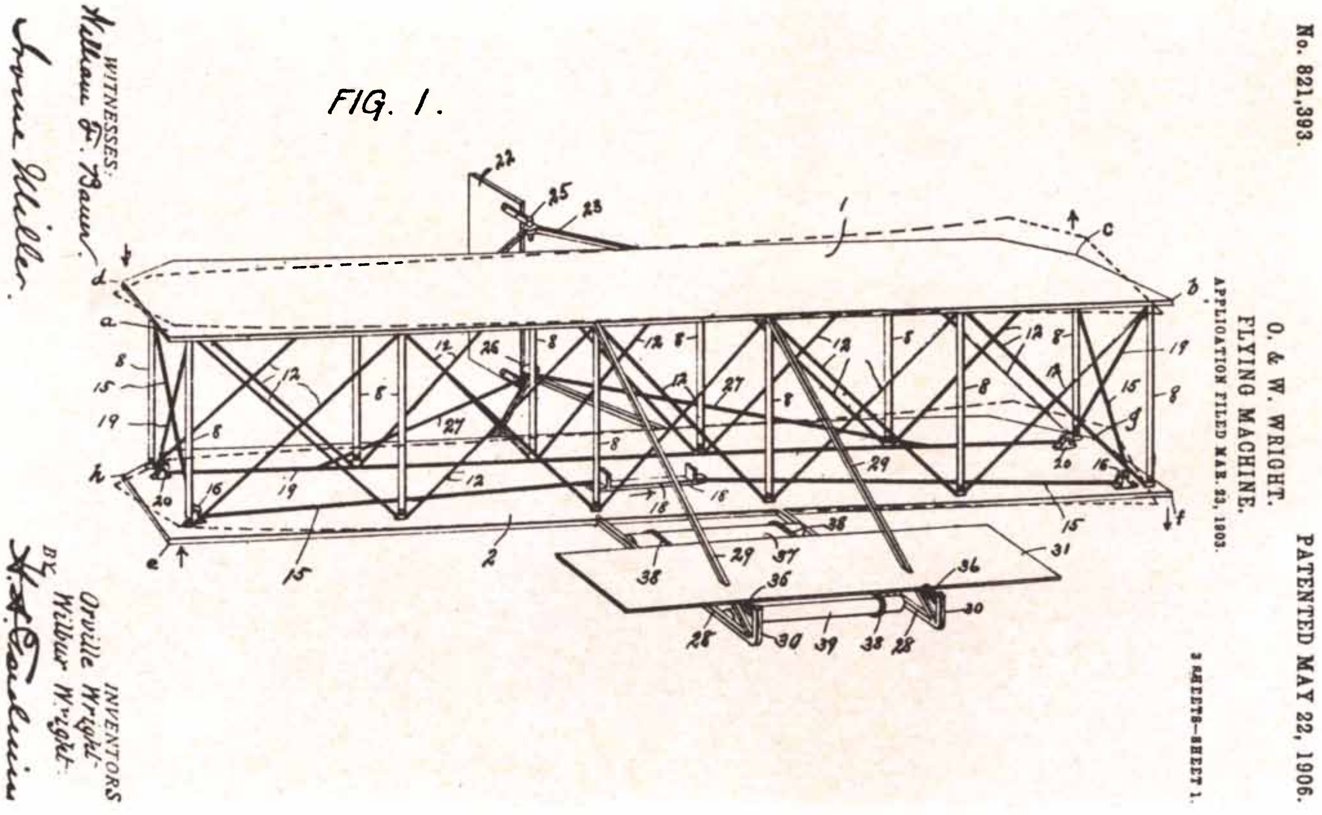
The question of the geographical distribution of patents was one of the matters investigated recently by a panel of 15 representatives of industry, the universities and several specialities of law including patent law. The panel, which was concerned with technological innovation and should not be confused with the President's Commission on the Patent System, was organized by the Commerce Technical Advisory Board of the Department of Commerce. The panelists found that some cities generate many more new technological enterprises than other cities do. Boston, for example, is appreciably ahead of Philadelphia.

Some light is shed on this particular disparity by a study made by the Federal Reserve Bank of Philadelphia; the data would seem to apply to a number of other areas. In the course of the study, executives of companies in Boston and Philadelphia were asked about the role of local universities in stimulating small, science-based firms and about the attitude of local banks toward financing such firms. Without exception the Boston respondents stated that local universities played an important role and that the attitude of local banks was good or excellent. In contrast, the Philadelphia executives replied without exception that local universities played a small role in stimulating technological companies; the attitude of local banks was described variously as "unreceptive," "poor" and "bad."

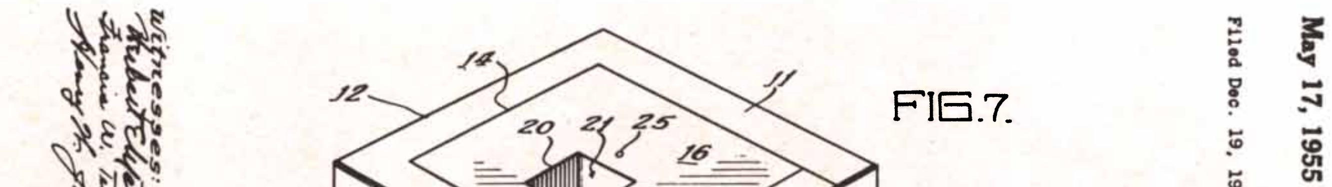
The data I have put forward suggest the description of an ideal environment for technological innovation. One requirement is a dynamic situation with regard to such variables as market needs, the level of income and the stage of economic development. In addition the environment needs (1) sophisticated sources of venture capital; (2) technical universities that feel comfortable in an entrepreneurial climate; (3) individual entrepreneurs who have been influenced by and can learn from other entrepreneurs, and (4) good working relations among these three elements.

Patents play a significant role in international commerce. A high production of inventions and patents reflects a strong and growing economy and enhances a nation's competitive position in international trade. The U.S. position in world trade is of vital importance, as is the continued strength of the American dollar, because much of that trade flows on the dollar. The U.S. is the world's largest trader. When it has a deficit in the international balance of payments, as it currently does, every trading nation is affected. The strongest single component on the plus side of the ledger is the American export trade, currently running at an annual rate of more than $30 billion per year. A significant portion of the exports consists of high-technology goods such as television, computers and aircraft. The high-technology content of American exports is reflected in the fact that more than 75 percent of the manufactured exports are produced by industries in which the hourly wage rates are above the national average for all manufacturing industries.

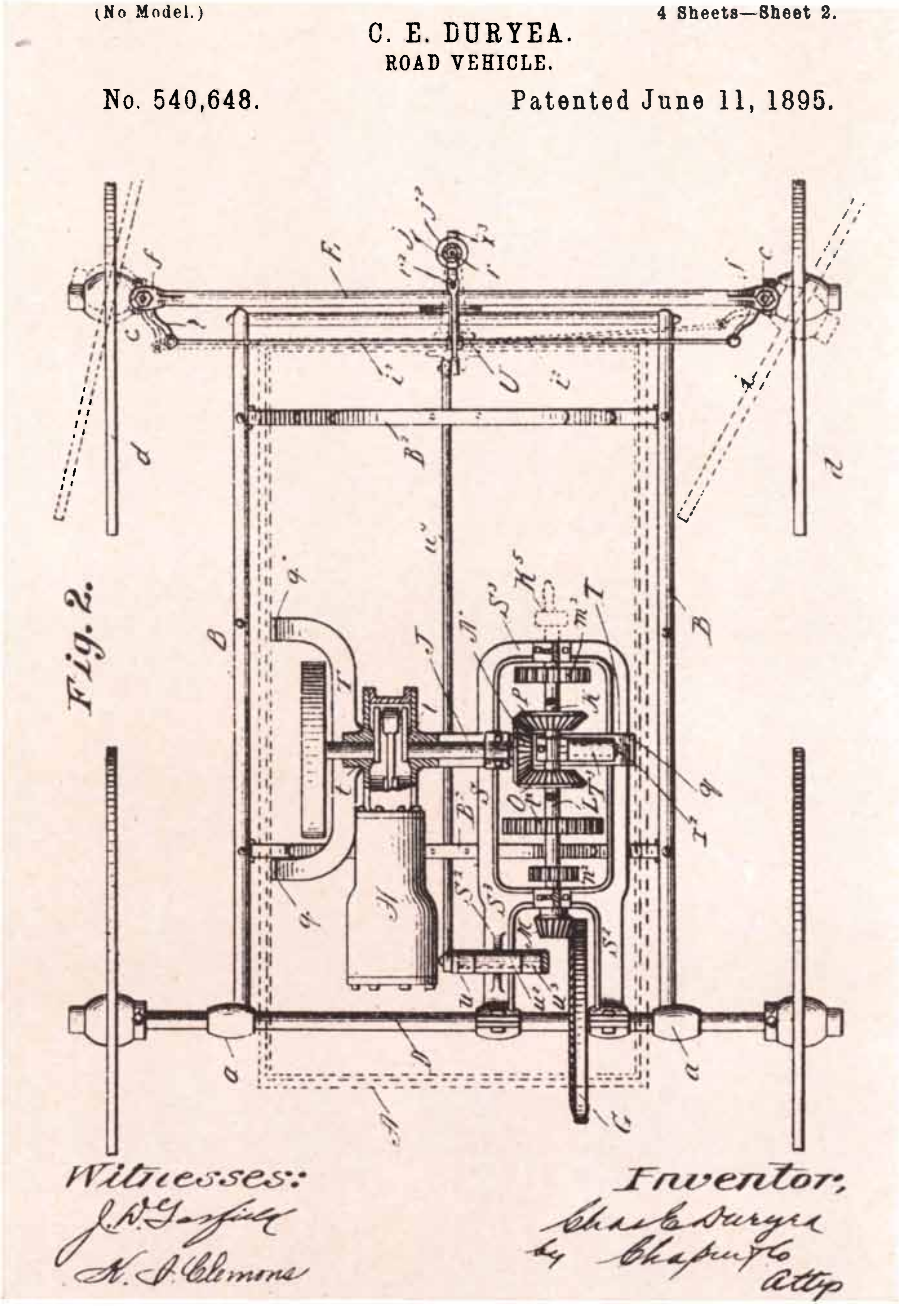
Patents enter directly into one element of the total balance of payments. This is in the technological balance of payments, a term used to describe the exchange among countries of payments for technical knowledge, patent royalties, licensing agreements and the like. A study by the Organization for Economic Cooperation and Development, covering the year 1961, showed that the U.S. paid $63 million for items included in the technological balance of payments and received $577 million from other countries. From the American standpoint this is a very favorable balance. Other nations understandably take a different view. To them, particularly the countries of western Europe, the deficit in the technological balance of payments provides further evidence of the "technology gap" they see between themselves and the U.S. The problem is complex



"FLYING MACHINE" was patented by Orville and Wilbur Wright in 1906. This is the first of five drawings they submitted to explain their invention; the numbers and letters are related to features of the aircraft that are discussed in the seven-page text of the patent.



"NEUTRONIC REACTOR" was the subject of a patent awarded to Enrico Fermi and others in 1955. They had applied for the patent in 1944; the delay was partly due to conditions of wartime secrecy. The drawing, one of 42 accompanying the patent, was described by the inventors as representing "a perspective view of a uranium-graphite reactor completely enclosed in a radiation shield."



"ROAD VEHICLE" was patented by Charles E. Duryea in 1895. It was designed for a gasoline engine, although the patent related to the suspension and gearing of the vehicle rather than the motor. The patent was the first for a U.S.-made gasoline-powered automobile.

and deserves a separate discussion of its own. It is noteworthy, however, that Japan, which has consistently run a deficit in its technological balance of payments, has at the same time achieved a rate of economic growth that any nation would welcome.

I believe the case for the importance of a patent system is clear. Against the background I have sketched, how effectively has the American system been operating? It certainly deserves good marks for effort; many important administrative and organizational improvements have been made in the Patent Office and in the system itself. The patent commissioner is limited, however, in the extent to which he can undertake such improvements. The procedural requirements outlined in the patent laws constitute one limitation. Another is that the commissioner, who is responsible for the quantity and quality of the Patent Office's output, has no control over the volume and scientific complexity of the input, which is in the form of patent applications.

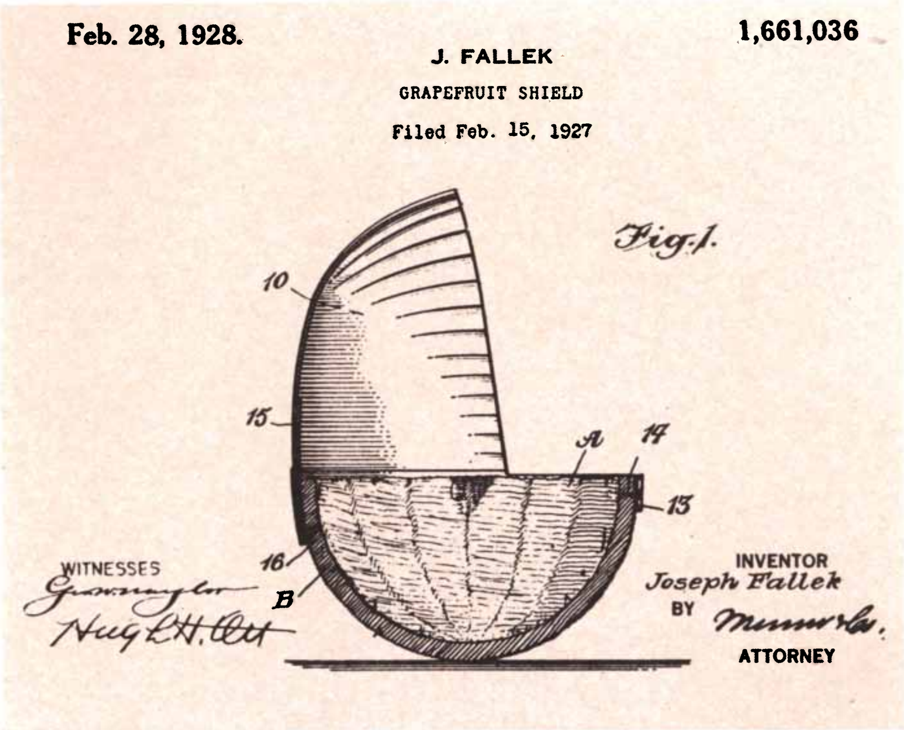
In terms of output, and given the existing limitations, the Patent Office falls short of maximum efficiency. The backlog of pending patent applications now stands at more than 200,000. Although in fiscal 1966 the office concluded action on 91,059 applications—issuing a record 66,243 patents—the number of new applications also set a record of 93,022.

The period between the filing of an application and the issuance of a patent now averages two and a half years. In a substantial number of cases the period is considerably longer. A recent increase in fees has raised the cost of obtaining a patent. The filing fee averages $85; the fee to be paid when a patent is issued averages $140. These are only the Government fees; most applicants also pay for the services of patent lawyers.

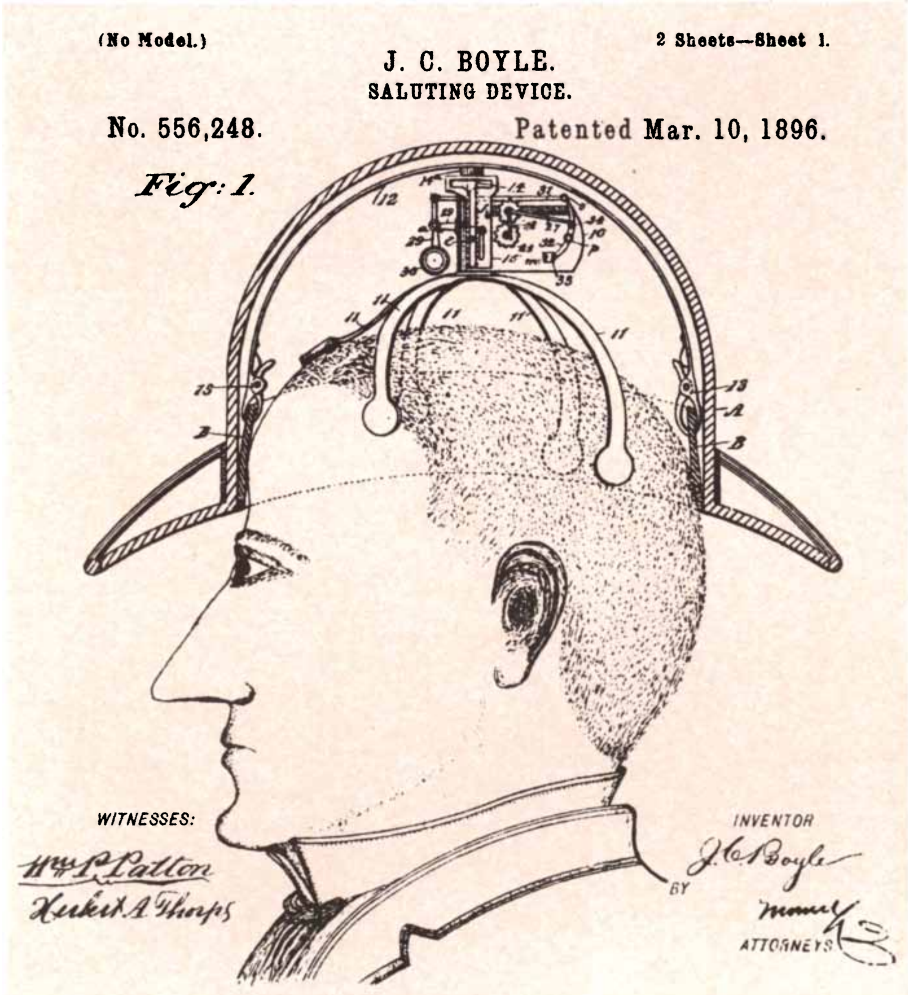
The fact that it now takes about three years to obtain a patent gives the patent system a bias in favor of large corporations. They have the resources for making certain before filing an application that their invention is new and patentable. They also have the resources for tooling up for a new process while a patent is pending. When the patent is issued, they can start to use the new process at once. They will benefit from the full term of the patent, which is 17 years from the date of issuance. An individual or a small company usually cannot make such extensive preparations and so may not be able to tool up until the patent is issued. The effective term of the patent is accordingly shortened by the time it takes the inventor to start benefiting from the patent.

A major difficulty confronting the patent systems of all countries arises from the fact that a patent confers protection only within the issuing nation. As a result every company interested in doing business abroad or desirous of protection from foreign competition against a patented product must apply for patents in several countries. The effect of this situation is that roughly half of the 650,000 patent applications filed throughout the world last year were duplicate or multiple filings of the same invention. The added burden on the patent offices of the world is staggering.

In 1965 American companies and individuals filed more than 100,000 patent applications in foreign countries, based on about 20,000 applications in the U.S. Foreign filings in the U.S. Patent Office that year totaled more than 22,000. It is estimated that in 1972 some 30,000 of the 100,000 patent applications that will be filed in the U.S. will originate abroad and will be duplicates of applications filed abroad. In turn 30,000 of the 70,000 applications originating in this country will be filed in an average of five foreign countries each, giving rise



GRAPEFRUIT SHIELD, patented in 1928, is one of many patented devices that never achieved much commercial success. It was intended to prevent the spattering of the juice.



AUTOMATIC HAT-TIPPER was patented in 1896. Described by its inventor as a "saluting device," apparatus was designed to enable a man to tip his hat without using his hands.

to an additional 150,000 worldwide applications.

In current international practice each of these applications will be independently searched and examined by each country requiring search and examination. Multiple filing has created what is referred to as the "international patent crisis." For the American inventor or company the practice can make the cost of obtaining sufficient protection in foreign countries run to thousands of dollars. A large company may find the expense tolerable, but an individual or a small business may not and will therefore be at a disadvantage.

The difficulties I have described are the targets of the proposals in the Patent Reform Act of 1967. President Johnson declared in transmitting the act that "its purposes are threefold: (1) to raise the quality and reliability of U.S. patents; (2) to reduce the time and expense of obtaining and protecting a patent; (3) to speed public disclosure of scientific and technological information." These changes, the President said, "will accomplish another important objective—they will bring the U.S. patent system more closely into harmony with those of other nations."

Probably the most significant of the many changes the bill would make is the establishment of a first-to-file basis for awarding patents. Under present law a patent may be issued to the first inventor, even if he is not the first person to file an application for a patent on the invention. When conflicting claims arise, a complex, costly and time-consuming "interference proceeding" is often necessary to determine who was the first inventor.

The President's Commission on the Patent System concluded that it would be far more equitable to award a patent to the inventor "who first appreciated the worth of the invention and promptly acted to make the invention available to the public." The change would permit the U.S. patent system to become compatible with the system of most other countries, thus contributing to the possibility of establishing an international patent system that would obviate the need for filing patent applications in several countries. A first-to-file system would also increase the quality and reliability of U.S. patents. In the present situation a patentee has to go through a period of doubt about his right to the patent because for a limited time the right can be challenged by anyone who contends that he made the same invention first. Even if the patent survives this period, it may be declared invalid by a court on the ground that the patentee was not the first inventor.

Another effect of a first-to-file system would be to encourage earlier disclosures of new technology. Suppose an inventor wants more time to tinker with his invention or thinks he would have greater commercial success by going on the market later. Under the present system he can delay his application for a patent with reasonable confidence that if another application is filed first, he can prove by records or witnesses that he was the first inventor.

To provide an inventor with a reasonable period in which to develop and test his invention the Patent Reform Act would permit him to file an informal technical disclosure of his invention at a nominal fee of perhaps $10. In this way he would establish himself legally as the first person to file for a patent on that invention.

The preliminary application and the first-to-file system together would reduce the time and expense of obtaining and protecting a patent. In addition to eliminating the burdensome interference proceeding the first-to-file approach would obviate the need for the elaborate record-keeping now practiced by sophisticated inventors and companies either to support their own patents or to use as a defense against the patents of competitors. To put the matter another way, the proposed system would remove the bias that now exists against individuals and small companies that are unfamiliar with the ground rules on what records will be most effective in proving that one was the first to invent something.

PATENT FILE in the U.S. Patent Office has copies of almost all U.S. patents. American patents were unnumbered until 1836; since then the U.S. has issued more than 3,250,000.

Under present law pending applications for patents are kept secret until a patent is granted. The bill proposes that a pending application be published 18 to 24 months after its effective filing date. The purpose of the change would be to speed the disclosure of new knowledge.

The term of an American patent now extends for a period of 17 years from the date of issuance. The proposed law would make the term 20 years from the date on which the application for the patent was filed. The present system encourages deliberate delays in the prosecution of patent applications, particularly those filed primarily for speculative reasons. Under the proposed reform an applicant would have an incentive to prosecute his application diligently; the change would help in the earlier disclosure of technology and also would bring the American patent system into closer conformity with foreign systems.

The final change I shall cite relates to the practice of examining applications for patents. An examination, which is made of every application, entails a search of technical literature and existing patents to see if the claimed invention is really new. An examination can take a long time. Moreover, the number of applications filed in a year usually exceeds the number of examinations that the Patent Office can complete during the year. For these reasons the examination system is the principal cause of the backlog in the Patent Office.

The proposed revision would provide standby authority for deferring examinations. An applicant could elect to have his patent application published immediately with examination deferred for up to five years. If by then neither he nor a third party had asked for an examination, the invention would go into the public domain unpatented. The change would reduce the work load of the Patent Office, because applications for patents on inventions that proved to have little economic significance probably never would be examined.

The Patent Reform Act has drawn some opposition, as might be expected with any proposal to make fundamental changes in a long-established system that has built up an elaborate structure of traditional practices. I would not argue that the act is the last word on patent reform. It does seem evident, however, that agreement on the need to modernize the patent system is virtually unanimous.

THE PRIMEVAL FIREBALL

The earth is bathed in radio waves that appear to have originated at the time of the primordial "big bang." This radiation provides the cosmologist with a rare new clue to the nature of the universe

by P. J. E. Peebles and David T. Wilkinson

Modern cosmology undertakes to substitute observational science for myth and speculation in dealing with such issues as: How did the universe originate? What is it like now? What will be its fate? Unfortunately the observational evidence is meager. There is a wealth of data but one becomes lost in detail; there is need for observations of simple and large-scale phenomena, the essential bases of theory. As a matter of fact, most contemporary cosmologies stem from just one such observation: Edwin P. Hubble's discovery that other galaxies are moving away from ours, and are doing so at speeds that are greater the more distant the galaxy. This general recession is the basis for such widely different concepts as the "big bang" cosmology (which holds that the universe originated in a superdense state some seven billion years ago) and the "steady state" one (in which the universe looks exactly the same through all time—past, present and future).

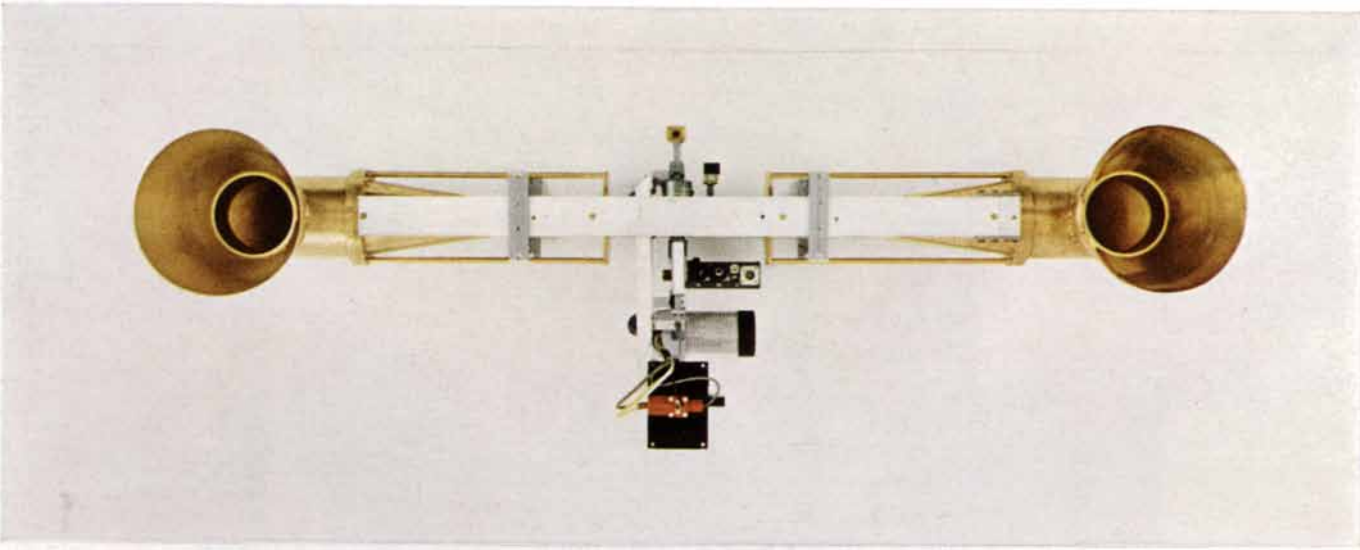
It now appears that radio astronomers have discovered another basic cosmological phenomenon that, like the recession of the galaxies, provides a view of the universe on a truly universal scale. It is low-energy cosmic radio radiation that apparently fills the universe and bathes the earth from all directions. Intense enough to be received by conventional radio telescopes, it has undoubtedly been detected, but not recognized, for years; indeed, it accounts for some of the "snow" seen on a television screen. When it was discovered by Arno A. Penzias and Robert W. Wilson of the Bell Telephone Laboratories about two years ago, they realized that it could not have originated in the earth's atmosphere or in our galaxy. It did fit in well, however, with an earlier suggestion by Robert H. Dicke of Princeton University that one ought to be able to detect a new kind of cosmic radio radiation: a "primeval fireball" of radiation surviving from the earliest days of the universe, when the universe was enormously hot and contracted. The theory and observation of this primeval fireball has been the subject of considerable work and excitement for us and several colleagues at Princeton: Dicke, P. G. Roll and R. B. Partridge.

The discovery and identification of this radiation must be considered a revolutionary development in cosmology. If, as we now believe, it is indeed the primeval fireball, it provides a view of the very early universe, just as optical radiation provides a look at the universe of more recent times. Our colleague John A. Wheeler has suggested an analogy: Compare man's observations of the evolving universe with the view downward from the observation platform of the Empire State Building. Street level corresponds to the beginning of the expansion of the universe. The most distant galaxy discovered so far then corresponds to a view down to the 60th floor, and the most distant quasi-stellar sources are at about the 20th floor. The fireball radiation is equivalent to a glimpse of something just half an inch above the street! With this expanded view of early events in the universe one may hope for a corresponding improvement in cosmological theory.

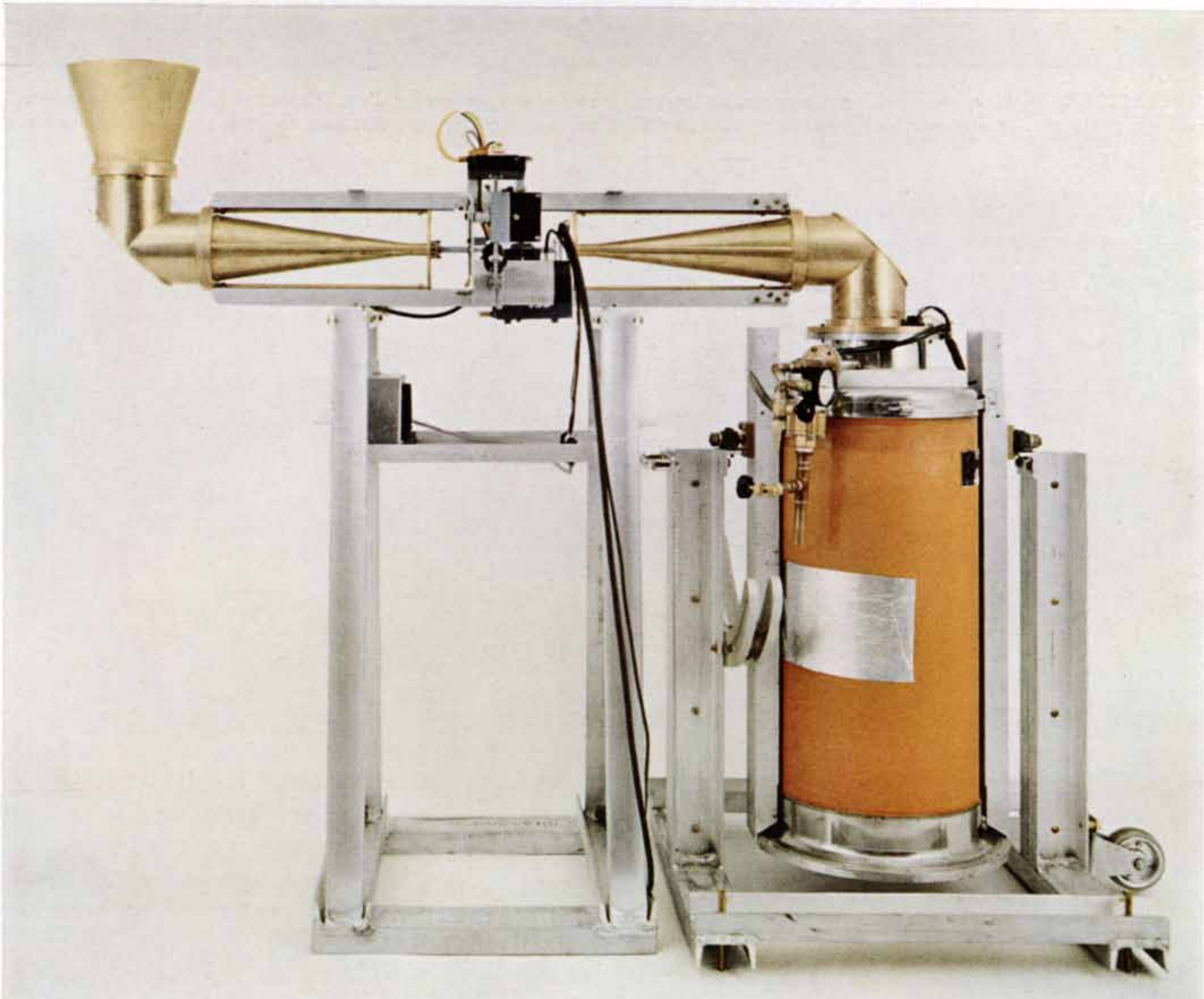
The concept of the primeval fireball is grounded on Hubble's observation of the general recession and the idea that flows from it: that the universe is in a state of rapid expansion. If this is so, according to big-bang theories at some time in the distant past—about seven billion years ago—all the matter in the universe must have been packed together in an inferno of particles and radiation. As the universe expanded out of this holocaust the matter cooled and condensed to form galaxies and stars. The radiation, which had started out as enormously energetic gamma rays, was also "cooled" by the expansion; its wavelength increased and it now appears mostly in the radio and microwave bands. The idea of a "fireball" dating from the big bang can be somewhat misleading, because what we have in mind is not radiation from some localized explosion off in one corner of the universe. The earth is immersed in this fireball; the radiation comes at us from every direction, and any observer anywhere in the universe should detect it as coming equally from all directions.

This is consistent with the basic theoretical framework developed between 40 and 50 years ago by Albert Einstein, Willem de Sitter, Alexander Friedmann, Georges Lemaître and others. Basic to the work of all of them was the picture of an evolving universe that looks the same to all observers, no matter where they are. In particular such a universe has no boundary, no edge. It is also isotropic, which is to say that it looks much the same in any direction. The presence of matter causes a uniform curvature of space.

A good two-dimensional analogy to this uniformly curved three-dimensional space is the surface of a balloon. The galaxies are inelastic polka dots pasted on the surface. Since the universe is expanding, imagine that the balloon is being inflated. As the balloon expands, a bug standing on any dot would see all the spots around it moving away, and it would see the more distant dots moving away more rapidly. The model thus reproduces the general recession of galaxies and even Hubble's law: that the speed of recession is proportional to the distance of the galaxy. It also points up the fact that the universe has no preferred center. Although the bug sees all

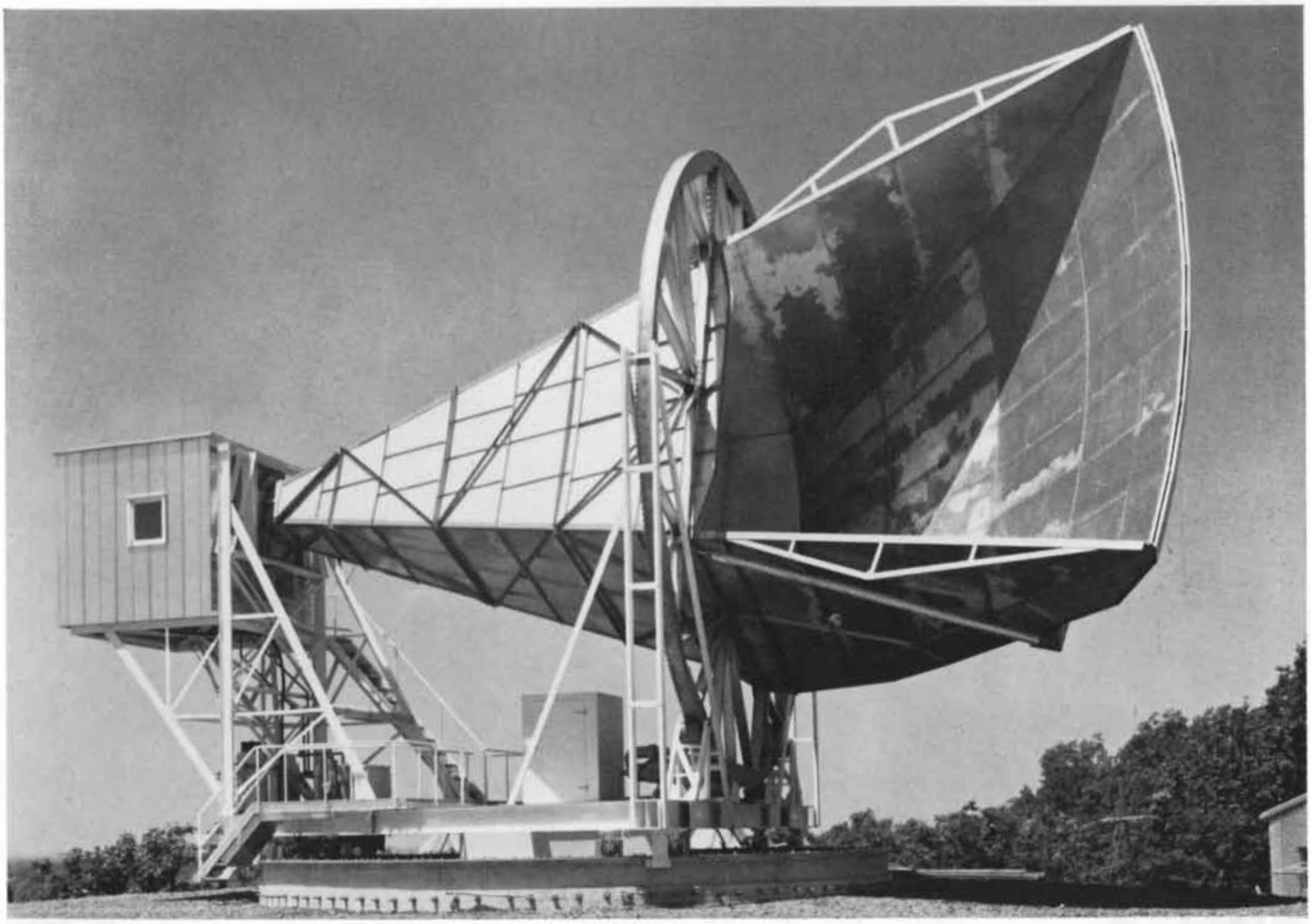


INSTRUMENT with which the primeval fireball is observed at Princeton University is a recent version of the Dicke radiometer, seen here from above. The antenna horns extend to the left and right and are directed upward to collect sky radiation; a switch, microwave receiver and amplifier are at the center. The instrument is operated both in this configuration and as illustrated below.



RADIOMETER is seen in a side view with one of the horns in position to receive radiation from the sky. The other horn of the radiometer is coupled to a wave guide leading to a reference source inside the orange Dewar flask. The source is immersed in boiling liquid helium and is therefore known to be radiating at 4.2 degrees Kelvin (degrees centigrade above absolute zero). The receiver input is switched back and forth between sky antenna and reference source and the intensities of the two are compared.

PRINCETON GROUP'S first fireball observations were made with an earlier version of the radiometer, here shown in position on the roof of the geology building. The slanted panels around the horn are wire-mesh screens that help to keep out ground radiation.



HORN ANTENNA of the Bell Telephone Laboratories receiver at Holmdel, N.J., was originally designed to collect signals reflected from Echo satellites. This was the antenna with which Arno A. Penzias and Robert W. Wilson first detected the fireball radiation.

the spots moving away from it, the bug should not conclude that it is on a preferred spot; another bug on another spot sees the same thing. Similarly, the general recession of the galaxies does not mean that the earth is at the center of the universe; an observer in any other galaxy would see the same general movement away from him.

On this model the primeval fireball radiation might be represented by a number of ants crawling over the surface of the balloon. They are uniformly distributed, and they crawl about in all directions. The number of ants in any given area of the surface decreases as the balloon is blown up. In the same way the density of photons in the primeval fireball decreases as the universe expands. Note also that no matter which way the ants move they will always move toward polka dots that are receding from them, and they must continuously lose energy as a result of this chase. In the real universe the photons of the fireball are always chasing galaxies that are receding from them, so that the photons undergo a continuous energy loss that accounts for the increase in their wavelength.

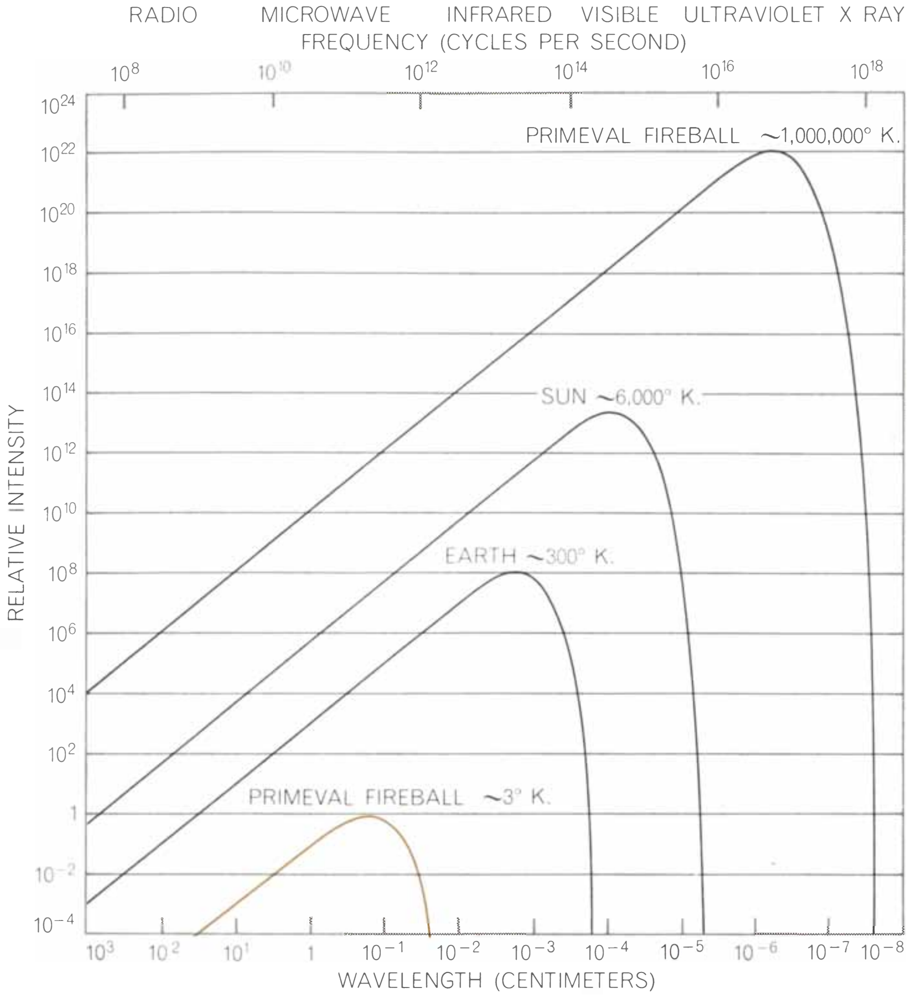
Based on this picture of the expanding universe it was possible to make two predictions about the nature of primeval fireball radiation. The first was that because it was emitted by a source (the condensed universe) in thermal equilibrium, its intensity should vary with wavelength in the manner characteristic of an ideal thermal radiator, or "black body." A severe test of whether the newly discovered radiation was indeed the primeval fireball would therefore consist in tracing out the observed intensity as a function of wavelength and seeing if the measurements fell on the black-body curve. The second major prediction was simply that the fireball radiation should be isotropic; that is, since the radiation presumably fills the universe and the earth is immersed in it, the observed intensity of the radiation should be the same in every direction.

There is a "window" through which one can observe the fireball radiation: the range of wavelengths from about one to about 20 centimeters. (At longer wavelengths radiation from our own galaxy is so strong that it submerges extragalactic signals; at less than one centimeter the earth's atmosphere radiates too strongly.) Radio astronomers have been observing through this window for many years but they overlooked the fireball because the methods that ordinarily enable one to separate signals of interest from background noise do not work in the case of the fireball radiation. For example, one can detect a weak signal when it is concentrated in a characteristic line in the electromagnetic spectrum. This is the case for the 21-centimeter emission of atomic hydrogen in interstellar clouds. Unfortunately the fireball radiation would have a smooth spectrum, much like that of terrestrial background noise, so that it would be hard to isolate in this way. One can also isolate extremely weak signals by scanning the antenna beam across a suspected localized source. The fireball was expected not to be localized, however, but to be spread across the entire sky as a uniform "glow."

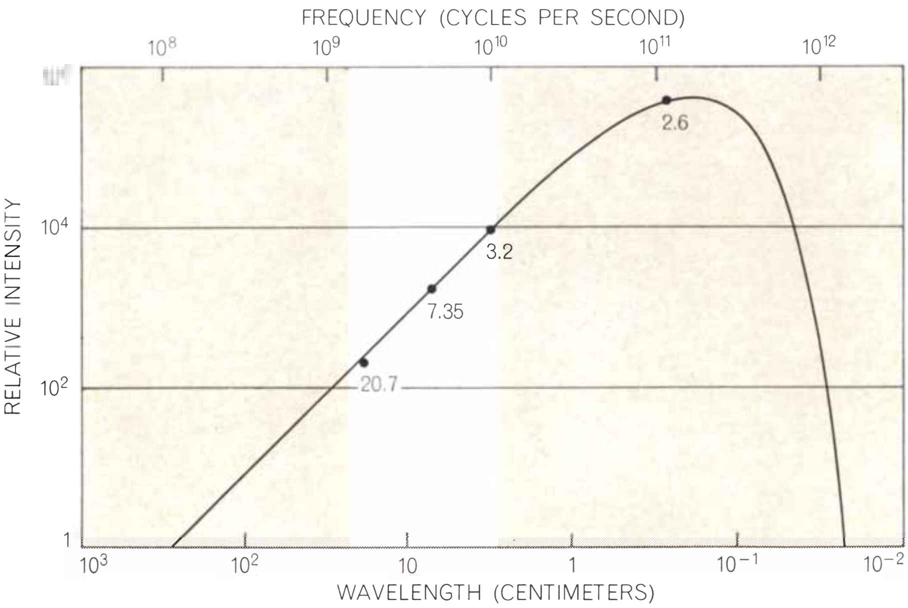
It was clear that the search for a primeval fireball called for a new and different kind of radio telescope, and in the fall of 1964 our group undertook to build such an instrument. The heart of our telescope is a modified microwave receiver known as a Dicke radiometer. Designed by Dicke in 1945, this instrument bypasses the noise generated within the receiver itself, which is about 1,000 times more intense than a weak signal such as the fireball. Dicke overcame the receiver noise problem by putting a switch between the antenna and the receiver that periodically—say 100 times a second—shifts the receiver input from the antenna to a reference source and back again [*see illustration on page 33*]. The receiver output therefore contains a 100-cycle-per-second signal whose strength depends on the difference between the radiation power collected by the antenna and the power emitted by the reference. Since the power of the reference source is known, the strength of the 100-cycle signal becomes a measure of the antenna power. This signal is still buried in receiver noise but is easily separated and measured by an amplifier sharply tuned to 100 cycles per second. In this way one can easily measure antenna power thousands of times weaker than the receiver noise.

Two more sources of terrestrial noise had to be overcome. One was thermal radiation from the ground, which fills half the space around an antenna and tends to leak into the usual parabolic antenna. This problem can be largely avoided by using a horn-shaped antenna,

REFERENCE SOURCE (*foreground*) **for the Princeton radiometer is made of metal-coated fiber-glass spikes. It has been removed from the Dewar flask and the pipelike wave guide that is normally coupled to the antenna horn. Wires on wave guide lead to thermocouples.**



"BLACK BODY" SOURCES of thermal radiation emit across a broad spectrum, the intensity of the radiation varying with wavelength as shown here for several sources. The shape of the curve persists as its position changes according to the temperature of the source. The top curve is for the fireball radiation billions of years ago, the bottom one for the radiation now.



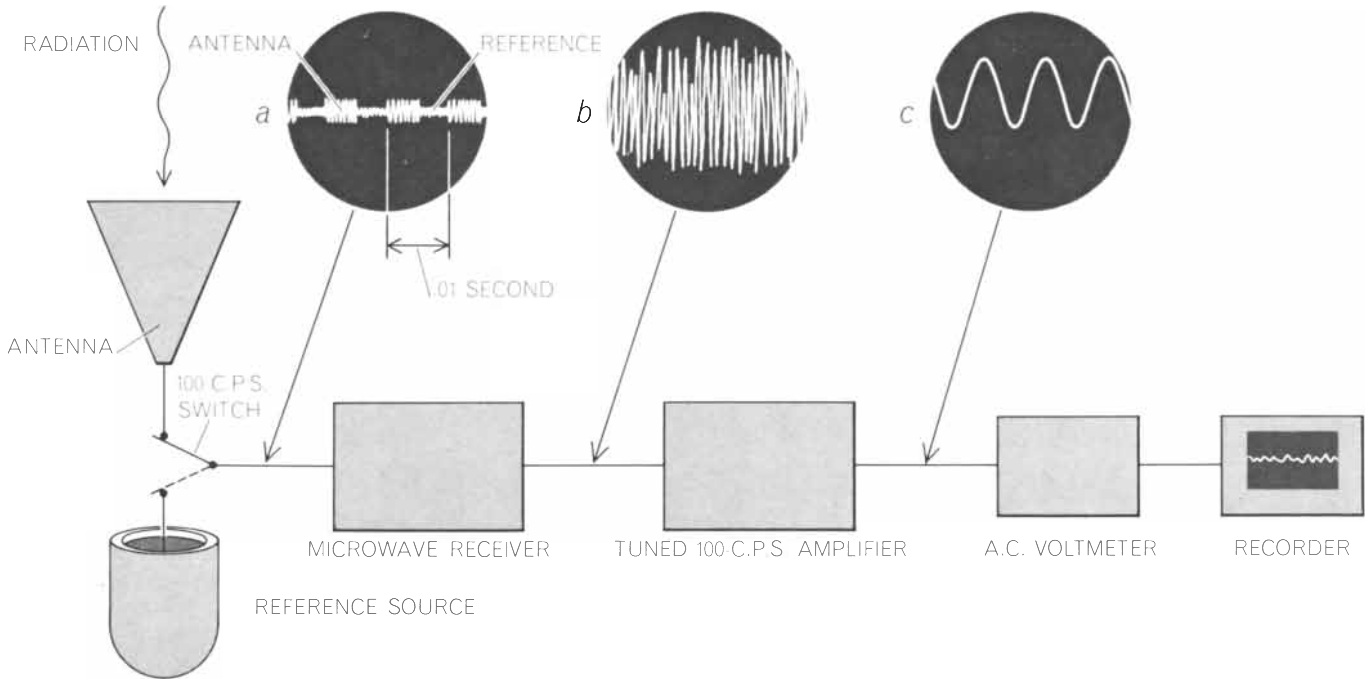
FIREBALL'S INTENSITY has been measured at four wavelengths and conforms to a three-degree black-body curve. Radiometer observations are hampered on either side of a central "window" (*white area*) by galactic (*left*) and atmospheric (*right*) radiation. Measurements at 2.6 millimeters can be obtained by observing light absorption of molecules in space.

which is less sensitive to ground radiation. The other source of terrestrial noise is radiation from oxygen and water molecules in the atmosphere. This emission can be measured and subtracted out if one tips the antenna beam to various angles from the vertical, thus increasing the length of the path through the atmosphere and therefore changing the atmospheric radiation component in a predictable way.

As it happened, the Bell Telephone Laboratories facility at Holmdel, N.J., already had a horn-shaped antenna, originally designed to receive signals reflected by the Echo satellites. Penzias and Wilson had modified the receiver for radio astronomy. Their instrument had all the properties necessary to uncover a primeval fireball, and it now developed that Penzias and Wilson had been attempting for some time to track down excess radio noise thought to be originating within the instrument itself. When Penzias heard what we were doing at Princeton, he invited us to visit Holmdel. What we saw there left us in little doubt that the Holmdel workers' excess noise was in fact extraterrestrial radiation—and was probably the fireball.

As we have already mentioned, the most crucial test of whether or not this new radiation is the primeval fireball is to trace out the spectrum and see if it is that of a black body. The Holmdel result constituted a first measurement of the possible fireball, at a wavelength of 7.35 centimeters. Fortunately the Princeton instrument had been designed to detect radiation of a wavelength different from the one received at Holmdel. We continued our work and about six months later measured a cosmic radiation intensity at 3.2 centimeters that fit in perfectly with the concept of a primeval fireball. Since that time still more measurements have been made at other wavelengths, including a radiometer measurement at 20.7 centimeters by T. F. Howell and J. R. Shakeshaft at the University of Cambridge. All the points so far fall on a typical black-body curve, one appropriate for a source with a temperature of three degrees Kelvin (degrees centigrade above absolute zero), and so the evidence is strong that we are indeed observing the primeval fireball [*see bottom illustration at left*].

The nature of the radio window, however, is such that direct observation at short wavelengths—in the most interesting region where the black-body curve rises to a peak and then falls off steeply—is almost impossible. At such wave-



DICKE RADIOMETER can detect signals far below the level of receiver-generated noise. A switch shifts the receiver input from antenna to reference source and back at, say, 100 cycles per second, producing a signal whose amplitude varies at 100 cycles according to the level of the antenna and the reference-source power (*a*). This small signal is obliterated by receiver noise, in which the 100-cycle signal becomes buried (*b*). The desired signal is recovered by filtering out the unwanted frequencies and amplifying the 100-cycle component. The resulting signal (*c*) is fed to a voltmeter that drives a recorder. The displacement of the recorder trace is proportional to the difference between the radiation power being collected by the antenna and the power emitted by the reference source.

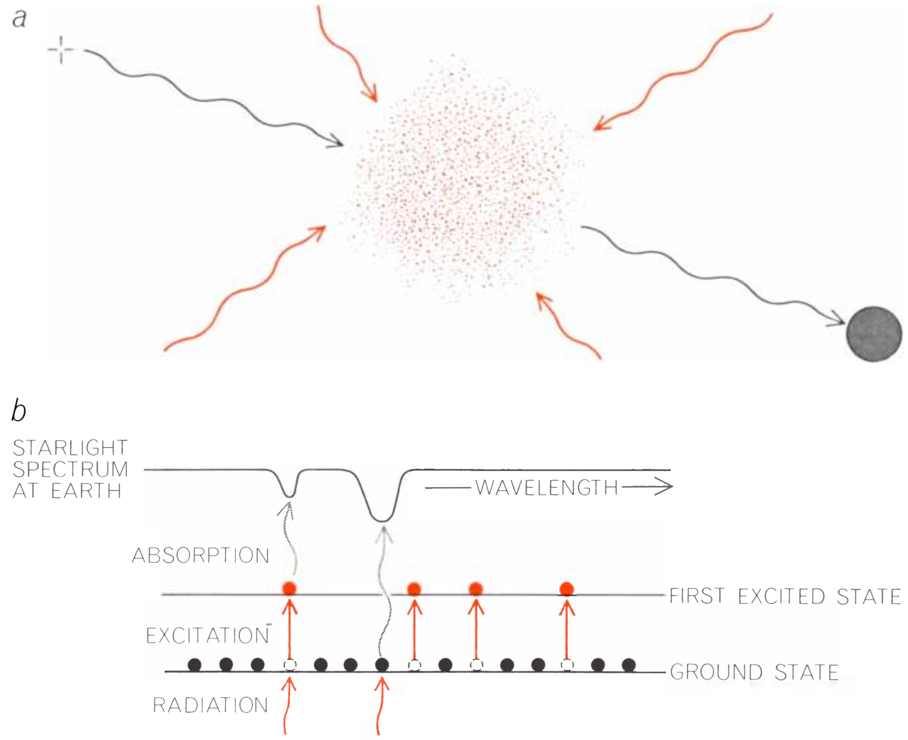
lengths one encounters technical problems in building a sensitive radiometer, and atmospheric emission becomes too strong for ground-based observations. These limitations have now been bypassed by an ingenious scheme for measuring the radiation temperature by reading a "molecular thermometer" in interstellar space.

The method depends on the fact that molecules of the carbon-nitrogen compound cyanogen (CN) in interstellar gas clouds are being bathed, along with everything else in the universe, in the black-body radiation of the primeval fireball. It happens that the cyanogen molecule is excited from its ground, or lowest-energy, state into its first excited state by radiation at a wavelength of 2.6 millimeters—a rather long wavelength for such a transition. A certain fraction of the molecules of cyanogen in a cloud exposed to 2.6-millimeter radiation will therefore be in the excited state rather than the ground state, and the size of the fraction is a measure of the intensity of the radiation. The fraction can be measured because the absorption of light by cyanogen molecules accounts for absorption lines in the spectra of certain stars, and light absorbed by molecules in the ground state has a slightly different wavelength from that absorbed by molecules in the excited state. A cloud of partially excited cyanogen molecules therefore causes two or more absorption lines to appear in the spectrum. The relative strength of the absorption lines characteristic of various states therefore gives the proportion of the molecules that are in each state. As long ago as 1941 Andrew McKellar of the Dominion Observatory in Canada used this method to calculate the degree of excitation of cyanogen molecules absorbing light from the star Zeta Ophiuchi. He reported that the molecules were excited as if by radiation with a temperature of 2.3 degrees K. The connection between this finding and a possible primeval fireball was not recognized; the molecules were assumed to be excited by collisions with other particles.

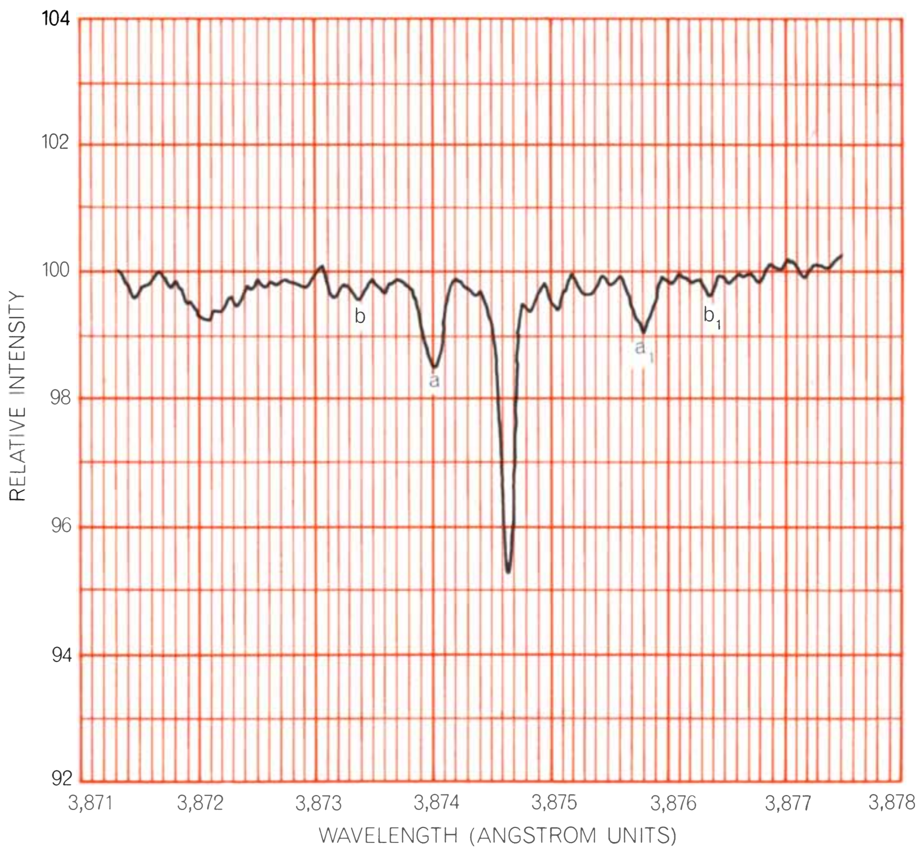
When the fireball hypothesis became generally known, George B. Field of the University of California at Berkeley and Neville J. Woolf of the University of Texas independently pointed out that interstellar cyanogen could be used as a probe to test for fireball radiation in space—and that McKellar's excitation temperature of 2.3 degrees was remarkably close to the three-degree temperature obtained from direct measurements. Field and John L. Hitchcock then reported a new value for the cyanogen excitation temperature. Working with spectra for Zeta Ophiuchi and Zeta Persei made by George H. Herbig of the Lick Observatory, they calculated a temperature range of from 2.7 to 3.4 degrees. The fact that two clouds in very different parts of the sky showed about the same excitation temperature provided an important check on the universality of the excitation mechanism—a necessary feature of fireball excitation.

At the same time Patrick Thaddeus and John F. Clauser of the Institute for Space Studies made some new measurements of Zeta Ophiuchi and obtained a result of 3.75 degrees. Clauser then developed a technique for summing, in digital form, the faint spectra on large numbers of star plates from the Mount Wilson Observatory. The technique has been used to examine the cyanogen absorption lines in the spectra from eight widely distributed stars. In every case the excitation temperature is about three degrees.

The cyanogen measurements are important results. Not only do they pin down the crest of the black-body curve but also they help to eliminate any cause of cyanogen excitation other than fireball radiation. The frequency and energy of particle collisions, for example, would be expected to vary from cloud to cloud depending on local conditions. The results for eight different clouds argue against such local excitation. Note, further, that we have here a very strong test for the fireball hypothesis: If just one cloud is found with a strong ground-state



CYANOGEN MOLECULES in space are bathed in fireball radiation (*colored arrows*) and absorb optical radiation (*black arrows*) on its way to the earth from a star (*a*). The wavelength absorbed depends on whether a molecule is in the "ground" state or in an excited state to which it is raised by fireball radiation (*b*). The amount of absorption at each wavelength depends on the number of molecules in each state. The starlight spectrum indicates the fraction of molecules in each state of excitation and thus the intensity of the fireball.



SPECTRUM of light from the star Zeta Ophiuchi was made by John F. Clauser of the Institute for Space Studies by summing the densitometer traces of a number of star plates. The deep trough marks the absorption line characteristic of the cyanogen ground state. Two dips (a, a_1) mark the two lines of the first excited state. Dips b and b_1, characteristic of the second excited state, may, if better resolved, provide a measurement at 1.3 millimeters.

absorption line and no excited-state line, we shall have to conclude that there is no cyanogen excitation in that cloud and therefore that the primeval fireball does not exist.

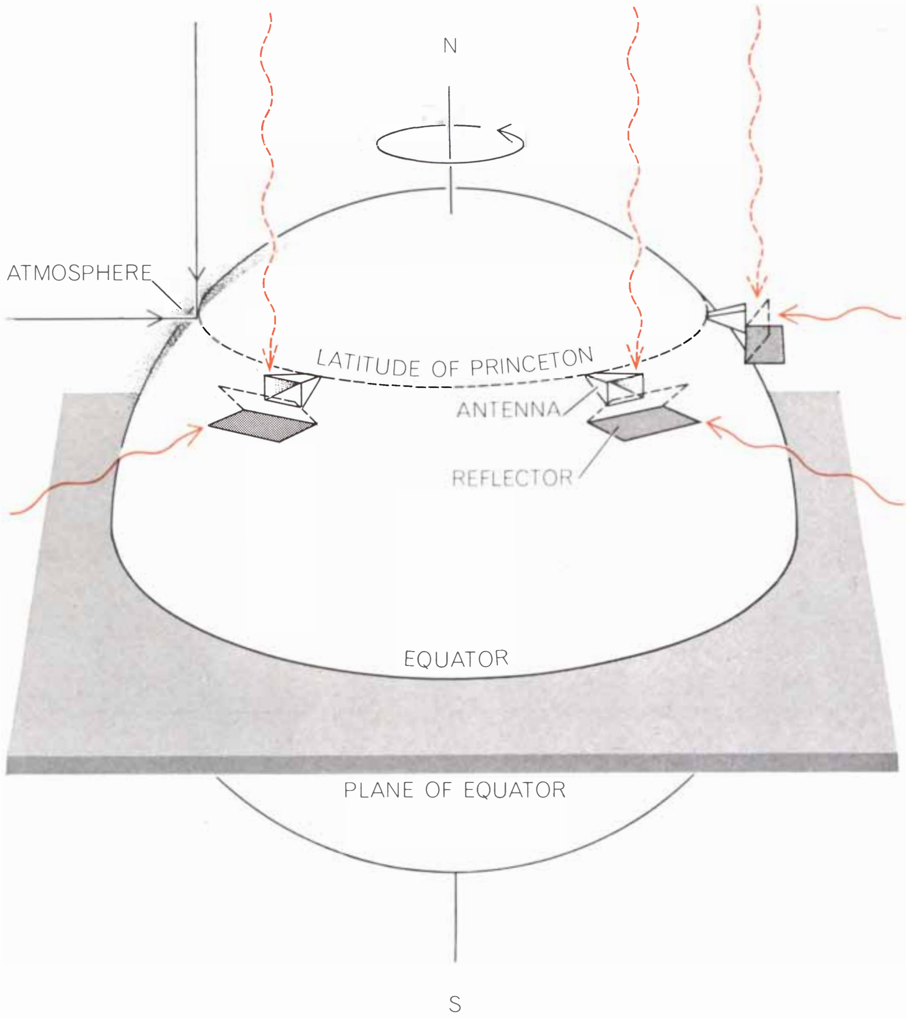
If one assumes that the universe in fact is isotropic, and if this newly discovered radiation in fact is the primeval fireball, the radiation should be isotropic. (Even the first assumption—that the universe is isotropic—should not be regarded as a self-evident principle. It is comforting to state assumptions as principles, but one must recognize the kinship between an assumption of isotropy and the old assumption that the earth is at the center of the universe. Both assumptions fit the poor observational data available at the time—and also the philosophical tenets of the day.) For the first time we now have a precise observational "handle" on the shape of the universe, and one of our current experiments at Princeton is aimed at making use of that handle.

We point the horn of our 3.2-centimeter radiometer toward the south at an angle of 45 degrees from the zenith so that it is directed approximately parallel to the plane of the earth's equator [*see top illustration on opposite page*]. As the earth rotates, the radiometer scans around this plane once a day. We cannot simply look at the record for daily variations and attribute them to some anisotropy in the primeval radiation; there are inevitably large daily effects due to solar heating, atmospheric changes and other phenomena. We correct for these variations by deflecting the antenna beam in the direction of the pole star every 15 minutes. Since that is a fixed point in the sky, it serves as a reference to which we can compare the reading along the equatorial plane. Keeping the apparatus running for many months further reduces the daily variations. Since any irregularity in the radiation would be fixed in relation to the stars, and therefore would traverse the antenna beam at different times of the day during different seasons of the year, we partly average out effects that have a period of one solar day. After about a year the experiment shows no differences between equatorial and polar radiation intensities greater than about .015 degree, which is to say it reveals no anisotropy greater than about ±.5 percent [*see bottom illustration on opposite page*].

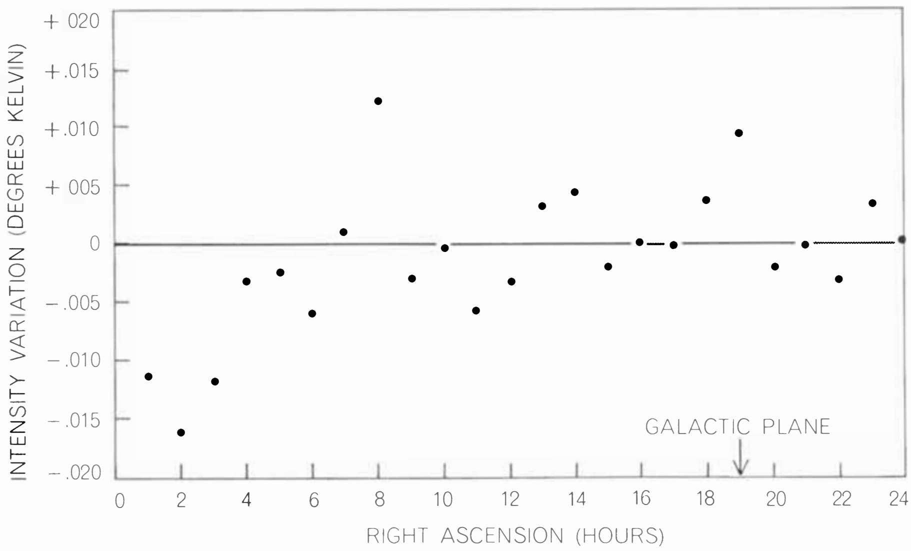
Whatever the final explanation for what we now believe to be fireball radiation, it must account for this remarkable isotropy. The source cannot be our own galaxy; the solar system is off to one side of the galaxy, and the radiation would have to be more intense in the direction of the main body of the galaxy. If the source were in the solar system itself, there would be recurring variations each solar day, but there are no such effects. It seems clear that the radiation must be extragalactic.

If the earth is moving in relation to the local frame of reference defined by the average motion of the primeval fireball radiation, the radiation should seem a little hotter when we observe in the direction of the earth's motion and a little colder when we look "backward." One cannot be sure what the total velocity of the earth should be in relation to this standard, but we do know the earth is moving around the center of our galaxy at 200 kilometers per second. If we suppose the center of the galaxy is at rest in this frame of reference, the radiation would appear to be .07 percent hotter (or more intense) than average in the direction of the earth's motion (toward the constellation Cygnus) and .07 percent colder than average 180 degrees away. Since our instrument scans in the plane of the Equator, however, we should not observe this full effect but rather a variation of about .04 percent from the mean [*see bottom illustration on next page*]. This is about half of the upper limit (roughly .1 percent) that we have been able to set so far for an anisotropy that has a period of 24 hours. (The radiation would appear hottest and coldest at 12-hour intervals.) We are now trying to improve the observations to a point at which we can actually see this effect of the earth's "absolute" motion through space.

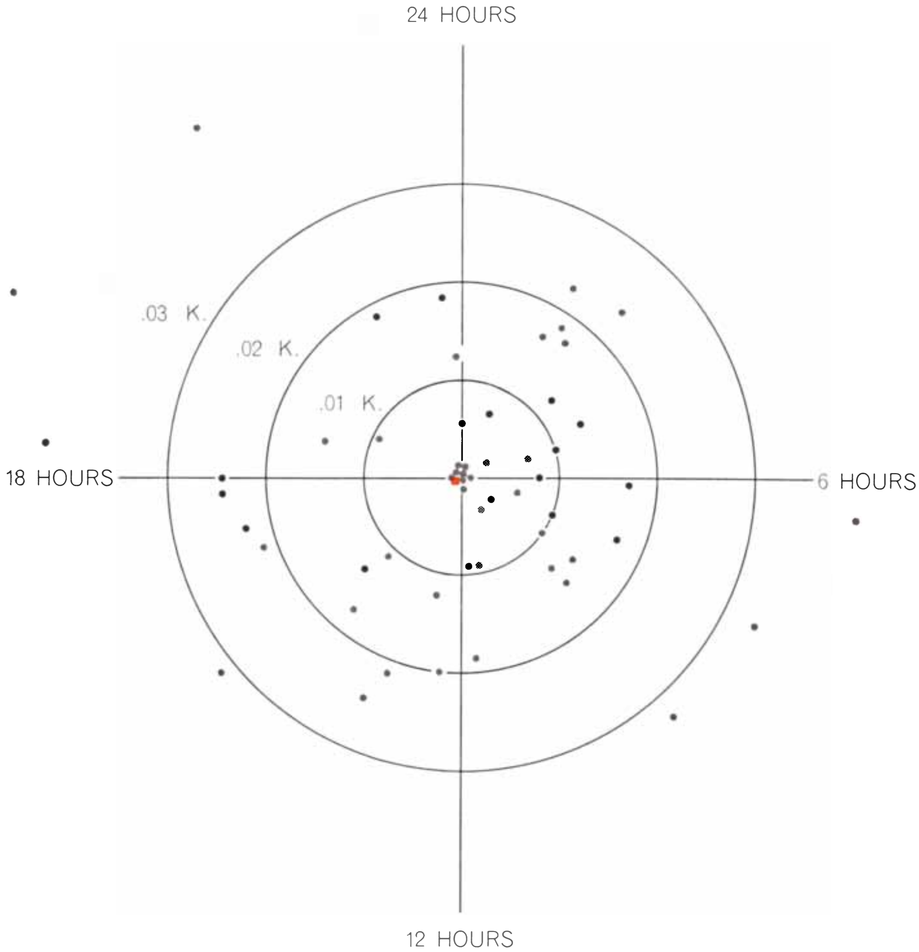
Unequivocal proof of the phenomenon of a primeval fireball would seem to rule out a number of competing cosmologies. The steady-state theory would be ruled out because its universe was never in a dense state and therefore could not have manufactured black-body radiation. The fireball also creates severe difficulties for any cosmology that includes a visible edge to the matter-filled part of space, for example the cosmology of Oskar Klein and Hannes Alfvén [see "Antimatter and Cosmology," by Hannes Alfvén; Scientific American, April]. If there is a visible boundary, then any radiation produced in the early days of the universe must long since have left the universe. Proponents of a visible-edge cosmology must therefore find a contemporary source for the radiation we attribute to a fireball. Unless the earth is right at the center of the universe—something most people would be reluc-



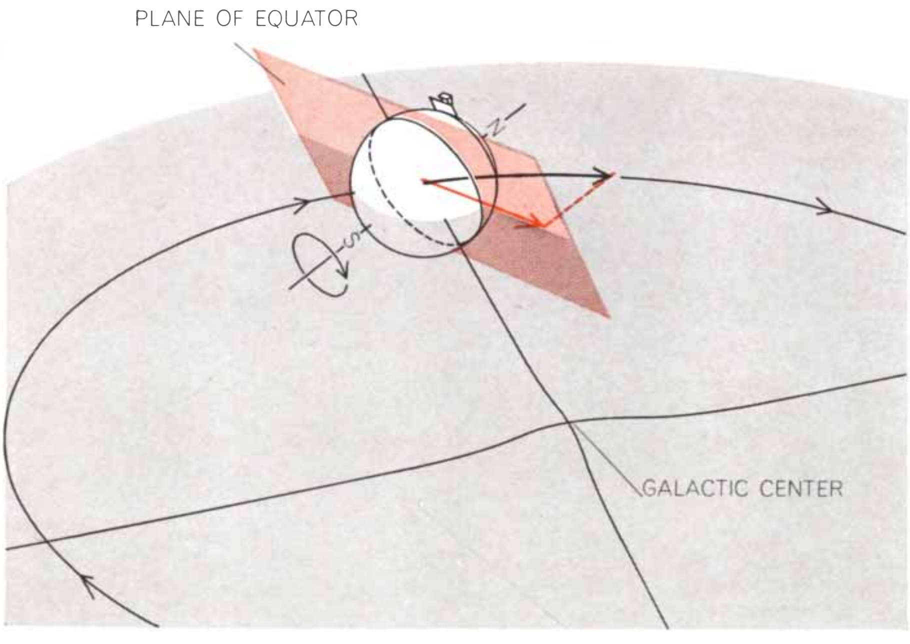
ISOTROPY is measured by pointing the horn antenna in the direction of the plane of the earth's equator and periodically raising a reflector that deflects radiation from the direction of the pole star into the horn. As the earth turns the radiometer measures the difference between the equatorial and the polar (or constant) radiation intensity. The length of the path through the atmosphere is the same in both directions (*left*), eliminating one source of error.



RESULTS of isotropy experiment, after about a year, indicate no anisotropy greater than about ±.5 percent. Each point represents the average difference between the equatorial radiation temperature in a given direction and the constant polar radiation temperature; the probable error in each point is about ±.003 degree. The scatter appears to be primarily random, although the dip at two hours may be real; more measurements are required to be sure.



ISOTROPY DATA were analyzed in an effort to bring out any 24-hour periodicity. Each point gives the magnitude and direction of the maximum difference between equatorial and polar radiation temperatures on a day's run. (Solid dots are full runs, gray dots runs that were incomplete and were given half-weight.) The vector sum of all points yielded a maximum difference of about .001 degree K., an anisotropy of .03 percent (*colored square*).



EARTH'S MOTION around the galaxy should be detectable as an apparent increase in radiation intensity in the direction of motion and a decrease in the opposite direction (see text). The direction of motion is not the same as the direction (in the plane of the Equator) in which the radiation is being observed, however. The observed effects should therefore be proportional to the equatorial projection (*colored arrow*) of the velocity of the earth.

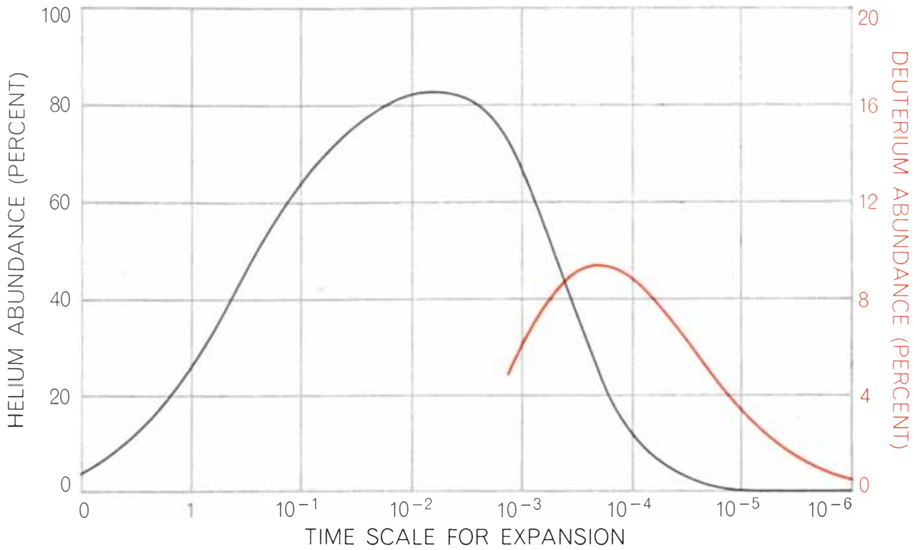
tant to suppose—no contemporary source within the universe could produce the isotropic radiation we observe.

Our discussion of cosmology so far has been merely descriptive, but if cosmology is to be a respectable science it must attempt numerical confrontations between theory and observation. Such a confrontation is provided by what cosmologists are now calling the "helium problem." There is a theoretical connection between the temperature of the primeval fireball and the amount of helium in the matter that came out of the big bang and eventually condensed into galaxies. It is worth examining as an example of the development of cosmological ideas and of the way in which a single observational result can prompt new theoretical work that in turn calls for new observations.

The story begins in about 1930 with the pioneering work of R. C. Tolman on thermodynamics and thermal radiation in an expanding universe. In 1938 C. F. von Weizsäcker tried theoretically to produce the heavy elements by "cooking" hydrogen in an early "superstar" stage of the universe, which later exploded into the expanding universe. George Gamow pointed out in 1948, however, that according to general relativity the universe could not have existed in a static, high-temperature state. He proposed instead that the elements were largely formed—and also that black-body radiation was emitted—during the early and very rapid expansion of the universe. Later calculations showed that although helium would have been produced in such a stage, it was impossible to account for the formation of heavier elements. An improved theory of element formation in stars finally eclipsed theories of element formation in the big bang itself, and the idea of thermal radiation in a big bang dropped out of sight. It is remarkable, however, that this theory, as developed by Gamow, Ralph Alpher, Robert Herman and others, implied that the present temperature of the fireball would be about equal to the observed value of three degrees K.

Dicke arrived at the idea of a primeval fireball from a different direction. In the summer of 1964 he was considering not the origin of the elements but the origin of the universe. It is difficult to explain the apparently spontaneous creation of matter that is called for if one associates the beginning of the expansion of the universe with its actual origin. Dicke therefore preferred an oscillating model, in which the present expansion of the universe is considered to have been preceded by a collapsing phase.

The contraction of the universe would have heated up its contents, producing thermal radiation when the universe became dense enough; the temperature would have risen to at least 10 billion degrees, at which point complex nuclei would have evaporated, yielding pure hydrogen. Such a process could account for the elimination of heavy elements—the "ashes" from the hydrogen burned in stars in the previous cycle. Dicke, in other words, introduced the fireball to eliminate the heavy elements rather than to produce them.



PRIMORDIAL ABUNDANCE of helium (*black*) and deuterium (*color*) is plotted for various assumptions about the rate of expansion of the universe. Unity on the horizontal scale corresponds to the time scale for expansion predicted by the general theory of relativity.

Perhaps because we are by training physicists rather than cosmologists, our group at Princeton was unaware for some time that there was a history of theoretical work on a primeval fireball and element production in the big bang. Having begun with the fireball idea, we reached the problem of element formation by a roundabout route. As our search for the fireball was getting under way we were concerned about how we would interpret the results we hoped to obtain. (One particularly wants to know this ahead of time when an experiment is highly speculative, as this one certainly was before the Bell Laboratories results became known.) We were anxious to establish some connection between a possible primeval fireball and some other observable quantity, so we asked ourselves what physical processes might be appropriate to the conditions encountered as the expansion of the universe is traced back in time to ever higher densities and temperatures.

We found that in the early stages of expansion conditions would have been right for the conversion of significant amounts of hydrogen to helium. The fractional amount of hydrogen that would have been converted to this primeval helium depends on two observable quantities: the present mean mass density in the universe and the present temperature of the primeval fireball. Given the present mass density, the primeval helium abundance would be lower for higher values of the present fireball temperature. This is because the helium would have formed at a certain temperature (about a billion degrees) and the amount of helium that formed would depend on the mass density at the epoch in which it formed. The higher the present fireball temperature, the less the radiation can have cooled since the epoch of helium production; the correspondingly lesser expansion of matter means a larger mass density at the helium epoch, and therefore more helium production.

We decided that if the present fireball temperature were 10 degrees K. or more, the primeval helium abundance could be well below the observed helium abundance in the sun. This seemed desirable because the sun also contains heavier elements thought to have been produced in earlier generations of stars, and we assumed that these earlier generations would also have produced substantial amounts of helium. It turned out, of course, that the fireball temperature is certainly not 10 degrees but rather three degrees. This pushes the calculated primeval helium abundance up to the range of 27 to 30 percent by mass, or just about the observed abundance of helium in the sun. That seemed surprisingly high.

Before considering the observational evidence that might confirm or rule out this theoretical finding, we should examine the assumptions that underlie the calculation. A number of variables from nuclear physics are involved, many of them actually measured and the rest derived from theory in which there is a good deal of confidence because it works well in conventional applications. Another basic ingredient in the calculation is the gravity theory, which determines how fast the universe would have expanded through the period of helium production. Here there are grounds for suspicion, because the conventional gravity theory—the general theory of relativity—has not been tested by a wide range of observations. The primordial helium abundance can be computed for various assumptions about the rate of expansion of the universe [*see illustration above*]. If the universe actually expanded just slightly faster than general relativity predicts, an unacceptably high amount of helium would have been produced. If the expansion rate were increased by a factor of about 10,000, the helium production would be acceptable but there would be too much deuterium. To avoid this requires an expansion rate so great that there would have been relatively little primeval helium. The principal competitor of general relativity, a generalization developed by Carl Brans and Dicke, predicts a faster expansion that might carry over into this area of negligible helium. If the rate of expansion could be shown to be somewhat slower, this difficult situation could be eased, but no one has suggested a reasonably attractive way to do this.

For the moment we are content to frame this question: Was the initial helium abundance in our galaxy very low or was it about equal to the solar value? The choice between these two clear-cut alternatives depends on the helium content of the oldest stars in the galaxy. Unfortunately these stars closely guard the secret of their helium abundance. They are small stars and generally have cool surfaces in which the spectral lines of helium are not seen, and so one cannot use the spectroscopic techniques that have been satisfactory for more massive stars with hotter surfaces. As for these massive stars, their lifetimes are relatively short, and the ones that formed early in the history of the galaxy have already burned out. The answer to the helium problem will be hard to obtain, but it will eventually add a fascinating piece of information to observational cosmology.

TEOTIHUACÁN

The first and largest city of the pre-Columbian New World arose in the Valley of Mexico during the first millennium A.D. At its height the metropolis covered a larger area than imperial Rome

by René Millon

When the Spaniards conquered Mexico, they described Montezuma's capital Tenochtitlán in such vivid terms that for centuries it seemed that the Aztec stronghold must have been the greatest city of pre-Columbian America. Yet only 25 miles to the north of Tenochtitlán was the site of a city that had once been even more impressive. Known as Teotihuacán, it had risen, flourished and fallen hundreds of years before the conquistadors entered Mexico. At the height of its power, around A.D. 500, Teotihuacán was larger than imperial Rome. For more than half a millennium it was to Middle America what Rome, Benares or Mecca have been to the Old World: at once a religious and cultural capital and a major economic and political center.

Unlike many of the Maya settlements to the south, in both Mexico and Guatemala, Teotihuacán was never a "lost" city. The Aztecs were still worshiping at its sacred monuments at the time of the Spanish Conquest, and scholarly studies of its ruins have been made since the middle of the 19th century. Over the past five years, however, a concerted program of investigation has yielded much new information about this early American urban center.

In the Old World the first civilizations were associated with the first cities, but both in Middle America and in Peru the rise of civilization does not seem to have occurred in an urban setting. As far as we can tell today, the foundation for the earliest civilization in Middle America was laid in the first millennium B.C. by a people we know as the Olmecs. None of the major Olmec centers discovered so far is a city. Instead these centers—the most important of which are located in the forested lowlands along the Gulf of Mexico on the narrow Isthmus of Tehuantepec—were of a ceremonial character, with small permanent populations probably consisting of priests and their attendants.

The Olmecs and those who followed them left to many other peoples of Middle America, among them the builders of Teotihuacán, a heritage of religious beliefs, artistic symbolism and other cultural traditions. Only the Teotihuacanos, however, created an urban civilization of such vigor that it significantly influenced the subsequent development of most other Middle American civilizations—urban and nonurban—down to the time of the Aztecs. It is hard to say exactly why this happened, but at least some of the contributing factors are evident. The archaeological record suggests the following sequence of events.

A settlement of moderate size existed at Teotihuacán fairly early in the first century B.C. At about the same time a number of neighboring religious centers were flourishing. One was Cuicuilco, to the southwest of Teotihuacán in the Valley of Mexico; another was Cholula, to the east in the Valley of Puebla. The most important influences shaping the "Teotihuacán way" probably stemmed from centers such as these. Around the time of Christ, Teotihuacán began to grow rapidly, and between A.D. 100 and 200 its largest religious monument was raised on the site of an earlier shrine. Known today as the Pyramid of the Sun, it was as large at the base as the great pyramid of Cheops in Egypt [*see bottom illustration on page 44*].

The powerful attraction of a famous holy place is not enough, of course, to explain Teotihuacán's early growth or later importance. The city's strategic location was one of a number of material factors that contributed to its rise. Teotihuacán lies astride the narrow waist of a valley that is the best route between the Valley of Mexico and the Valley of Puebla. The Valley of Puebla, in turn, is the gateway to the lowlands along the Gulf of Mexico.

The lower part of Teotihuacán's valley is a rich alluvial plain, watered by permanent springs and thus independent of the uncertainties of highland rainfall.

CEREMONIAL HEART of Teotihuacán is seen in an aerial photograph looking southeast toward Cerro Patlachique, one of a pair of mountains that flank the narrow valley dominated by the city. The large pyramid in

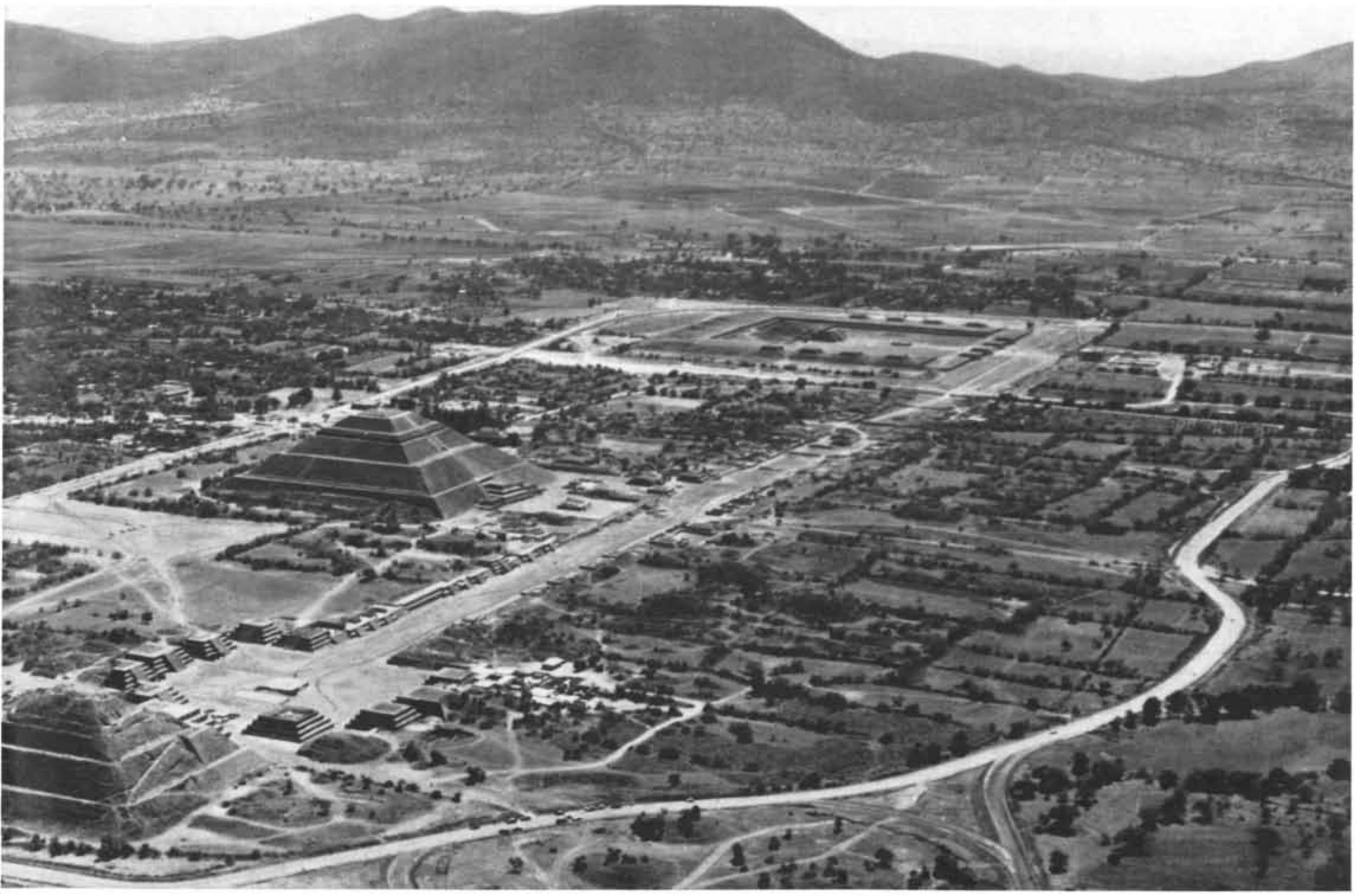
The inhabitants of the valley seem early to have dug channels to create an irrigation system and to provide their growing city with water. Even today a formerly swampy section at the edge of the ancient city is carved by channels into "chinampas": small artificial islands that are intensively farmed. Indeed, it is possible that this form of agriculture, which is much better known as it was practiced in Aztec times near Tenochtitlán, was invented centuries earlier by the people of Teotihuacán.

The valley had major deposits of obsidian, the volcanic glass used all over ancient Middle America to make cutting and scraping tools and projectile points. Obsidian mining in the valley was apparently most intensive during the city's early years. Later the Teotihuacanos appear to have gained control of deposits of obsidian north of the Valley of Mexico that were better suited than the local material to the mass production of blade implements. Trade in raw obsidian and obsidian implements became increasingly important to the economy of Teotihuacán, reaching a peak toward the middle of the first millennium A.D.

The recent investigation of Teotihuacán has been carried forward by specialists working on three independent but related projects. One project was a monumental program of excavation and reconstruction undertaken by Mexico's National Institute of Anthropology, headed by Eusebio Dávalos. From 1962 to 1964 archaeologists under the direction of Ignacio Bernal, director of the National Museum of Anthropology, unearthed and rebuilt a number of the structures that lie along the city's principal avenue ("the Street of the Dead"); they have also restored Teotihuacán's second main pyramid ("the Pyramid of the Moon"), which lies at the avenue's northern end. Two of the city's four largest structures, the Pyramid of the Sun and the Citadel, within which stands the Temple of Quetzalcoatl, had been cleared and restored in the 1900's and the 1920's respectively. Among other notable achievements, the National Institute's work brought to light some of the city's finest mural paintings.

As the Mexican archaeologists were at work a group under the direction of William T. Sanders of Pennsylvania State University conducted an intensive study of the ecology and the rural-settlement patterns of the valley. Another group, from the University of Rochester, initiated a mapping project under my direction. This last effort, which is still under way, involves preparing a detailed topographic map on which all the city's several thousand structures will be located. The necessary information is being secured by the examination of surface remains, supplemented by small-scale excavations. One result of our work has been to demonstrate how radically different Teotihuacán was from all other settlements of its time in Middle America. It was here that the New World's urban revolution exploded into being.

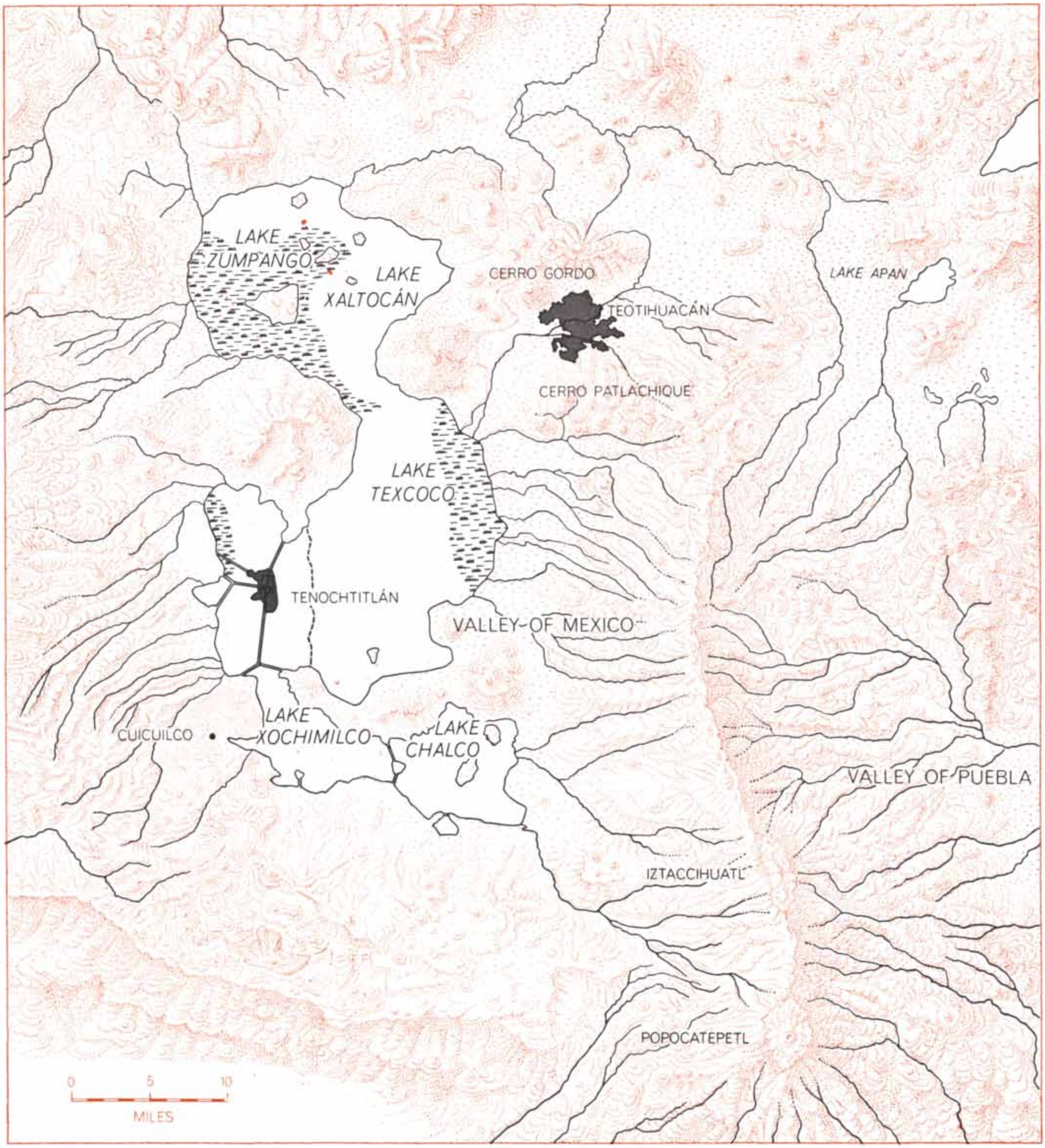
It had long been clear that the center



the foreground is the Pyramid of the Moon. The larger one beyond it is the Pyramid of the Sun. Many of the more than 100 smaller religious structures that line the city's central avenue, the Street of the Dead, are visible in the photograph. South of the Pyramid of the Sun and east of the central avenue is the large enclosure known as the Citadel. It and the Great Compound, a matching structure not visible in the photograph, formed the city's center. More than 4,000 additional buildings, most no longer visible, spread for miles beyond the center. At the peak of Teotihuacán's power, around A.D. 500, the population of the city was more than 50,000.

of Teotihuacán was planned, but it soon became apparent to us that the extent and magnitude of the planning went far beyond the center. Our mapping revealed that the city's streets and the large majority of its buildings had been laid out along the lines of a precise grid aligned with the city center. The grid was established in Teotihuacán's formative days, but it may have been more intensively exploited later, perhaps in relation to "urban renewal" projects undertaken when the city had become rich and powerful.

The prime direction of the grid is slightly east of north (15.5 degrees). The basic modular unit of the plan is close to 57 meters. A number of residential structures are squares of this size. The plan of many of the streets seems to repeat various multiples of the 57-meter



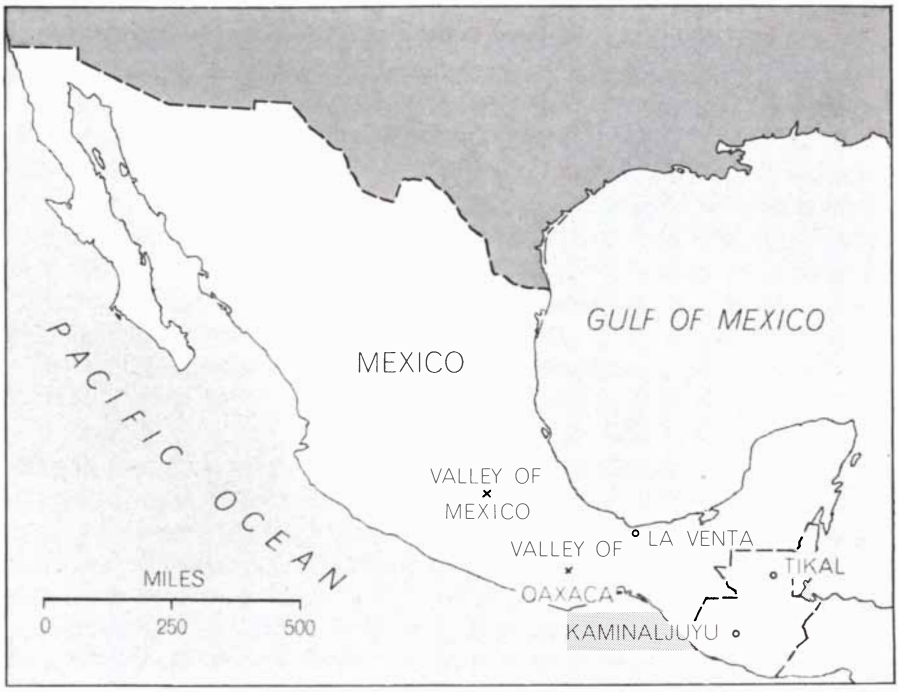
VALLEY OF MEXICO was dominated by shallow lakes in late pre-Hispanic times; in the rainy season they coalesced into a single body of water. Teotihuacán was strategically located; it commanded a narrow valley a few miles northeast of the lakes that provided the best route between the Valley of Mexico and the Valley of Puebla, which leads to the lowlands along the Gulf of Mexico (*see map at top of opposite page*). It was an important center of trade and worship from 100 B.C. until about A.D. 750. Centuries after its fall the Aztec capital of Tenochtitlán grew up in the western shallows of Lake Texcoco, 25 miles from the earlier metropolis.

unit. The city's major avenues, which run parallel to the north-south axis, are spaced at regular intervals. Even the river running through the center of the city was canalized to conform to the grid. Miles from the city center the remains of buildings are oriented to the grid, even when they were built on slopes that ran counter to it. A small design composed of concentric circles divided into quadrants may have served as a standard surveyor's mark; it is sometimes pecked into the floors of buildings and sometimes into bare bedrock. One such pair of marks two miles apart forms a line exactly perpendicular to the city's north-south axis. The achievement of this kind of order obviously calls for an initial vision that is both audacious and self-confident.

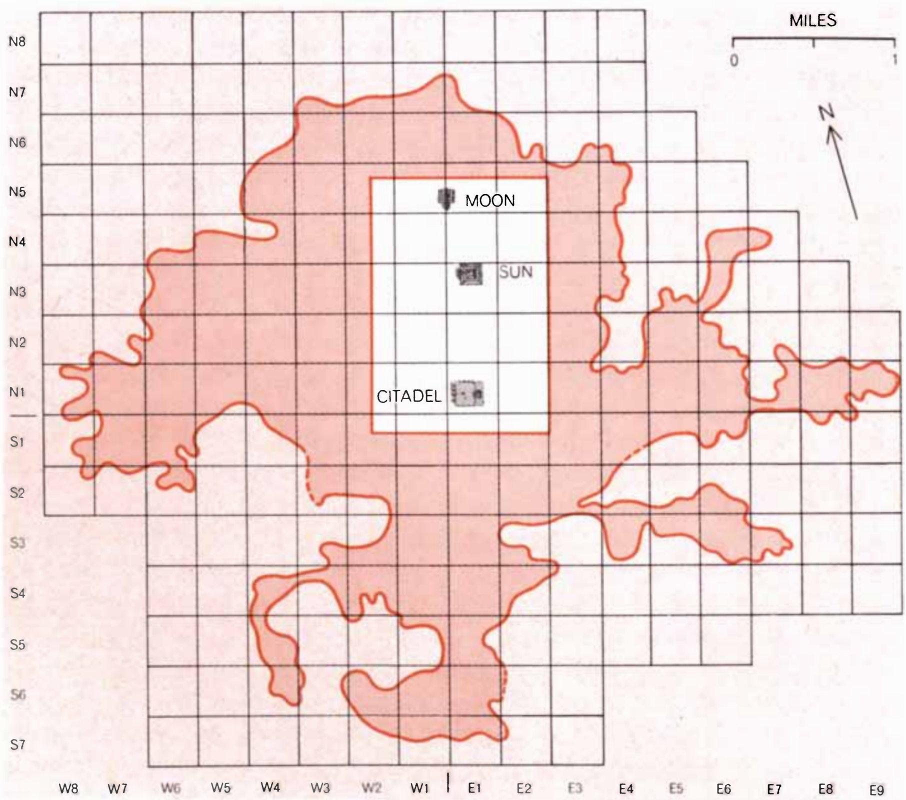
A city planner's description of Teotihuacán would begin not with the monumental Pyramid of the Sun but with the two complexes of structures that form the city center. These are the Citadel and the Great Compound, lying respectively to the east and west of the city's main north-south avenue, the Street of the Dead. The names given the various structures and features of Teotihuacán are not, incidentally, the names by which the Teotihuacanos knew them. Some come from Spanish translations of Aztec names; others were bestowed by earlier archaeologists or by our mappers and are often the place names used by the local people.

The Street of the Dead forms the main axis of the city. At its northern end it stops at the Pyramid of the Moon, and we have found that to the south it extends for two miles beyond the Citadel-Compound complex. The existence of a subordinate axis running east and west had not been suspected until our mappers discovered one broad avenue running more than two miles to the east of the Citadel and a matching avenue extending the same distance westward from the Compound.

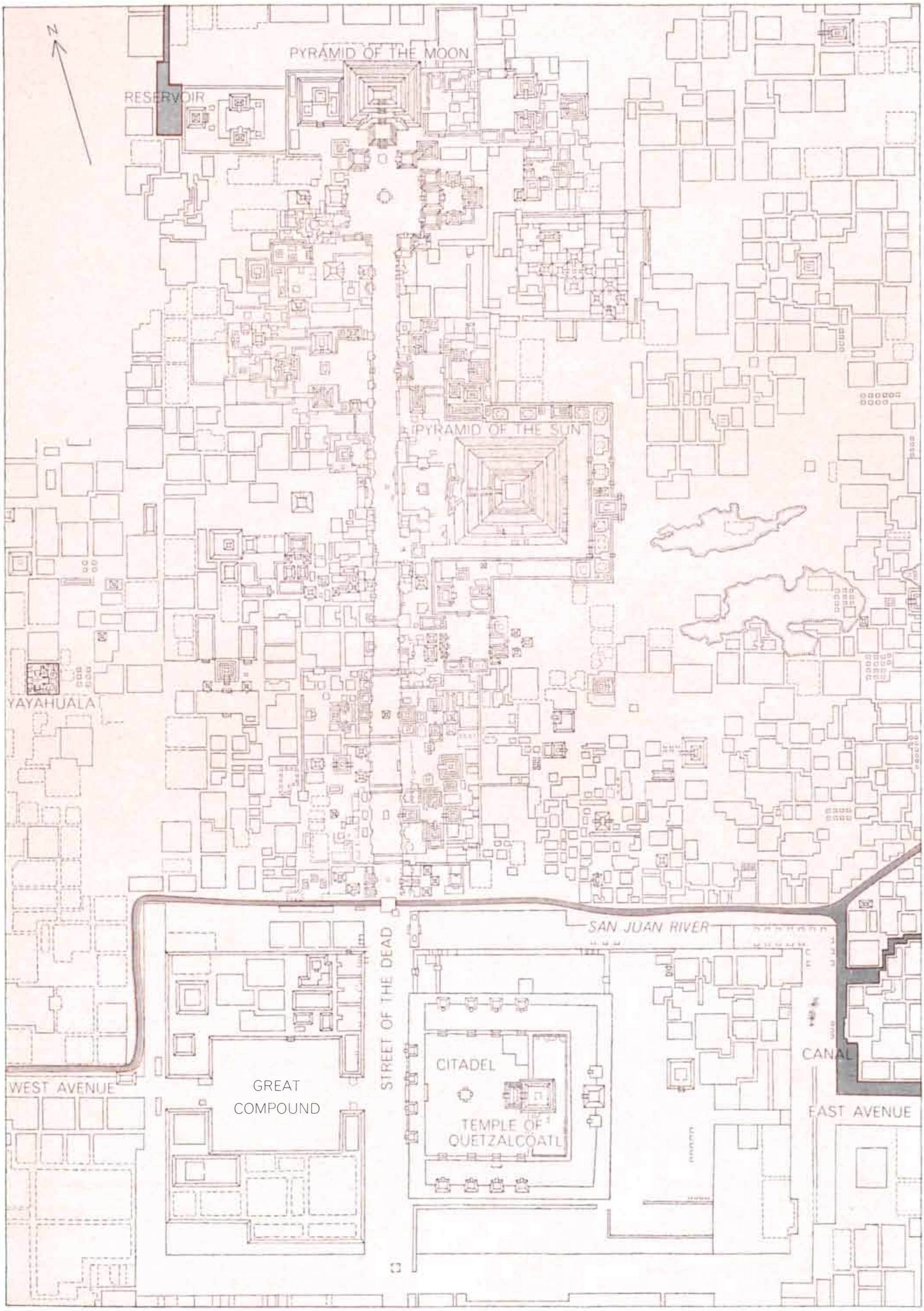
To make it easier to locate buildings over so large an area we imposed our own 500-meter grid on the city, orienting it to the Street of the Dead and using the center of the city as the zero point of the system [*see bottom illustration at right*]. The heavy line defining the limits of the city was determined by walking around the perimeter of the city and examining evidence on the surface to establish where its outermost remains end. The line traces a zone free of such remains that is at least 300 meters wide and that sharply separates the city from



EARLY CIVILIZATION in Middle America appeared first in the lowlands along the Gulf of Mexico at such major centers of Olmec culture as La Venta. Soon thereafter a number of ceremonial centers appeared in the highlands, particularly in the valleys of Oaxaca, Puebla and Mexico. Kaminaljuyu and Tikal, Maya centers respectively in highlands and lowlands of what is now Guatemala, came under Teotihuacán's influence at the height of its power.



IRREGULAR BOUNDARY of Teotihuacán is shown as a solid line that approaches the edges of a grid, composed of 500-meter squares, surveyed by the author's team. The grid parallels the north-south direction of the Street of the Dead, the city's main avenue. One extension of the city in its early period, which is only partly known, has been omitted. A map of Teotihuacán's north-central zone (*light color*) is reproduced on the next page.


N
PYRAMID OF THE MOON
RESERVOIR
PYRAMID OF THE SUN
YAYAHUALA
SAN JUAN RIVER
STREET OF THE DEAD
CITADEL
TEMPLE OF QUETZALCOATL
GREAT COMPOUND
WEST AVENUE
EAST AVENUE
CANAL

the countryside. The Street of the Dead, East Avenue and West Avenue divide Teotihuacán into quadrants centered on the Citadel-Compound complex. We do not know if these were formally recognized as administrative quarters of the city, as they were in Tenochtitlán. It is nonetheless possible that they may have been, since there are a number of other similarities between the two cities.

Indeed, during the past 25 years Mexican scholars have argued for a high degree of continuity in customs and beliefs from the Aztecs back to the Teotihuacanos, based partly on an assumed continuity in language. This hypothetical continuity, which extends through the intervening Toltec times, provides valuable clues in interpreting archaeological evidence. For example, the unity of religion and politics that archaeologists postulate at Teotihuacán is reinforced by what is known of Aztec society.

The public entrance of the Citadel is a monumental staircase on the Street of the Dead. Inside the Citadel a plaza opens onto the Temple of Quetzalcoatl, the principal sacred building in this area. The temple's façade represents the most successful integration of architecture and sculpture so far discovered at Teotihuacán [*see bottom illustration on page 46*].

The Great Compound, across the street from the Citadel, had gone unrecognized as a major structure until our survey. We found that it differs from all other known structures at Teotihuacán and that in area it is the city's largest. Its main components are two great raised platforms. These form a north and a south wing and are separated by broad entrances at the level of the street on the east and west. The two wings thus flank a plaza somewhat larger than the one within the Citadel. Few of the structures on the platforms seem to have been temples or other religious buildings. Most of them face away from the Street of the Dead, whereas almost all the other known structures along the avenue face toward it.

CITY CENTER is composed of two sets of structures, the Great Compound and the Citadel (*bottom of illustration on opposite page*). They stand on either side of the Street of the Dead, the main north-south axis of the city. A pair of avenues approaching the center of the city from east and west form the secondary axis. The city's largest religious monuments were the Pyramid of the Sun, the Pyramid of the Moon and the Temple of Quetzalcoatl, which lies inside the Citadel. Yayahuala (*left of center*) was one of many residential compounds. Its architecture is shown in detail on page 47.

One therefore has the impression that the Compound was not devoted to religious affairs. In the Citadel there are clusters of rooms to the north and south of the Temple of Quetzalcoatl, but the overall effect conveyed by the temples and the other buildings that surround the Citadel's plaza is one of a political center in a sacred setting. Perhaps some of its rooms housed the high priests of Teotihuacán.

The plaza of the Compound is a strategically located open space that could have been the city's largest marketplace. The buildings that overlook this plaza could have been at least partly devoted to the administration of the economic affairs of the city. Whatever their functions were, the Citadel and the Compound are the heart of the city. Together they form a majestic spatial unit, a central island surrounded by more open ground than is found in any other part of Teotihuacán.

The total area of the city was eight square miles. Not counting ritual structures, more than 4,000 buildings, most of them apartment houses, were built to shelter the population. At the height of Teotihuacán's power, in the middle of the first millennium A.D., the population certainly exceeded 50,000 and was probably closer to 100,000. This is not a particularly high figure compared with Old World religious-political centers; today the population of Mecca is some 130,000 and that of Benares more than 250,000 (to which is added an annual influx of a million pilgrims). One reason Teotihuacán did not have a larger population was that its gleaming lime-plastered residential structures were only one story high. Although most of the inhabitants lived in apartments, the buildings were "ranch-style" rather than "high-rise."

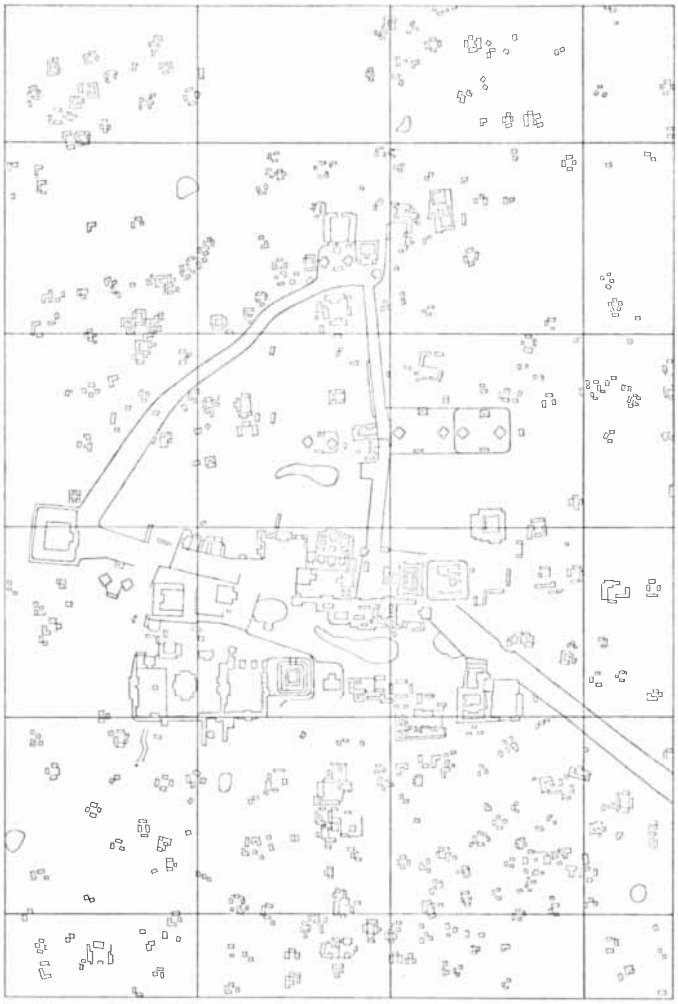
The architects of Teotihuacán designed apartments to offer a maximum of privacy within the crowded city, using a concept similar to the Old World's classical atrium house [*see illustration on page 47*]. The rooms of each apartment surrounded a central patio; each building consisted of a series of rooms, patios, porticoes and passageways, all secluded from the street. This pattern was also characteristic of the city's palaces. The residential areas of Teotihuacán must have presented a somewhat forbidding aspect from the outside: high windowless walls facing on narrow streets. Within the buildings, however, the occupants were assured of privacy. Each patio had its own drainage system; each admitted light and air to the surrounding apartments; each made it possible for the inhabitants to be out of doors yet alone. It may be that this architectural style contributed to Teotihuacán's permanence as a focus of urban life for more than 500 years.

The basic building materials of Teotihuacán were of local origin. Outcrops of porous volcanic rock in the valley were quarried and the stone was crushed and mixed with lime and earth to provide a kind of moisture-resistant concrete that was used as the foundation for floors and walls. The same material was used for roofing; wooden posts spaced at intervals bore much of the weight of the roof. Walls were made of stone and mortar or of sunbaked adobe brick. Floors and wall surfaces were then usually finished with highly polished plaster.

What kinds of people lived in Teotihuacán? Religious potentates, priestly bureaucrats and military leaders presumably occupied the top strata of the city's society, but their number could not have been large. Many of the inhabitants tilled lands outside the city and many others must have been artisans: potters, workers in obsidian and stone and craftsmen dealing with more perishable materials such as cloth, leather, feathers and wood (traces of which are occasionally preserved). Well-defined concentrations of surface remains suggest that craft groups such as potters and workers in stone and obsidian tended to live together in their own neighborhoods. This lends weight to the hypothesis that each apartment building was solely occupied by a "corporate" group, its families related on the basis of occupation, kinship or both. An arrangement of this kind, linking the apartment dwellers to one another by webs of joint interest and activity, would have promoted social stability.

If groups with joint interests lived not only in the same apartment building but also in the same general neighborhood, the problem of governing the city would have been substantially simplified. Such organization of neighborhood groups could have provided an intermediate level between the individual and the state. Ties of cooperation, competition or even conflict between people in different neighborhoods could have created the kind of social network that is favorable to cohesion.

The marketplace would similarly have made an important contribution to the integration of Teotihuacán society. If the greater part of the exchange of goods and services in the city took place in one or more major markets (such as the one that may have occupied the plaza



DENSITY OF SETTLEMENT at Teotihuacán is compared with that at Tikal, largest of the lowland Maya ceremonial centers in Middle America. The maps show the central area of each settlement at the same scale. The data for Teotihuacán (*left*) are from surveys by the author and the Mexican government. Those for Tikal (*right*) are from a survey by the University of Pennsylvania. Even though its center included many public structures, Teotihuacán's concentrated residential pattern shows its urban character.

PYRAMID OF THE SUN is as broad at the base as the great pyramid of Cheops in Egypt, although it is only half as high. It was built over the site of an earlier shrine during Teotihuacán's first major period of growth, in the early centuries of the Christian era.

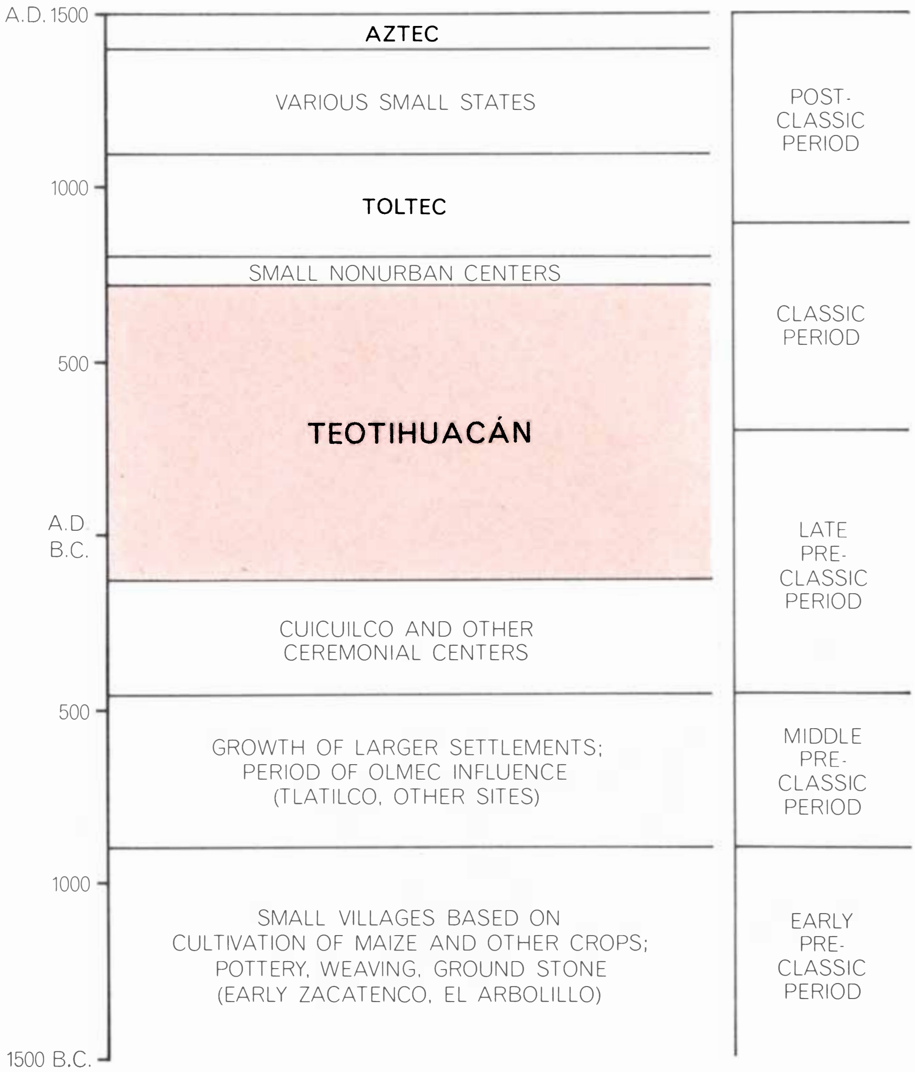
of the Great Compound), then not only the Teotihuacanos but also the outsiders who used the markets would have felt a vested interest in maintaining "the peace of the market." Moreover, the religion of Teotihuacán would have imbued the city's economic institutions with a sacred quality.

The various social groups in the city left some evidence of their identity. For example, we located a walled area, associated with the west side of the Pyramid of the Moon, where large quantities of waste obsidian suggest that obsidian workers may have formed part of a larger temple community. We also found what looks like a foreign neighborhood. Occupied by people who apparently came to Teotihuacán from the Valley of Oaxaca, the area lies in the western part of the city. It is currently under study by John Paddock of the University of the Americas, a specialist in the prehistory of Oaxaca. Near the eastern edge of the city quantities of potsherds have been found that are characteristic of Maya areas and the Veracruz region along the Gulf of Mexico. These fragments suggest that the neighborhood was inhabited either by people from those areas or by local merchants who specialized in such wares.

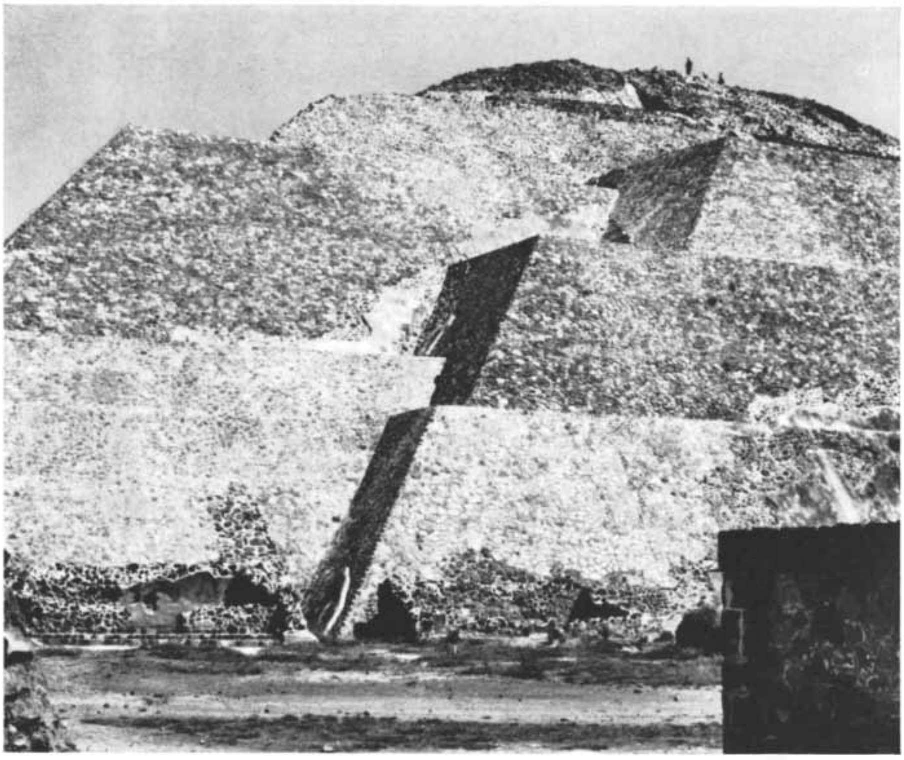
We have found evidence that as the centuries passed two of the city's important crafts—the making of pottery and obsidian tools—became increasingly specialized. From the third century A.D. on some obsidian workshops contain a high proportion of tools made by striking blades from a "core" of obsidian; others have a high proportion of tools made by chipping a piece of obsidian until the desired shape was obtained. Similar evidence of specialization among potters is found in the southwestern part of the city. There during Teotihuacán's period of greatest expansion one group of potters concentrated on the mass production of the most common type of cooking ware.

The crafts of Teotihuacán must have helped to enrich the city. So also, no doubt, did the pilgrim traffic. In addition to the three major religious structures more than 100 other temples and shrines line the Street of the Dead. Those who visited the city's sacred buildings must have included not only peasants and townspeople from the entire Valley of Mexico but also pilgrims from as far away as Guatemala. When one adds to these worshipers the visiting merchants, traders and peddlers attracted by the markets of Teotihuacán, it seems likely

HUMAN FIGURE, wearing a feather headdress, face paint and sandals, decorates the side of a vase dating from the sixth century A.D. Similar figures often appear in the city's murals.



CITY'S BIRTH took place during the late pre-Classic Period in the Valley of Mexico, about a century before the beginning of the Christian era. Other highland ceremonial centers such as Cuicuilco in the Valley of Mexico and Cholula in the Valley of Puebla were influential at that time. Although Teotihuacán fell in about A.D. 750, near the end of the Classic Period, its religious monuments were deemed sacred by the Aztecs until Hispanic times.



PYRAMID OF THE MOON, excavated in the early 1960's by a Mexican government group under the direction of Ignacio Bernal, stands at the northern end of the Street of the Dead. The façade presented to the avenue (*above*) consists of several interlocking, truncated pyramids thrusting toward the sky. The structure, 150 feet high and 490 feet wide at the base, is smaller than the Pyramid of the Sun but is architecturally more sophisticated.

TEMPLE OF QUETZALCOATL is the major religious structure within the Citadel, the eastern half of Teotihuacán's city center. The building is believed to represent the most successful integration of sculpture and architecture to be achieved throughout the city's long history. A covering layer of later construction protected the ornate façade from damage.

that many people would have been occupied catering to the needs of those who were merely visiting the city.

Radical social transformations took place during the growth of the city. As Teotihuacán increased in size there was first a relative and then an absolute decline in the surrounding rural population. This is indicated by both our data from the city and Sanders' from the countryside. Apparently many rural populations left their villages and were concentrated in the city. The process seems to have accelerated around A.D. 500, when the population of the city approached its peak. Yet the marked increase in density within the city was accompanied by a reduction in the city's size. It was at this time, during the sixth century, that urban renewal programs may have been undertaken in areas where density was on the rise.

Such movements of rural and urban populations must have conflicted with local interests. That they were carried out successfully demonstrates the prestige and power of the hierarchy in Teotihuacán. Traditional loyalties to the religion of Teotihuacán were doubtless invoked. Nevertheless, one wonders if the power of the military would not have been increasingly involved. There is evidence both in Teotihuacán and beyond its borders that its soldiers became more and more important from the fifth century on. It may well be that at the peak of its power and influence Teotihuacán itself was becoming an increasingly oppressive place in which to live.

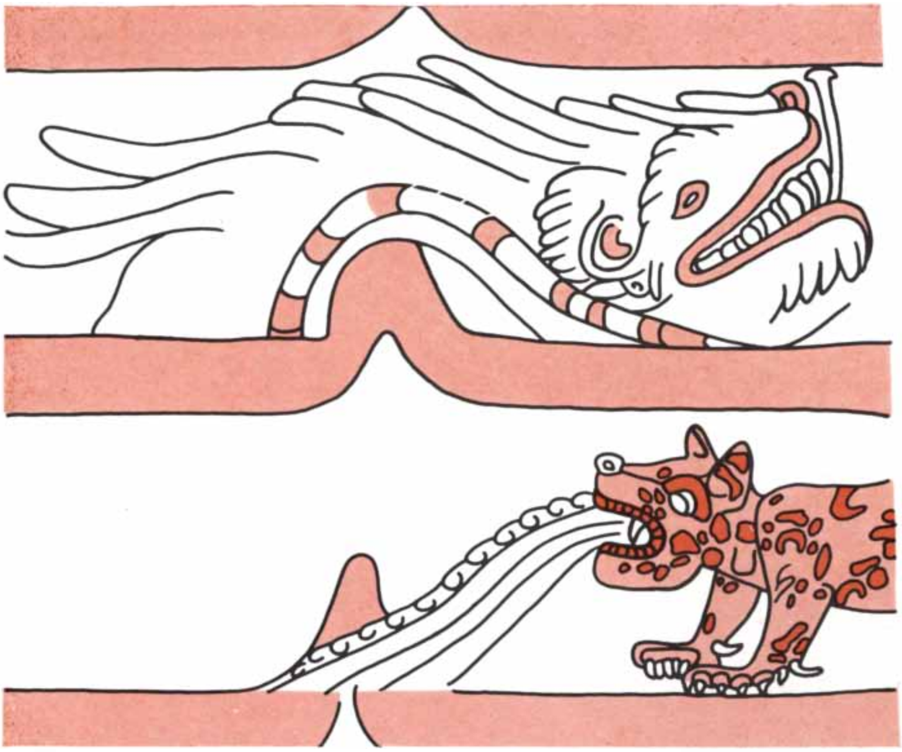
The best evidence of the power and influence that the leaders of Teotihuacán exercised elsewhere in Middle America comes from Maya areas. One ancient religious center in the Maya highlands—Kaminaljuyu, the site of modern Guatemala City—appears to have been occupied at one time by priests and soldiers from Teotihuacán. Highland Guatemala received a massive infusion of Teotihuacán cultural influences, with Teotihuacán temple architecture replacing older styles. This has been recognized for some time, but only recently has it become clear that Teotihuacán also influenced the Maya lowlands. The people of Tikal in Guatemala, largest of the lowland Maya centers, are now known to have been under strong influence from Teotihuacán. The people of Tikal adopted some of Teotihuacán's artistic traditions and erected a massive stone monument to Teotihuacán's rain god. William R. Coe of the University of Pennsylvania and his colleagues, who are working at

Tikal, are in the midst of evaluating the nature and significance of this influence.

Tikal provides an instructive measure of the difference in the density of construction in Maya population centers and those in central Mexico. It was estimated recently that Tikal supported a population of about 10,000. As the illustration at the top of page 44 shows, the density of Teotihuacán's central area is strikingly different from that of Tikal's. Not only was Teotihuacán's population at least five times larger than Tikal's but also it was far less dispersed. In such a crowded urban center problems of integration, cohesion and social control must have been of a totally different order of magnitude than those of a less populous and less compact ceremonial center such as Tikal.

What were the circumstances of Teo-

APARTMENT HOUSE typical of the city's many multiroomed dwellings was excavated in 1961 by Laurette Séjourné. The outer walls of the compound conform with the 57-meter module favored by the city's planners. Within its forbidding exterior (*see south façade at bottom of illustration*) individual apartments comprised several rooms grouped around unroofed patios (*smaller white areas*).



FEATHERED SERPENT, from one of the earlier murals found at Teotihuacán, has a free, flowing appearance. The animal below the serpent is a jaguar; the entire mural, which is not shown, was probably painted around A.D. 400. It may portray a cyclical myth of creation and destruction. The city's principal gods were often represented in the form of animals.

LATER SERPENT GOD, with a rattlesnake tail, is from a mural probably painted less than a century before the fall of Teotihuacán. The figure is rendered in a highly formal manner. A trend toward formalism is apparent in the paintings produced during the city's final years.

tihuacán's decline and fall? Almost certainly both environmental and social factors were involved. The climate of the region is semiarid today, and there is evidence that a long-term decline in annual rainfall brought the city to a similar condition in the latter half of the first millennium A.D. Even before then deforestation of the surrounding hills may have begun a process of erosion that caused a decrease in the soil moisture available for crops. Although persistent drought would have presented increasingly serious problems for those who fed the city, this might have been the lesser of its consequences. More ominous would have been the effect of increasing aridity on the cultivators of marginal lands and the semisedentary tribesmen in the highlands north of the Valley of Mexico. As worsening conditions forced these peoples to move, the Teotihuacanos might have found themselves not only short of food but also under military pressure along their northern frontier.

Whether or not climatic change was a factor, some signs of decline—such as the lowering of standards of construction and pottery-making—are evident during the last century of Teotihuacán's existence. Both a reduction in population and a tendency toward dispersion suggest that the fabric of society was suffering from strains and weaknesses. Once such a process of deterioration passed a critical point the city would have become vulnerable to attack.

No evidence has been found that Teotihuacán as a whole had formal defenses. Nonetheless, the valley's drainage pattern provides some natural barriers, large parts of the city were surrounded by walls or massive platforms and its buildings were formidable ready-made fortresses. Perhaps the metropolis was comparatively unprotected because it had for so long had an unchallenged supremacy.

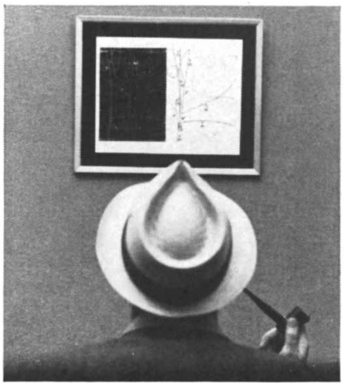
In any case, archaeological evidence indicates that around A.D. 750 much of central Teotihuacán was looted and burned, possibly with the help of the city's own people. The repercussions of Teotihuacán's fall seem to have been felt throughout civilized Middle America. The subsequent fall of Monte Alban, the capital of the Oaxaca region, and of many Maya ceremonial centers in Guatemala and the surrounding area may reasonably be associated with dislocations set in motion by the fall of Teotihuacán. Indeed, the appropriate epitaph for the New World's first major metropolis may be that it was as influential in its collapse as in its long and brilliant flowering.

The hope of doing each other some good prompts these advertisements

A service for the bubble-chamber trade

Kodak is now thinking in terms of two basic bubble-chamber films for high-energy physics: bright-field and dark-field. The two films need be nothing more than points of departure for further adaptation to special requirements, as necessary. A reorganized and growing force of Kodak men is busy working out details with the designers and operators of bubble chambers. Their mission is to hold and extend a position of leadership in this branch of photographic technology. This can be accomplished only through the physical results delivered. It is a hard route, without alternatives. Newcomers to the dialogue make contact by addressing Instrumentation Products, Eastman Kodak Company, Rochester, N. Y. 14650.

There is a lot of money in high-energy physics, which fact creates severe problems for the physicists and justifies Kodak's interest in it under terms of Kodak's charter. Because goings-on in the subnuclear zoo have large denominators in their probabilities, bubble chambers consume film by the ton. Millions of pictures of tracks of bubbles are screened at public expense by large numbers of ladies to find which ones are worth submitting to further scrutiny by computers in hopes that a few of the pictures will shake out as possible evidence for or against hypotheses tentatively put forth by a few theoreticians and tentatively questioned by a few others. The cost of the film and the wages of the ladies represent, of course, only a small fraction of the bill that the physicists have to explain, somehow. When ladies sit packing sardines into cans instead of looking at pictures of bubbles, no explanation is required.



This man likes sardine sandwiches. He also votes in congressional elections. We are not sure whether he drives a cab in Manhattan or tries to grow a little tobacco in Kentucky. In either case, life has not been easy. He hopes his son will do better. Bright kid, doing real well in college, where he has a scholarship and where in the physics department is displayed the bubble-track picture from Brookhaven National Laboratory that established the existence of the omega-minus particle.

The what?

The kid wants to go on for a doctor's degree in physics. He probably has to know what things like that mean.

We are of two minds about that man's son. On the one hand, we'd like to see him use his time in physics lab toward an engineering career. We simply cannot understand why more kids aren't going into engineering. Maybe they don't know what an engineer does, how he determines the most efficient way to get things done, whether it's getting sardines into a can with less labor or manufacturing photographic film or hunting intermediate vector bosons or saying how much photographic quality is worth in the boson hunt. Engineers find money convenient, particularly for the measurement of efficiency, and we can understand that.

On the other hand, if the kid thinks he wants to understand more than that, maybe he ought to make himself into one of those hypothesizing theoreticians who keep the film-consuming bubble chambers busy.

A polymer is only a polymer

Since textile technology antedates science, it may still have some catching up to do. It can use new talent. It enjoys plenty of economic support of a nature that strongly couples textile technology and science to the world of marketing.

There is no present shortage of kinds of polymer that might conceivably be spun into fibers, and there are certainly a lot more to come. But how will they fare with the girls on Fifth Avenue? What will the boys say on Seventh Avenue and in the Lodi, N.J. dye plants and in the knitting mills of the Carolinas?

Opinions, desires, likes, dislikes, whims—they matter. The subjective is no less important than the objective. People who respect both sides of the coin and strive to relate them make good marketers. It's hard to get very far in fibers without them, any more than we can get along without those who can easily put together an hour's lecture on stereospecificity.

We have gotten rather far in fibers with our trademarks "Kodel," "Verel," "Estron," "Chromspun." To get farther we need recruits prepared to accept and develop a concept of marketing so broad as to encompass at one end the creation and propagation of basic and badly needed improvements in some of mankind's oldest and most undeniably essential technologies, and at the other end to convince the world that the improvements are worth having.

Through Business and Technical Personnel Department, Eastman Kodak Company, Rochester, N. Y. 14650, technical people (and even non-technical people) can investigate career opportunities with our subsidiary Eastman Chemical Products, Inc., which markets fibers from our manufacturing divisions Tennessee Eastman Company and Carolina Eastman Company.

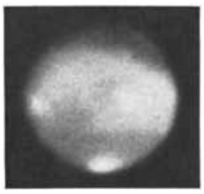
Mars photography: what to do it on

Plates for photographing Mars are still mighty small business though Mars photographers have been at it for a long time. For this year's opposition, the Observatory of New Mexico State University is photographing the planet in six spectral bands every two hours. The most fluctuation in appearance and the most bafflement to explain it occur in the band centered at 550mμ. For this band Dr. Bradford A. Smith, the observatory's director, has chosen KODAK "Spectroscopic" Plates, Type III-G, which establish the long-wavelength limit of sensitivity at about 600mμ, have high speed for the job, and are not too grainy to show detail in the 1 to 3-millimeter image of the planet's disk formed by the observatory's 30-meter focal length instrument. He also uses the same type of plates for Jupiter, where the 550mμ band probes the upper layers of the giant planet's dense atmosphere.

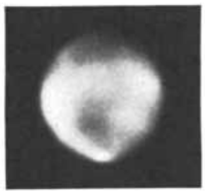
Elsewhere other astronomers maintain a watch on Mars also, whatever arrangements the space travel agencies have in mind for closer looks than the one that earthbound astronomers will be given at the midsummer '69 opposition and the considerably closer one of September, 1971. After that, the high ellipticity of the Martian orbit will impose a 15-year wait for another really close opposition.

Dr. Smith's need has pulled Type III-G plates out of the limbo to which we had prematurely abandoned the type. Astronomy with feet firmly planted on the ground still has vigils to keep photographically.

Inquiries about specialized photographic plates for scientific purposes should be directed to Eastman Kodak Company, Industrial Photo Methods, Rochester, N. Y. 14650.



Feb. 26, 1965



April 20, 1965

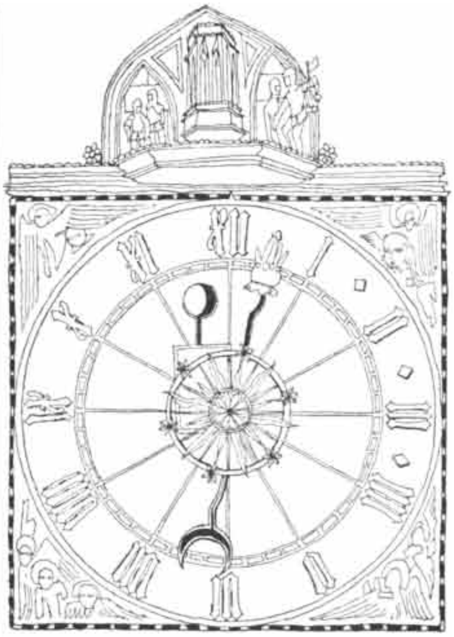
April 22, 1965

April 25, 1965

New Mexico State University Observatory photographs on KODAK "Spectroscopic" Plates, Type III-G.

Kodak

SCIENCE AND



Controlled Technology

In an apparent effort to retard the development of nuclear weapons in other nations the U.S. has brought a halt to privately sponsored work on the gas-centrifuge process for the production of uranium 235. The policy appears to reflect concern that the details of the process, which could lend itself to undetected weapon-making, might pass to other countries. Research on the gas-centrifuge technique will continue, but it will all be conducted by the Government or by private companies under the contractual control of the Atomic Energy Commission.

The gas-centrifuge process was one of the several techniques considered during World War II for separating uranium 235 from natural uranium. The process adopted for large-scale production was gaseous diffusion. Both processes take advantage of the fact that U-235 is somewhat lighter than U-238, the principal isotope of uranium. Both processes begin with natural uranium in the form of a gaseous compound. In the diffusion process the separation of U-235 from U-238 is achieved by forcing the gas through membranes; U-235 passes through them a trifle more easily. In the centrifuge the separation takes place when the gas is spun at high speed.

The centrifuge process has not been perfected for large-scale operation. Several years ago the AEC authorized research on the process by private industry, which is interested in obtaining uranium only slightly enriched with U-235 for use in the reactors of atomic power plants. The question was whether or not the process could be made economically competitive with gaseous diffusion, which is expensive and uses large quantities of electricity but for which big Government-owned plants already exist.

As long ago as 1960 John A. McCone, then chairman of the AEC, pointed out that the gas-centrifuge process could complicate efforts to restrain the spread of nuclear weapons. "A production plant using the gas-centrifuge method could be simply housed," he said. "Its power requirements would be relatively small, and there would be no effects of operation that would easily disclose the plant." The AEC, announcing the new policy under its statutory authority to restrict access to nuclear information for reasons of national security, said it might modify the policy "if at some future time it is in the national interest to allow private participation in gas-centrifuge developments."

The Feel of the Moon

The first tactile exploration of an extraterrestrial body, performed on the moon last month by *Surveyor 3*, suggests that the material of the lunar surface is denser than other data had indicated. The material, at least in the section of the Ocean of Storms where *Surveyor 3* landed, had the consistency of a slightly cohesive fine sand or silt. A material less dense, lighter and perhaps powdery had seemed likely on the basis of radar data and temperature changes of the lunar surface recorded during eclipses.

Surveyor 3 conducted its mechanical exploration of the lunar surface with a small scoop that could be extended as much as five feet out from the spacecraft and could dig trenches or bang on the surface over an area of about 24 square feet. The spacecraft also had a television camera that could observe the scoop and could, like the *Surveyor 1* camera that made more than 11,000 photographs of the lunar surface a year ago, examine the area around the spacecraft.

Ronald F. Scott of the California Institute of Technology, who was chief scientist for the digging operations of *Surveyor 3*, said on the basis of preliminary analysis of the data that the material examined by the scoop did not appear to be of low density. (Earlier estimates had set the density of the lunar surface material at one gram per cubic centimeter or lower.) He described the material as "granular, soil-like, with particles of minerals that are very small" and said that, like soil on the earth, the material "firms up the deeper you go."

Useful Tracks

Charged nuclear particles, it was discovered less than a decade ago, leave tracks in a wide range of solids. Techniques for bringing out and interpreting these tracks have now been developed, providing what appears to be a powerful new tool with potential applications in areas as dissimilar as nuclear physics and archaeology. The work has been done primarily by Robert M. Walker, now at Washington University in St. Louis, and R. L. Fleischer and P. B. Price of the General Electric Research Laboratory.

When a charged particle moves through a solid, it ionizes atoms along its path. In insulating solids (most minerals, glasses and plastics) the ionization leads to disruption of the solid's structure, leaving a narrow trail of damage that can sometimes be discerned with difficulty in an electron micrograph. At General Electric in 1961 Walker and Price learned how to "develop" the tracks in mica by etching a sample with acid. The acid attacks the damaged region preferentially, creating a channel that can be enlarged by prolonged etching until it is readily visible with a light microscope. Fleischer and Price extended the technique to other minerals and to glasses and plastics, and during a year at the University of Paris, Walker and his colleagues there discovered particle tracks in meteorites.

Two broad categories of uses have opened up for the technique, one involving man-made tracks and the other involving natural "fossil" tracks. In the first category are such applications as particle detectors for nuclear physics and a new kind of microfilter (made by irradiating a thin sheet of plastic with a beam of particles and etching the resulting tracks to the desired diameter).

The second category includes what may be the most exciting applications: the examination of natural materials—terrestrial and extraterrestrial—in order to date them and learn their radiation

history. Most terrestrial minerals contain traces of uranium 238, which fissions spontaneously at a known rate. By counting the fission tracks in a specimen and comparing the number with the specimen's present content of U-238 one can determine the date when a mineral became cool enough to retain tracks. The method, which is simple compared with other dating techniques, has been applied to archaeological artifacts of glass and of other materials as well as to geological specimens, and over a time range of about a year (in uranium-rich samples) to a billion years. In the case of extraterrestrial material such as meteorites, tracks are produced not only by spontaneous U-238 fission but also by various kinds of cosmic ray events and perhaps by spontaneous fission of isotopes that are now extinct. One can distinguish tracks that arose in different ways on the basis of their characteristics and the composition of the sample. It is therefore possible to capitalize on the great age of meteorites and their long exposure to cosmic rays in order to learn about the history of the solar system and the nature of cosmic radiation.

Now Walker and W. H. Huang have reported in *Science* on a new kind of fossil track dating. It depends on the fact that when uranium or thorium atoms decay by emitting alpha particles, the emitting nucleus recoils, leaving a short track. The track can be etched and viewed with a phase-contrast microscope. There are thousands of times as many alpha-recoil tracks as fission tracks in a mineral, and so the newly discovered tracks give promise of greatly improved sensitivity in dating and other studies.

Turned-off Genes

Living cells, and even viruses, have more genes than they need at any particular time. A theory that cells and viruses have "repressor" genes capable of switching off unneeded genes has been confirmed in a series of experiments at Harvard University.

Late last year Walter Gilbert and Benno Müller-Hill reported the isolation of the product of the lactose repressor gene, a gene in the bacterium *Escherichia coli* that can switch off the genetic machinery for making beta-galactosidase. This is an enzyme that splits lactose sugar, and thus it is needed only if the bacterium's diet contains lactose. If lactose is absent, production of the enzyme is switched off by the repressor gene.

Gilbert and Müller-Hill found that the product of this gene—the lactose repressor itself—is a protein. They isolated the protein by assuming that it is bound to an "inducer" molecule, which they surmised was either lactose or a closely related compound. The inducer turned out to be the latter: isopropyl-thio-galactoside, a compound the *E. coli* cell evidently produces from lactose. By binding itself to the lactose repressor the inducer inactivates the repressor, whereupon the genes that make beta-galactosidase are free to function.

At about the same time another Harvard investigator, Mark Ptashne, independently isolated a repressor made by the bacterial virus known as phage lambda. This repressor, which blocks the function of phage genes, also proved to be a protein.

When these two repressor proteins—one from a bacterium, the other from a virus—were first announced, their mode of action was still not known. In proposing the existence of repressor genes several years ago François Jacob and Jacques Monod of the Pasteur Institute considered several modes of operation. The simplest would be for the repressor substance to bind itself directly to one or more genes responsible for the synthesis of a particular enzyme, such as beta-galactosidase. Since frequently more than one gene is needed to specify an enzyme, Jacob and Monod suggested that the expression of these genes is controlled by an "operator" gene. In that case the repressor would have to bind itself only to the operator. One can, however, conceive of many other ways in which the repressor could prevent the synthesis of a particular enzyme.

Ptashne has now reported in a recent issue of *Nature* that the phage lambda repressor is bound directly to a region of the molecule of deoxyribonucleic acid (DNA) that comprises the genes of the phage. In parallel studies Gilbert and Müller-Hill have found that the lactose repressor is bound to a region of the DNA of *E. coli*. (A report of their work is in press.) Thus the simplest hypothesis of repressor action has evidently been confirmed.

Cosmic Reversal?

The discovery of miniature tektites in cores of sediment brought up from the ocean bottom off Java and Australia has raised the possibility that the most recent reversal of the earth's magnetic field, some 700,000 years ago, was caused by a collision with a cosmic body. At the April meeting of the American Geophysical Union, Bill Glass and Bruce C. Heezen of Columbia University's Lamont Geological Observatory reported that many of the distinctive glassy beads that are apparently the product of collisions between the earth or the moon and stray wanderers in space have been found at or just above the points in nine cores at which the reversal of the earth's magnetic field is evident.

Only a few hundredths of an inch in diameter, these microtektites have the same age as the larger glassy objects that occupy a "strewn field" extending from Thailand to Tasmania; both therefore probably have the same origin. Before the existence of the submerged tektites was known, the total weight of the material in the Australasian strewn field had been estimated at 1,000 tons. Heezen and Glass have raised this estimate to 150 million tons, equivalent to a sphere roughly a third of a kilometer in diameter. They suggest that an encounter between the earth and such a body could have produced mechanical or electromagnetic effects sufficient to upset the magnetohydrodynamic motions of the earth's core and cause a reversal of the main dipole field.

The Galactic Core Revealed

The center of our galaxy, which is presumably thick with stars, cannot be seen at visible wavelengths because it is hidden behind huge masses of interstellar dust. In recent months, however, Eric Becklin and Gerry Neugebauer of the California Institute of Technology have demonstrated that the center can be observed through the dust with infrared detectors used in conjunction with optical telescopes.

It is estimated that the dust lying between us and the galactic center reduces the light originating in the center by a factor of 10 billion. For infrared radiation with a wavelength of one micron the reduction is 100,000, and for infrared at 2.2 microns it drops to about 10. Becklin and Neugebauer made their initial observations of the galactic center last summer at wavelengths between two and 2.4 microns, using a 24-inch reflecting telescope on Mount Wilson equipped with a lead sulfide infrared detector cooled with liquid nitrogen. More detailed studies at 1.65, 2.2 and 3.4 microns were later made with the 60-inch Mount Wilson reflector and the 200-inch reflector on Palomar Mountain.

Observed in the infrared, the galactic center coincides in position and size with the celestial radio source known as Sagittarius A, which lies either in the galactic center or along our line of sight to it. (Radio waves are almost totally unaffected by interstellar dust.) In high-reso-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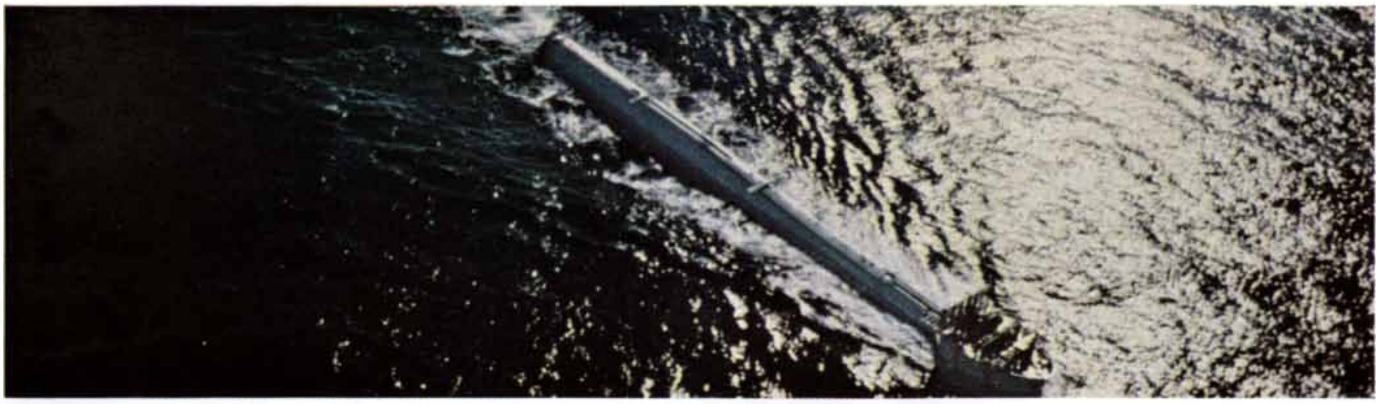
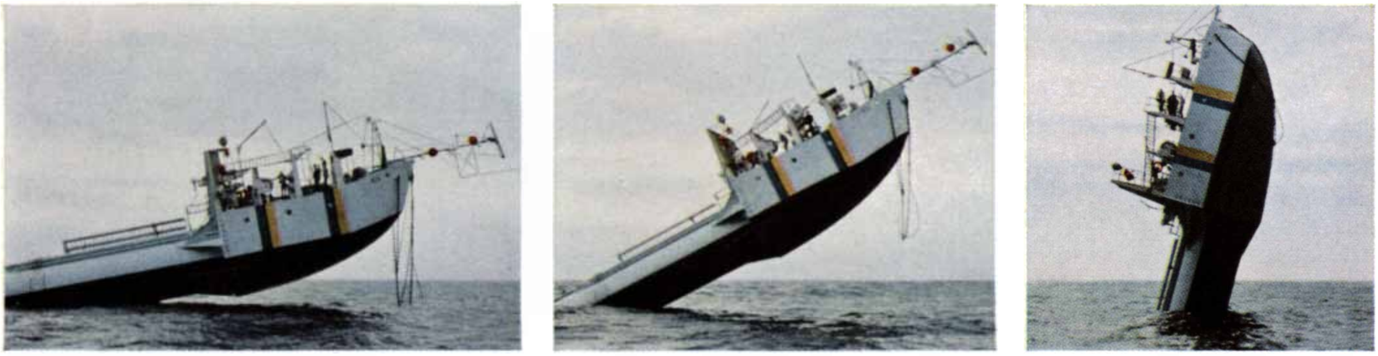
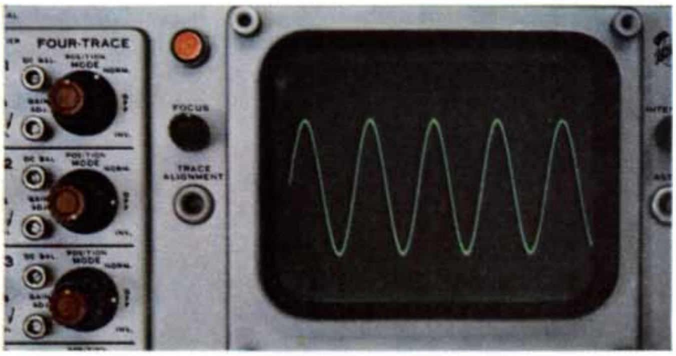


FLIP (short for Floating Instrument Platform) is one of the most unusual research laboratories ever built. It is used to study the behavior of sound in the sea's depths. Underway, FLIP is long and slender, and it must resist excessive sagging in heavy seas. Its designers needed a special steel to make the hull capable of handling the stresses, and they found it in USS TRI-TEN High Strength Steel.



When FLIP is flooded at one end, the other end rises to form a nearly rock-solid floating platform. In 35-ft. seas, FLIP bobs a scant 3 inches. Upright, 300 of FLIP's 355 ft. are underwater.



FLIP studies will help develop superior sonar systems for our nation's defense. USS-innovated TRI-TEN Steel is 40% stronger than regular steel. Thus, the extra strength needed to make FLIP's hull design possible could be obtained without using thicker steel plates, saving many tons of useless dead weight. For more information about USS High Strength Steels, write United States Steel, Room 4522, 525 William Penn Place, Pittsburgh, Pa. 15230.

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USS United States Steel: where the big idea is innovation

lution infrared scans made with the 200-inch telescope the galactic center shows up as a brilliant core 30 seconds of arc in diameter, which is a sixtieth of the apparent diameter of the moon. Near the galactic center there are several weaker and more extended sources of infrared. The observations made so far indicate that the nucleus of our galaxy closely resembles the nucleus of our galactic neighbor the Great Nebula in Andromeda.

Becklin and Neugebauer estimate that the energy emitted from the galactic core, the diameter of which is some five light-years, approaches 10^{40} ergs per second. This is equivalent to the output of some three million suns. If this estimate is correct, the density of matter in the core is about 10 million times greater than the density in the spiral arm—30,000 light-years from the galactic center—where our sun is located.

Earliest New World Men

Primitive tools found in association with the remains of long-extinct mammals in Mexico and the Canadian Northwest suggest that early man reached the Western Hemisphere at least 20,000 years ago and perhaps as much as 40,000 years ago. Heretofore evidence of man's presence in the New World earlier than some 12,000 years ago has been doubtful. The Mexican discovery consists of stone tools embedded in a deep deposit of gravels in the central state of Puebla. Beginning in 1962 Juan Armenta Camacho of the University of Puebla and Cynthia Irwin-Williams of Eastern New Mexico University have unearthed the tools at a number of sites in the gravels, which have also yielded the bones of mammoths and of extinct forms of the horse and the camel. One site shows evidence that the occupants had killed a mastodon, another of the primitive elephants that inhabited the Americas during the ice age. At three of the sites a layer of volcanic ash overlies the gravel in which the tools are found: a tree trunk buried in the ash layer has now yielded conflicting carbon-14 dates. Some wood samples appear to be about 20,000 years old, others about 40,000. Efforts are being made to resolve the discrepancy, but even the more recent date would nearly double the antiquity of man in the New World.

The sites in Mexico may have to share honors with the one in Canada. The discovery there consists of several bone implements, including one made out of mammoth bone, found among the remains of mammoths, sloths and extinct forms of the horse and the camel in a glacial deposit on the banks of the Old Crow River in the Yukon. C. R. Harington, a paleontologist at Canada's National Museum, came on the site while exploring the river last year; W. N. Irving, an archaeologist at the museum, joined him in excavating the bones. Carbon-14 and other age determinations have not yet been completed, but the investigators point out that carbon-14 dating has shown mammoth remains in Alaska and Siberia to be more than 20,000 years old. Any mammoth-bone implement found elsewhere in the Arctic, they contend, should be at least as old and possibly older.

Self-induced Transparency

A novel effect of the light produced by a pulsed laser has been discovered by physicists at the University of California at Berkeley. They have succeeded in passing short bursts of coherent light from such a laser through a thickness of material that is opaque to a similar burst of incoherent light from an ordinary lamp. The new effect, called "self-induced transparency by pulsed coherent light," was the subject of a paper delivered by E. L. Hahn of the Berkeley group at the spring meeting of the American Physical Society held in Washington.

According to Hahn, when ordinary incoherent light is absorbed by an opaque material, the light pulse gives up its energy of vibration to the target atoms as it penetrates a short distance into the material. This energy can never return to the light beam. In contrast, a short burst of coherent laser light can be intense enough to overcome atomic friction: the atoms' electrons are forced momentarily to absorb the light energy, but they promptly return the energy to the laser beam in the same direction in which it was originally traveling. This happens because the electrons are set in a cooperative motion that is synchronous with the coherent-light vibrations.

So far the transparency effect has been observed only in insulators and not in metals. Theoretically the same effect should be obtainable with radio waves, microwaves or even sound waves, all of which are usually absorbed in matter. Hahn and his colleagues believe the new effect may be useful in studying the rapid motions of atoms and electrons in solids. The slowing down of the light pulse as it passes through the material may also prove to be useful in communications and computer technology.

PATENT NO. 3117260: THE DIFFUSION ISOLATION TECHNIQUE

VACUUM COATED STEELS

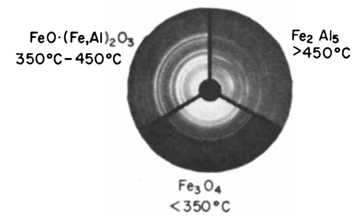
An idea borrowed from the electronics field, "vacuum evaporation", has multiplied the number of potential steel coatings to create a new generation of valuable products.

by R. P. Morgan, Research Manager

As if to emphasize the technological changes which are taking place in many of its processing operations, the steel industry recently borrowed an idea from the electronics field, scaled it up a hundred times and introduced a new steel coating process. The technique, used in the production of transistors and other space age electronic components, consists of evaporating metallic or non-metallic materials in high vacuum and condensing them onto a prepared substrate to form a coating. Youngstown Steel has been working with this process for the past four years, exploring its general utility. In many cases, special surface properties have been obtained on steel strip which could not have been economically achieved by other means, and from this work a new generation of coated steel products has emerged.

Research has reached a stage where a high speed pilot line is being used to prepare coils of steel with different coatings for customer evaluation. A key feature of the system is a series of remarkably effective roll seals. These seals enable a clean strip to pass continuously from the atmosphere into the high vacuum evaporation chamber operating at a pressure below 10^{-4} Torr, and out again. Inside the evaporating chamber, a specially designed crucible containing the coating material is heated by a beam of high energy electrons to some characteristic temperature at which large quantities of vapor are rapidly evolved. For example, with aluminum this temperature is about 1700°C. The vapor is immediately condensed onto the moving steel strip to form the desired coating. A number of individual evaporators is used in order to increase the operating speed and to produce a coating on both sides of the strip ranging in thickness from 0.001 to 1.0 mil. The use of the electron beam as a heating device permits the evaporation of a wide range of coating materials including those with very high evaporation temperatures.

One of the important technical problems in this field is that of obtaining good adhesion between the condensate and the steel substrate. Procedures vary for each material; however, again taking aluminum as an example, the steel must be pickled and subsequently preheated to a temperature of 400°C in vacuum before deposition of the coating. Electron diffraction studies of the interface between the steel and the aluminum have shown that a magnetite film is present at substrate temperatures below about 350°C, (see illustration) and is accompanied by poor adhesion.



VARIATIONS IN INTERMEDIATE LAYER BETWEEN VACUUM DEPOSITED ALUMINUM AND STEEL

As the substrate temperature is increased towards 450°C, an alumina spinel of varying composition is formed and the adhesion and corrosion resistance of the coating increase markedly. At temperatures above 450°C, an Fe_2Al_5 phase can be detected. Adhesion at this point is excellent but rapid total conversion of thin films to the brittle intermetallic can occur. This operating range is therefore generally avoided. Other coating metals of low melting point and high vapor pressure, such as zinc, require more critical control of substrate temperature. In addition, they require the use of an intermediate layer of a second metal to secure acceptable adhesion.

Other aspects of the process are under investigation including those connected with the control of coating properties and those related to the development of new equipment designs for more efficient operation. Data are steadily being accumulated through operation of the pilot facility and this information will eventually be used to further the construction of full scale production equipment.

Much of the work which has already been carried out points to the unusual flexibility of the new technique and the commercial significance of the products. For example, the "tin" can which is, of course, basically a "steel" can could be manufactured by substituting another metal for tin. Aluminum or chromium are contenders in this respect. They provide an attractive finish, are readily available, and have chemical properties which encourage their use in certain food containers.

There are many additional examples of ways in which vapor deposited coatings can be used to broaden the performance of a steel product. Zinc, for special automotive applications, and stainless steel for architectural usage are both promising materials. Experiments have already shown that stainless steel compositions can be evaporated and condensed to form finishes with great corrosion resistance. The application of metals such as copper for brazability, or titanium for chemical inertness is also under consideration.

A great deal of additional research and development will be necessary to create the systems which will economically process a hundred thousand tons of these new strip products a year. Nevertheless, it is apparent at this time that the steel industry in its search for effective new techniques has discovered in vacuum evaporation a method with significant potential.

Steel and steel application problems are continually under investigation at Youngstown's research center in support of Youngstown's position as a major supplier of a wide variety of low carbon and low alloy products. The work on coated products represents only a small part of the 24 hour a day research effort. If you think Youngstown can help you, call at your convenience, or write Department 251 E6.

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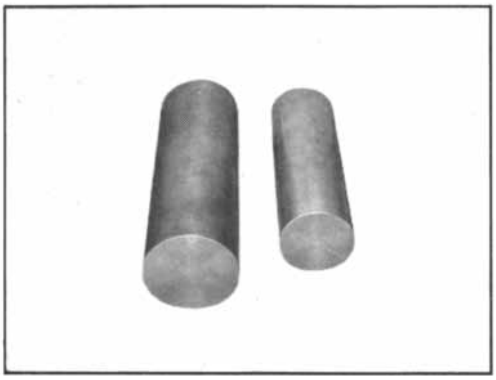

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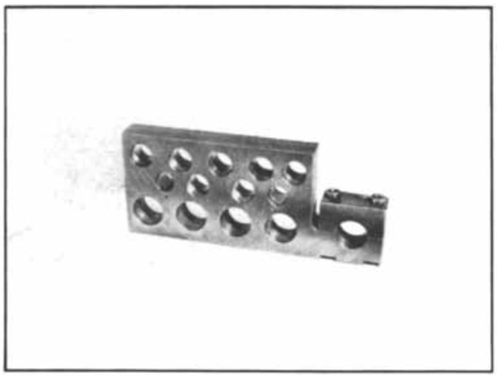

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NAVY

Diamonds help keep the Phantoms flying.

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Molecular Isomers in Vision

Certain organic compounds can exist in two or more forms that have the same chemical composition but different molecular architecture. One of them is the basis for vision throughout the animal kingdom

by Ruth Hubbard and Allen Kropf

Molecular biology, which today is so often associated with very large molecules such as the nucleic acids and proteins, actually embraces the entire effort to describe the structure and function of living organisms in molecular terms. We are coming to see how the manifold activities of the living cell depend on interactions among molecules of thousands of different sizes and shapes, and we can speculate on how evolutionary processes have selected each molecule for its particular functional properties. The significance of precise molecular architecture has become a central theme of molecular biology.

One of the more recent observations is that biological molecules are not static structures but, in a number of well-established cases, change shape in response to outside influences. As an example, the molecule of hemoglobin has one shape when it is carrying oxygen from the lungs to cells elsewhere in the body and a slightly different shape when it is returning to the lungs without oxygen [see "The Hemoglobin Molecule," by M. F. Perutz; SCIENTIFIC AMERICAN, November, 1964]. A somewhat similar changeability in the molecule of lysozyme, which breaks down the walls of certain bacterial cells, was described in these pages last November by David C. Phillips of the University of Oxford. In this article we shall describe some of the simplest changes in shape that can take place in much smaller organic molecules and show how change of this type provides the basis of vision throughout the animal kingdom.

A "Childish Fantasy"

The notion that molecules of the same atomic composition might have different spatial arrangements is less than 100 years old. It dates back to a paper titled *"Sur les formules de structure dans l'espace,"* written in 1874 by Jacobus Henricus van't Hoff, then an obscure chemist at the Veterinary College of Utrecht. At that time it was still respectable to doubt the existence of atoms; to speak of the three-dimensional arrangement of atoms in molecules was a speculative leap of great audacity. Van't Hoff's paper provoked Hermann Kolbe, one of the most eminent organic chemists of his day, to publish a withering denunciation.

"Not long ago," Kolbe wrote in 1877, "I expressed the view that the lack of general education and of thorough training in chemistry of quite a few professors of chemistry was one of the causes of the deterioration of chemical research in Germany.... Will anyone to whom my worries may seem exaggerated please read, if he can, a recent memoir by a Herr van't Hoff on 'The Arrangements of Atoms in Space,' a document crammed to the hilt with the outpourings of a childish fantasy. This Dr. J. H. van't Hoff, employed by the Veterinary College at Utrecht, has, so it seems, no taste for accurate chemical research. He finds it more convenient to mount his Pegasus (evidently taken from the stables of the Veterinary College) and to announce how, on his daring flight to Mount Parnassus, he saw the atoms arranged in space."

Van't Hoff's "childish fantasy" was put forth independently by the French chemist Jules Achille le Bel and was soon championed by a number of leading chemists. In spite of Kolbe's opinion, evidence in support of the three-dimensional configuration of molecules rapidly accumulated. In 1900 van't Hoff was named the first recipient of the Nobel prize in chemistry.

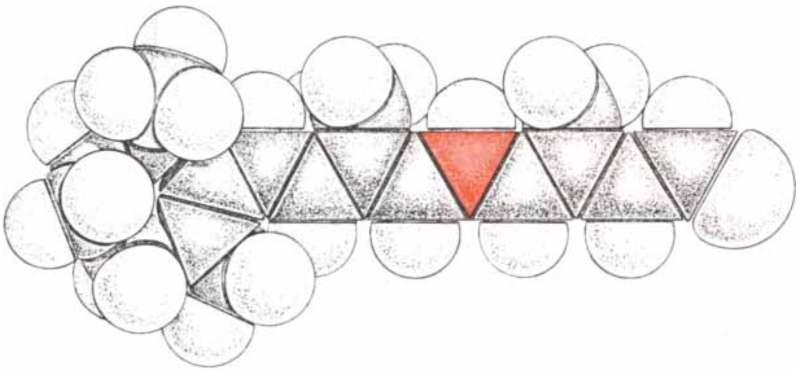
Even before van't Hoff's paper of 1874 chemists had begun using the concept of the valence bond, commonly represented by a line connecting two atoms. It was not unnatural, therefore, to associate the valence bond concept with the idea that atoms were arranged precisely in space. The simplest hydrocarbon, methane (CH_4), would then be represented as a regular tetrahedron with a hydrogen atom at each vertex joined by a single valence bond to a carbon atom at the center of the structure [*see illustration on page 66*].

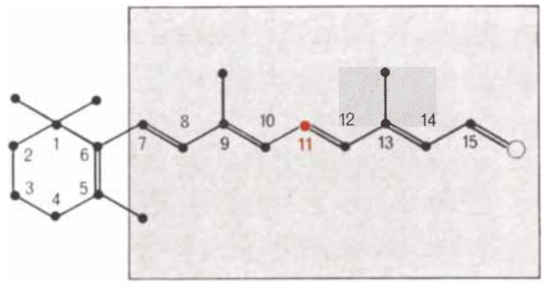
The valence bond remained an elusive concept, however, until G. N. Lewis postulated in 1916 that a common type of bond—the covalent bond—was formed when two atoms shared two electrons. "When two atoms of hydrogen join to form the diatomic molecule," he wrote, "each furnishes one electron of the pair which constitutes the bond. Representing each valence electron by a dot, we may therefore write as the graphical formula of hydrogen H : H." He visualized this bond to be "that 'hook and eye,' which is part of the creed of the organic chemist." To explain why electrons should tend to pair in this manner, Lewis could offer nothing beyond an intuitive principle that he called "the rule of two."

The rule of two entered the physicist's description of the atom when Wolfgang Pauli put forward the exclusion principle in 1923. This states that electrons in atoms and molecules are found in "orbitals" that can accommodate at most two electrons. Since electrons can be regarded as minuscule spinning negative charges, and thus as tiny electromagnets, the two electrons in each orbital must be spinning in opposite directions.

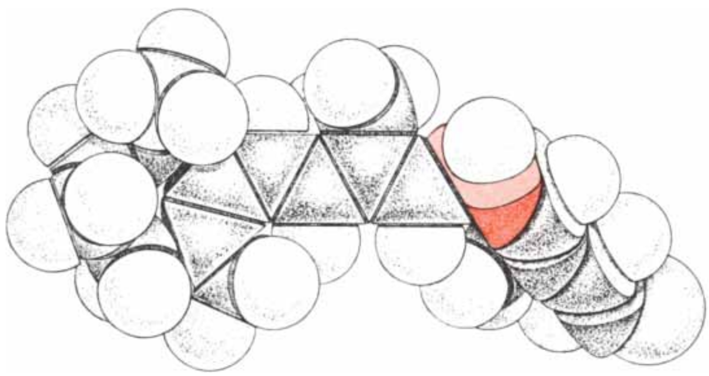
Let us return, however, to some of the chemical observations that gave rise to van't Hoff's ideas of stereochemistry late in the 19th century. Chemists were confronted by a series of puzzling observations best exemplified by two simple compounds: maleic acid and fumaric acid [*see illustrations on page 67*]. Here were two distinct, chemically pure substances, each with four atoms of carbon, four of hydrogen and four of oxygen ($C_4H_4O_4$). It was known, moreover, that the connections between atoms in the two molecules were exactly the same and that the two central carbon atoms in each molecule were connected by a double bond. Yet the two compounds were indisputably different. Whereas crystals of maleic acid melted at 128 degrees centigrade, crystals of fumaric acid did not melt until heated to about 290 degrees C. Furthermore, maleic acid was about 100 times more soluble in water and 10 times stronger as an acid than fumaric acid. When maleic acid was heated in a vacuum, it gave off water vapor and became a new substance, maleic anhydride, which readily recombined with water and reverted to maleic acid. Fumaric acid underwent no such reaction. On the other hand, if either compound was heated in the presence of hydrogen, it was transformed into the identical compound, succinic acid ($C_4H_6O_4$), which contains two more hydrogen atoms per molecule than maleic or fumaric acid.

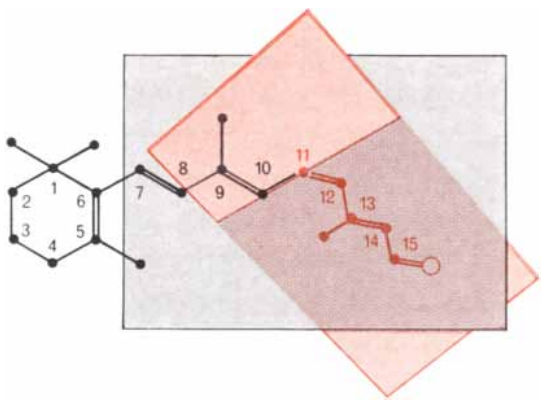
It was known that the four carbon atoms in maleic and fumaric acids form a chain. The only way to explain the differences between the compounds is to assume that the two halves of a molecule that are connected by a double bond are not free to rotate with respect to each other. Thus the form of the $C_4H_4O_4$ molecule in which the two terminal COOH groups lie on the same side of the double bond (maleic acid) is not identical with the form in which the COOH groups lie on opposite sides (fumaric acid). Molecules that assume distinct shapes in this way are called geometrical or *cis-trans* isomers of one another. "*Cis*" is from the Latin meaning on the same side; "*trans*" means on opposite sides. Therefore maleic acid is the *cis* isomer of the $C_4H_4O_4$ molecule and fumaric acid is the *trans* isomer. When the double carbon-carbon bond of either isomer is reduced to a single bond by the addition of two more hydrogen atoms, the two halves of the molecule are free





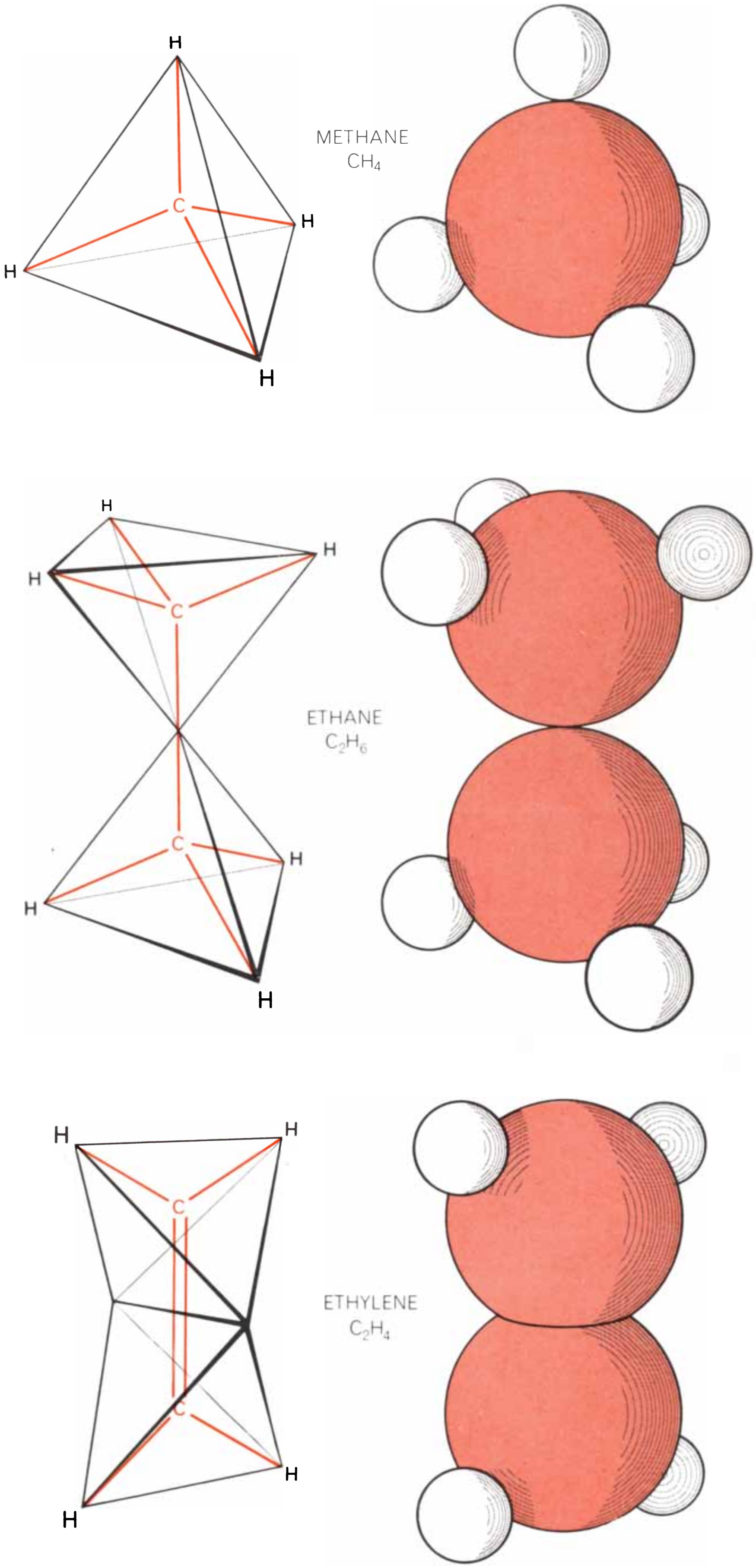
ALL-*TRANS* RETINAL





11-*CIS* RETINAL

FUNDAMENTAL MOLECULE OF VISION is retinal ($C_{20}H_{28}O$), also known as retinene, which combines with proteins called opsins to form visual pigments. Because the nine-member carbon chain in retinal contains an alternating sequence of single and double bonds, it can assume a variety of bent forms. Each distinct form is termed an isomer. Two isomers of retinal are depicted here. In the models (*left*) carbon atoms are dark, except carbon No. 11, which is shown in color; hydrogen atoms are light. The large atom attached to carbon No. 15 is oxygen. In the structural formulas (*right*) hydrogen atoms are omitted. The parts of each isomer that lie in a plane are marked by background panels. When tightly bound to opsin, retinal is in the bent and twisted form known as 11-*cis*. When struck by light, it straightens out into the all-*trans* configuration. This simple photochemical event provides the basis for vision.



SIMPLEST HYDROCARBON MOLECULES are methane, ethane and ethylene. In methane the carbon atom lies at the center of a tetrahedron that has a hydrogen atom at each apex. The models at right show relative diameters of carbon and hydrogen. Ethane can be visualized as two tetrahedrons joined apex to apex. Ethylene, the simplest hydrocarbon that has a carbon-carbon double bond, can be visualized as two tetrahedrons joined edge to edge. The C=C bond in ethylene is about 15 percent shorter than the C—C bond in ethane.

to rotate with respect to each other and a single compound results: succinic acid.

Van't Hoff proposed that when two carbon atoms are joined by a single bond they can be regarded as the centers of two tetrahedrons that meet apex to apex, thus allowing the two bodies to rotate freely. To represent a double bond, he visualized the two tetrahedrons as being joined edge to edge so that they were no longer free to rotate. Apart from minor modifications his proposals have stood up extremely well.

Electrons in Orbitals

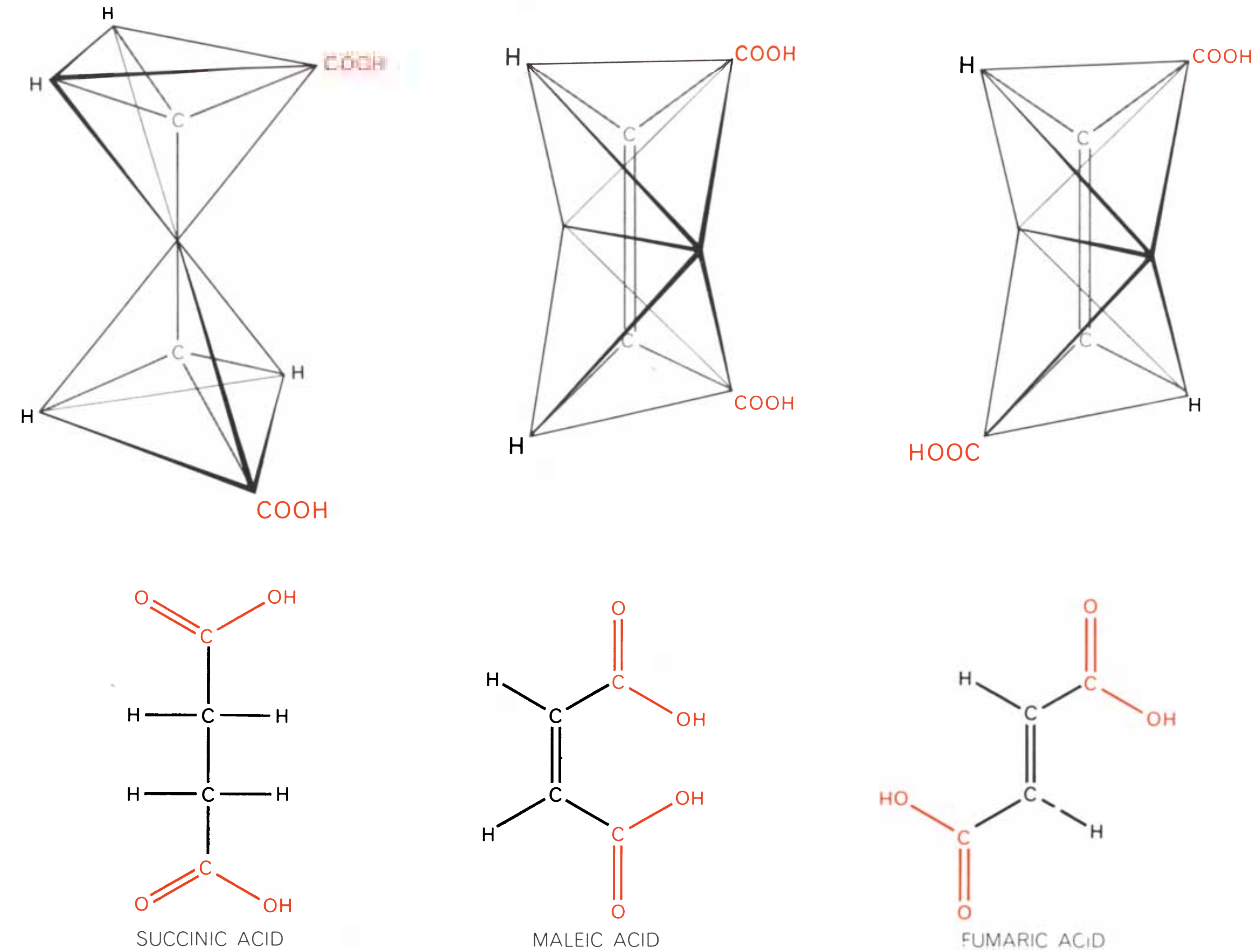
Van't Hoff's explanation, of course, was a purely formal one and provided no real insight into *why* a double bond prevents the parts of a molecule it joins from rotating with respect to each other. This was not understood for another 50 years, when the development of wave mechanics by Erwin Schrödinger set the stage for one of the most productive periods in theoretical chemistry. With Schrödinger's wave equation to guide them, chemists and physicists could compute the orbitals around atoms where pairs of electrons could be found. The valence bonds, which chemists had been drawing as lines for almost a century, now took on physical reality in the form of pairs of electrons confined to orbitals that were generally located in the regions where the valence lines had been drawn.

The first molecule to be analyzed successfully by the new wave mechanics was hydrogen (H_2). Walter Heitler and Fritz London applied Schrödinger's prescription and obtained the first profound insight into the nature of chemical bonding. Their results define the region in space most likely to be frequented by the pair of electrons associated with the two hydrogen atoms in the hydrogen molecule. The region resembles a peanut, each end of which contains a proton, or hydrogen nucleus [*see top illustration on page 68*].

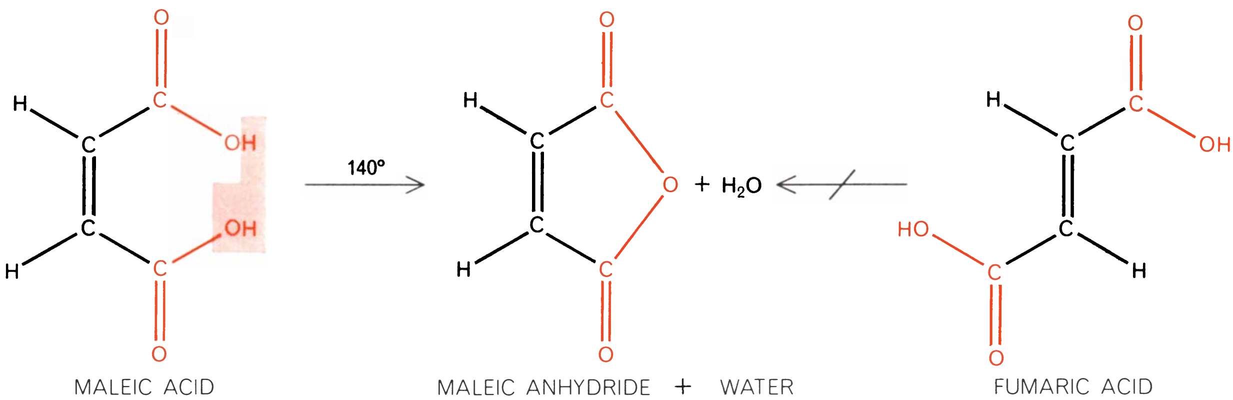
The phrase "most likely to be frequented" must be used because, as Max Born convincingly argued in the late 1920's, the best one can do in the new era of quantum mechanics is to calculate the probability of finding electrons in certain regions; all hope of placing them in fixed orbits must be abandoned. The new methods were quickly applied to many kinds of molecule, including some with double bonds.

One of the most fruitful methods for describing doubly bonded molecules—the molecular-orbital method—was devised by Robert S. Mulliken of the University of Chicago, who last year received the Nobel prize in chemistry. In Mulliken's concept a double bond can be visualized as three peanut-shaped regions [*see bottom illustration on next page*]. The central peanut, the "sigma" orbital, encloses the nuclei of the two adjacent atoms, as in the hydrogen molecule. The other two peanuts, which jointly form the "pi" orbital, lie along each side of the sigma orbital. The implication of this model is that in forming the sigma orbital the two electrons occupy a common volume, whereas in forming the pi orbital both electrons tend to occupy the two separate volumes simultaneously.

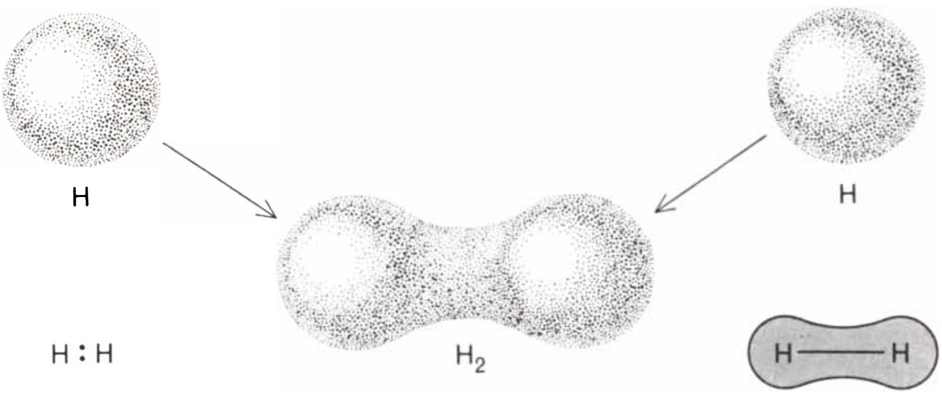
One can say that the sigma bond connects the atoms like an axle that joins two wheels but leaves them free to rotate separately. The pi bond ties the



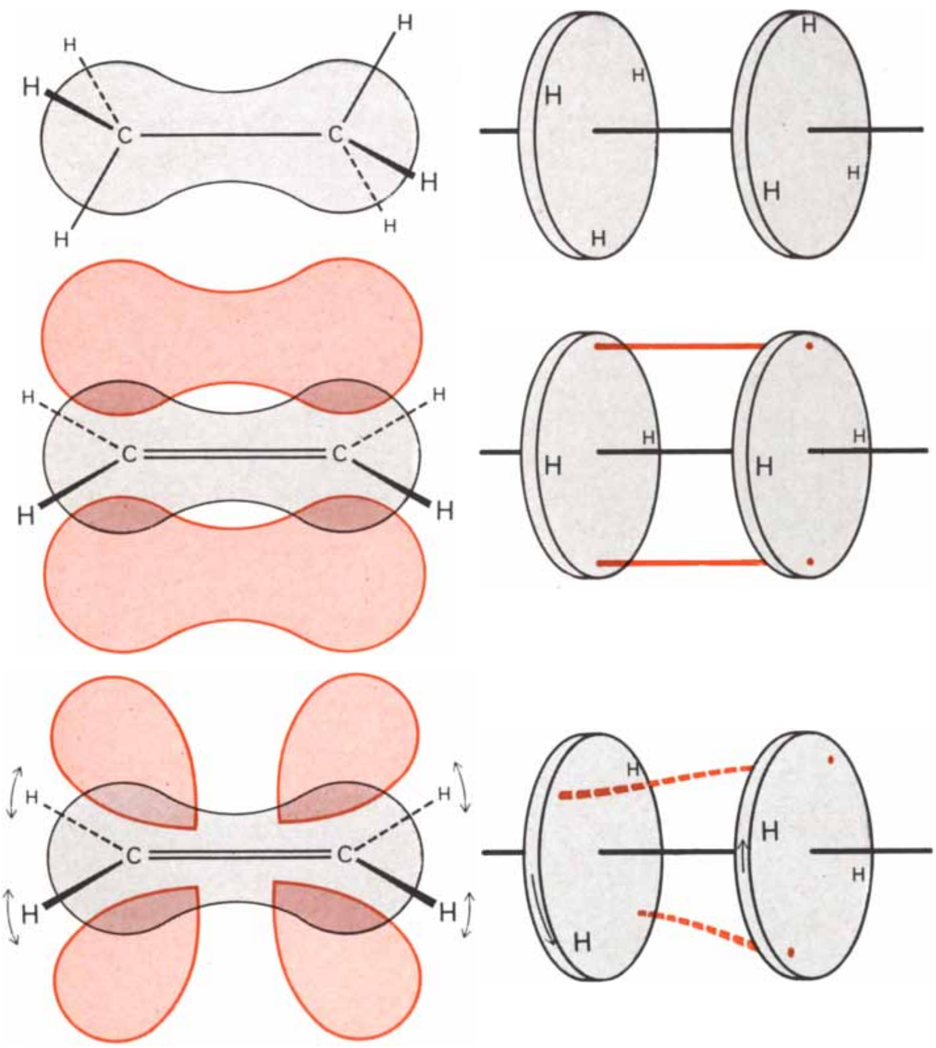
MOLECULAR PUZZLE was presented to chemists of the 19th century by maleic acid and fumaric acid, which have the same formula, $C_4H_4O_4$, and can be converted to succinic acid by the addition of two hydrogen atoms. Nevertheless, maleic and fumaric acids have very different properties. In 1874 Jacobus Henricus van't Hoff suggested that the central pair of carbon atoms in the three acids could be visualized as occupying the center of tetrahedrons that were joined edge to edge in the case of maleic and fumaric acids and apex to apex in the case of succinic acid. Thus the spatial relations of the two carboxyl (COOH) groups would be rigidly fixed in maleic and fumaric acids but not in succinic acid, because in the latter molecule the tetrahedrons would be free to rotate.



ONE CONSEQUENCE OF ISOMERISM is that maleic acid readily loses a molecule of water when heated, yielding maleic anhydride. Fumaric acid does not undergo this reaction because its carboxyl groups are held apart at opposite ends of the molecule.



HYDROGEN MOLECULE is formed when two atoms of hydrogen (*H*) are joined by a chemical bond. The bond is created by the pairing of two electrons, one from each atom, which must have opposite magnetic properties if the atoms are to attract each other. The position of the electrons as they orbit around the hydrogen nuclei cannot be precisely known but can be represented by an "orbital," a fuzzy region in which the electrons spend most of their time. Known as a sigma orbital, it can be stylized as at lower right. The formula for the hydrogen molecule can be written as at lower left; the dots indicate electrons.



MOLECULAR ORBITALS help to explain why molecules held together by single bonds differ from molecules with double bonds. For example, the two carbon atoms in ethane are joined by two electrons in a sigma orbital, similar to the orbital in the hydrogen molecule. The two ends of the molecule, like wheels joined by a simple axle, are able to rotate. The two carbon atoms in ethylene (*middle*) are joined by two additional electrons in a "pi" orbital (*color*), as well as by two electrons in a sigma orbital. The four hydrogen atoms in ethylene are held in a plane perpendicular to the plane of the orbitals. The effect is as if two wheels were held together by two rigid rods in addition to an axle. When ethylene is in an "excited" state (*bottom*), one of the pi electrons occupies the four-lobed orbital. This lessens the rigidity of the double bond and gives it more of the character of a single bond.

two wheels together so that they must rotate as a unit. It also forces the two halves of the molecule to lie in the same plane, exactly as if two tetrahedrons were cemented edge to edge. In this way the molecular-orbital description of bonding provides a quantum-mechanical explanation of *cis-trans* isomerism.

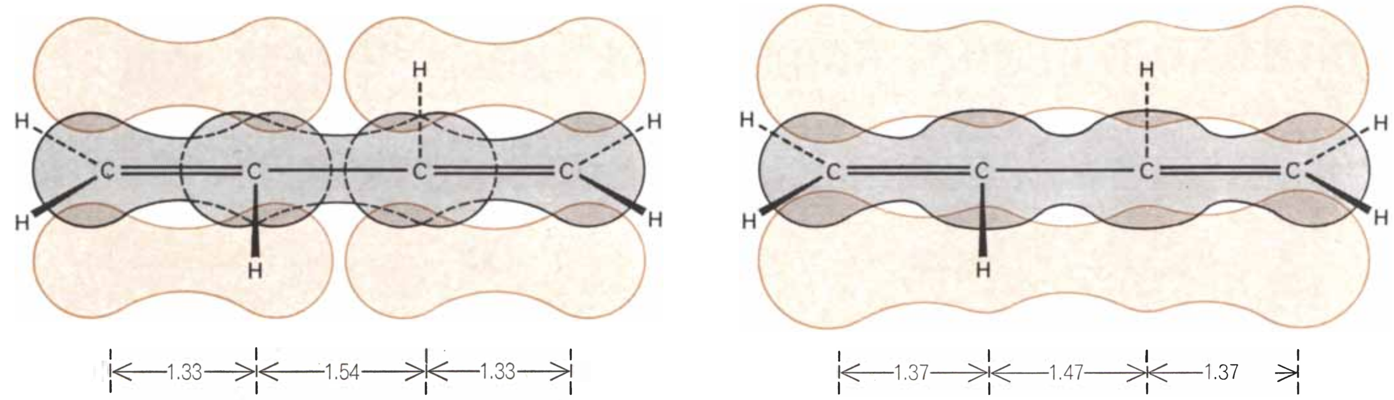
The single bond joining two atoms, such as the carbon atoms of the two methyl groups in ethane (CH_3–CH_3), is a sigma bond, which leaves the groups attached to the two carbons free to rotate with respect to each other. Actually the two methyl groups in ethane are known to have a preferred configuration, so that they are not completely freewheeling. Nonetheless, at ordinary temperatures enough energy is available to make 360-degree rotations so frequent that derivatives of ethane (in which one hydrogen in each methyl group is replaced by a different kind of atom) do not form *cis-trans* isomers. There are exceptions, however, if the groups of atoms that replace hydrogen are so bulky that they collide and prevent rotation. In general, therefore, *cis-trans* isomerism is confined to molecules incorporating double bonds.

Electrons Delocalized

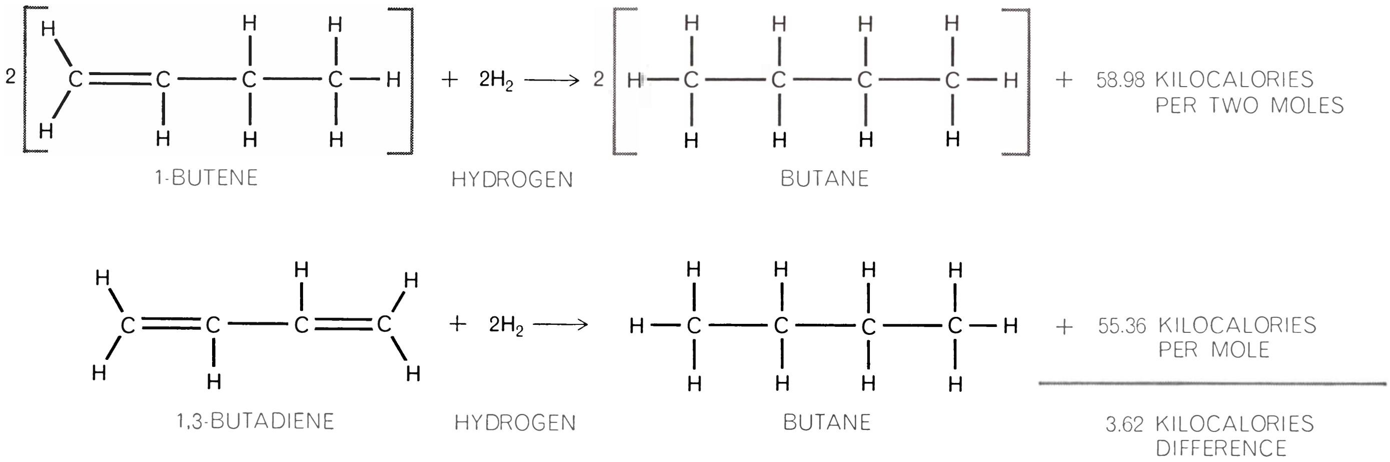
So much for molecules that have one double bond. What is the situation when a molecule has two or more double bonds? Specifically, what stereochemical behavior can be expected when single and double bonds alternate to form what is called a conjugated system?

The simplest conjugated system is found in 1,3-butadiene, a major ingredient in the manufacture of synthetic rubber, which can be written C_4H_6 or CH_2=CH–CH=CH_2. The designation "1,3" indicates that the double bonds originate at the first and third carbon atoms. Some of the properties of the biologically more interesting conjugated molecules are exhibited by butadiene. From the foregoing discussion one might expect that the second and third carbon atoms in the molecule would be free to rotate around the sigma bond connecting them. In actuality the rotation is not free: all the atoms in butadiene tend to lie in a plane.

It can also be shown that the energy content of each double bond in butadiene differs significantly from the energy content of the one double bond in the closely related compound 1-butene (CH_2=CH–CH_2–CH_3). The energy released in changing the two double bonds



DELOCALIZED ORBITALS are found in "conjugated" systems: molecules in which single and double bonds alternate. The simplest conjugated molecule is 1,3-butadiene (C_4H_6). If its pi orbitals (*color*) were simply confined to the double bonds, as in ethylene, its orbital structure and carbon-carbon distances (in angstrom units) would be as shown at the left. Even in the lowest energy state, however, the pi electrons tend to spread across the entire molecule (*right*). As a result double bonds are lengthened and the single bond is shortened, making each type of bond more like the other. As a consequence the entire molecule is planar, or flat.



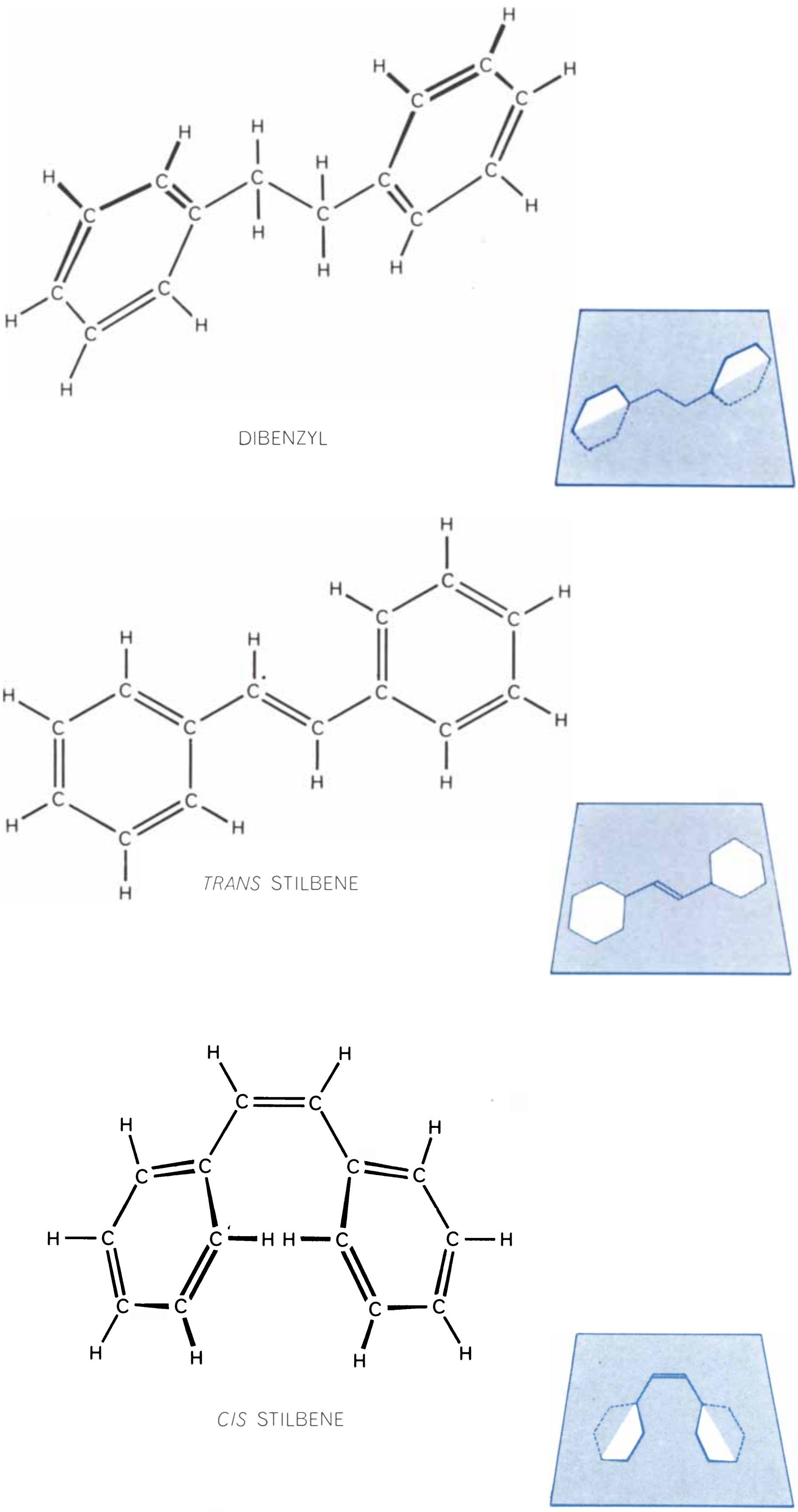
EVIDENCE FOR BOND MODIFICATION in a conjugated molecule can be obtained by measuring the energy released when double bonds are converted to single bonds by adding hydrogen. Hydrogenation of the double bond in 1-butene, which is not a conjugated molecule, yields 29.49 kilocalories for every mole of reactant. A mole is a weight in grams equal to the molecular weight of a substance: 56 for butene and 54 for butadiene. Hydrogenation of two moles of butene, hence the hydrogenation of twice as many double bonds, would therefore yield 58.98 kilocalories. Hydrogenation of the same number of double bonds in butadiene (present in a single mole) yields only 55.36 kilocalories. The difference is 3.62 kilocalories per mole for the two bonds, or 1.81 kilocalories for each double bond. The lesser energy in the butadiene double bonds indicates that they are more stable than the double bond in 1-butene.

of butadiene into the single bonds of butane (CH_3–CH_2–CH_2–CH_3) is about 55,400 calories per mole of butane formed. (A mole is a weight in grams equal to the molecular weight of the molecule: 58 for butane, 54 for butadiene.) The energy released in converting 1-butene, which has only one double bond, into butane is about 29,500 calories per mole. When expressed in terms of equivalent numbers of double bonds hydrogenated, the latter reaction yields some 1,800 calories more than the former [*see lower illustration above*]. The greater energy release means that the double bond in 1-butene is more reactive than either of those in 1,3-butadiene.

The added stability of the bonds in 1,3-butadiene was not unexpected; the same kind of result had been obtained for benzene, whose famous ring structure is formed by six carbon atoms connected alternately by single and double bonds. One can picture the extra energy of stabilization as arising from the tendency of electrons in the pi orbitals to leak out and become delocalized. Indeed, the phenomenon is called delocalization. The pi orbitals spread over larger portions of conjugated molecules than one might have thought, so that the properties of delocalized systems can no longer be described in terms of the properties of the double and single bonds as they are usually drawn. In order to represent the pi orbitals of 1,3-butadiene more accurately one must stretch them across all four carbon atoms of the molecule [*see upper illustration above*]. The stretching helps to explain why butadiene is not completely free to rotate around the central single bond: the bond has some of the characteristics of a double bond.

The altered character of butadiene's central carbon-carbon bond has been confirmed by X-ray-diffraction studies of butadiene. Whereas the usual carbon-carbon bond lengths are about 1.54 angstrom units for a single bond and 1.33 angstroms for a double bond, the length of the central single bond in 1,3-butadiene is only 1.47 angstroms. (An angstrom is 10^{-8} centimeter.) Linus Pauling, who did much to clarify the nature of the chemical bond, has estimated that the observed shortening of the central carbon-carbon bond of butadiene implies that it has about 15 percent of the double-bond character. One consequence of this is that the molecular configuration of butadiene tends to remain planar, or flat.

The tendency toward planarity in



PREFERENCE FOR FLATNESS in conjugated systems is exhibited by molecules of dibenzyl and two isomers of stilbene. The latter have a double bond in the carbon-carbon bridge linking the two benzene rings, whereas dibenzyl has a single bond. In dibenzyl the two rings are practically at right angles to the plane of the bridge. In *trans* stilbene all the atoms lie essentially in a plane. In *cis* stilbene, as can be demonstrated with molecular models, the two rings interfere with each other and thus cannot lie flat. The twisting of the rings has been established by X-ray studies of a related compound, *cis* azobenzene, in which the two rings are joined through a doubly bonded nitrogen (N=N) bridge.

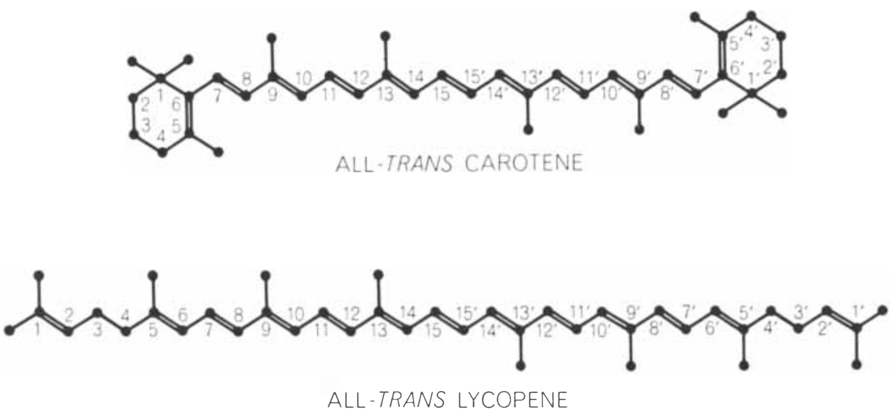
conjugated systems was clearly demonstrated by the Scottish X-ray crystallographer J. M. Robertson and his colleagues in the mid-1930's. They compared the configurations of dibenzyl and *trans* stilbene, both of which contain two benzene rings joined by two carbon atoms [*see illustration at left*]. The difference between the two molecules is that in dibenzyl the two carbons are joined by a single bond, whereas in stilbene they are joined by a double bond. Robertson showed that the rings in dibenzyl are essentially at right angles to the connecting carbon-carbon bridge. In the *trans* form of stilbene the rings and the bridge lie in a plane, and the single bonds that join the rings to the two carbons in the bridge are foreshortened from the normal single-bond length to about 1.44 angstroms. In the *cis* form of stilbene the two rings cannot lie in a plane because they bump into each other.

Light-sensitive Molecules

We turn now to *cis-trans* isomerism in the family of molecules we have worked with most directly, the carotenoids and their near relatives, retinal (also known as retinene) and vitamin A. These molecules are built up from units of isoprene, which is like 1,3-butadiene in every respect but one: at the second carbon of isoprene a methyl group (CH_3) replaces the hydrogen atom present in butadiene. Natural rubber is polyisoprene, a long conjugated chain of carbon atoms with a methyl group attached to every fourth carbon.

The compound known as beta-carotene, which is responsible for the color of carrots, consists of an 18-carbon conjugated chain terminated at both ends by a six-member carbon ring, each of which adds another double bond to the conjugated system. The molecule has 40 carbon atoms in all and is presumably assembled from eight isoprene units [*see illustration on page 72*].

Until about 15 years ago the *cis-trans* isomers of the carotenoids entered biology in only one rather trivial way: in determining the color of tomatoes. Laszlo T. Zechmeister and his collaborators at the California Institute of Technology found in the early 1940's that normal red tomatoes contain the carotenoid lycopene in the all-*trans* configuration. (Lycopene differs from beta-carotene only in that the six carbon atoms at each end of the molecule do not close to form rings.) The yellow mutant known as the tangerine tomato contains



TWO NATURAL CAROTENOIDS are examples of highly conjugated systems. Like other carotenoids, they are built up from units of isoprene (C_5H_8), also known as 2-methyl butadiene. In these diagrams hydrogen atoms are omitted so that the carbon skeletons can be seen more clearly. Both molecules contain 40 carbon atoms and are symmetrical around the central carbon-carbon double bond, numbered 15–15′. Beta-carotene gives carrots their characteristic orange color. *Trans* lycopene is responsible for the red color of tomatoes.

a yellow *cis* isomer of lycopene called prolycopene. Zechmeister, who contributed more than anyone else to our present understanding of carotenoid chemistry, liked to demonstrate how a yellow solution of prolycopene, extracted from tangerine tomatoes, could be converted into a brilliant orange solution of all-*trans* lycopene simply by adding a trace of iodine in the presence of a strong light.

The discovery that the *cis-trans* isomerism of a carotenoid plays a crucial role in biology was made in the laboratory of George Wald of Harvard University, where it was found that the *cis-trans* isomerism of retinal is intrinsic to the way in which visual pigments react to light. The discovery of these pigments is usually attributed to the German physiologist Franz Boll.

The Chemistry of Vision

In 1877, the same year that Kolbe was ridiculing van't Hoff's work on stereochemistry, Boll noted that a frog's retina, when removed from the eye, was initially bright red but bleached as he watched it, becoming first yellow and finally colorless. Subsequently Boll observed that in a live frog the red color of the retina could be bleached by a strong light and would slowly return if the animal was put in a dark chamber. Recognizing that the bleachable substance must somehow be connected with the frog's ability to perceive light, Boll named it "erythropsin" or "Sehrot" (visual red). Before long Willy Kühne of Heidelberg found the red pigment in the retinal rod cells of many animals and renamed it "rhodopsin" or "Sehpurpur" (visual purple), which it has been called ever since. Kühne also named the yellow product of bleaching "Sehgelb" (visual yellow) and the white product "Sehweiss" (visual white).

The chemistry of the rhodopsin system remained largely descriptive until 1933, when Wald, then a postdoctoral fellow working in Otto Warburg's laboratory in Berlin and Paul Karrer's laboratory in Zurich, demonstrated that the eye contains vitamin A. Wald showed that the vitamin appears when rhodopsin is bleached by light—the physiological process known as light adaptation—and disappears when rhodopsin is resynthesized during dark adaptation [see "Night Blindness," by John E. Dowling; SCIENTIFIC AMERICAN, October, 1966]. He found that rhodopsin consists of a colorless protein (later named opsin) that carries as its chromophore, or color bearer, an unknown yellow carotenoid that he called retinene. Wald went on to show that the bleaching of rhodopsin to visual yellow corresponds to the liberation of retinene from its attachment to opsin, and that the fading of visual yellow to visual white represents the conversion of retinene to vitamin A. During dark adaptation rhodopsin is resynthesized from these precursors.

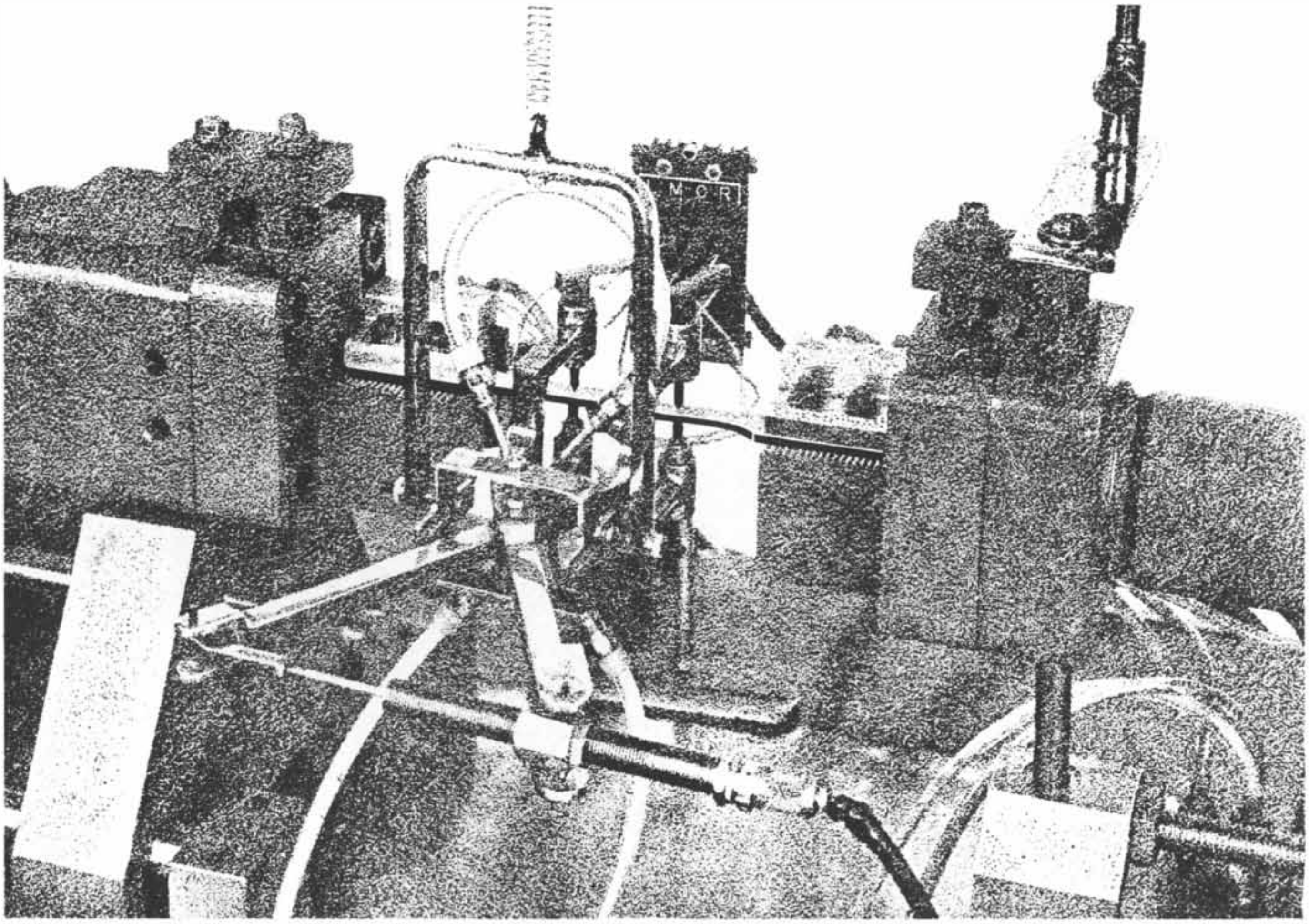
The chemical relation between retinene and vitamin A was elucidated in 1944 by R. A. Morton of the University of Liverpool. He showed that retinene is formed when vitamin A, an alcohol, is converted to an aldehyde, a change that involves the removal of two atoms of hydrogen from the terminal carbon atom of the molecule. As a result of Morton's finding the name retinene was recently changed to retinal.

In 1952 one of us (Hubbard), then a graduate student in Wald's laboratory, demonstrated that only the 11-*cis* isomer of retinal can serve as the chromophore of rhodopsin. This has since been confirmed for all the visual pigments whose chromophores have been examined. These pigments found in both the rod and cone cells of the eye contain various opsins, which combine either with retinal (strictly speaking retinal$_1$) or with a slightly modified form of retinal known as retinal$_2$. One other isomer of retinal, the 9-*cis* isomer, also combines with opsins to form light-sensitive pigments, but they are readily distinguishable from the visual pigments in their properties and have never been found to occur naturally. They have been called isopigments.

In 1959 we showed that the only thing light does in vision is to change the shape of the retinal chromophore by isomerizing it from the 11-*cis* to the all-*trans* configuration [*see illustration on page 65*]. Everything else—further chemical changes, nerve excitation, perception of light, behavioral responses—are consequences of this single photochemical act.

The change in the shape of the chromophore alters its relation to opsin and ushers in a sequence of changes in the mutual interactions of the chromophore and opsin, which is observed as a sequence of color changes. In vertebrates the all-*trans* isomer of retinal and opsin are incompatible and come apart. In some invertebrates, such as the squid, the octopus and the lobster, a metastable state is reached in which the all-*trans* chromophore remains bound to opsin.

Until the structure of opsin is established there is no way to know just how 11-*cis* retinal is bound to the opsin molecule. In the 1950's F. D. Collins, G. A. J. Pitt and others in Morton's laboratory showed that in cattle rhodopsin the aldehyde (C=O) group of 11-*cis* retinal forms what is called a Schiff's base with an amino (NH_2) group in the opsin molecule. Recently Deric Bownds in Wald's laboratory has found that the amino group belongs to lysine, one of the amino acid units in the opsin molecule, and has identified the amino acids in its immediate vicinity. There is little doubt that 11-*cis* retinal also has secondary points of attachment to opsin; otherwise it would be hard to explain why only the 11-*cis* isomer serves as the chromophore in visual pigments. Light changes the shape of the chromophore and thus alters its spatial relation to opsin. This leads, in turn, to changes in the shape of the



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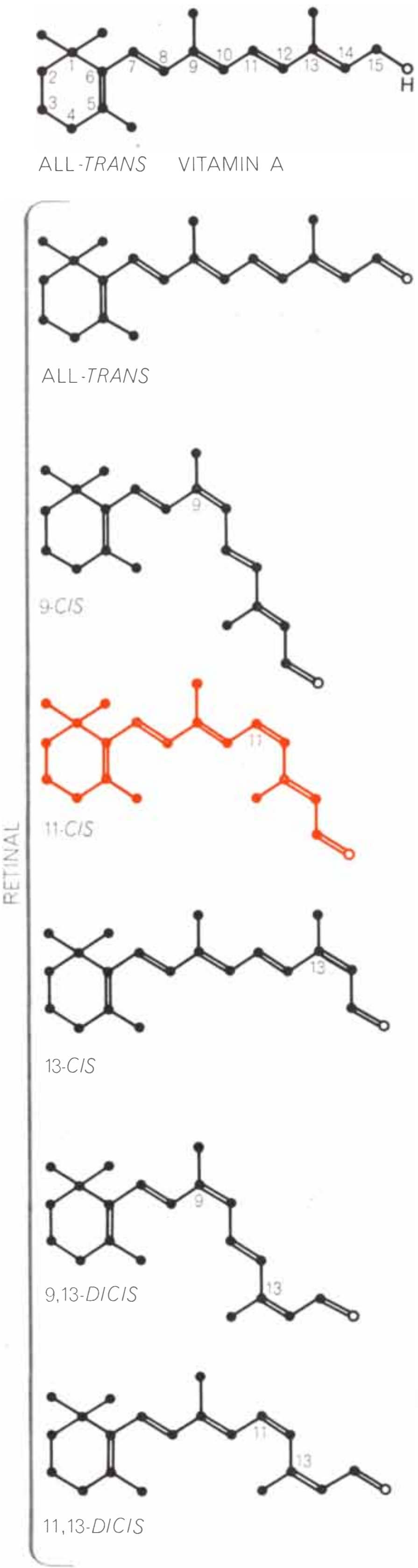

SIX ISOMERS OF RETINAL are represented in skeleton form below the structure of all-*trans* vitamin A. Hydrogen atoms are omitted, except for the H in the hydroxyl group of vitamin A. If that H and one other on the final carbon are removed, all-*trans* retinal results. This isomer and 11-*cis* retinal, which combines with opsin to form rhodopsin, are the isomers involved in vision.

opsin molecule [*see lower illustration on page 76*]. The details of these changes, however, are still obscure.

How Molecules Twist

Let us examine somewhat more closely the various isomers of retinal. The six known isomers are illustrated at the left: the all-*trans* isomer and five *cis* isomers of one kind or another. Experiments with models, together with other evidence, show that four of the six isomers are essentially planar. The two that are not are the 11-*cis* isomer and the 11,13-*dicis* isomer. In these isomers there is considerable steric hindrance, or intramolecular crowding, between the hydrogen atom on carbon No. 10 (C_{10}) and the methyl group attached to C_{13}. Thus the double bond that joins C_{11} and C_{12} cannot be rotated by 180 degrees from the *trans* to a planar *cis* configuration. In the 11-*cis* isomers the tail of the molecule from C_{11} through C_{15} is therefore twisted out of the plane formed by the rest of the molecule.

This twisted geometry introduces two configurations, called enantiomers, that are mirror images of each other; if the molecule could be viewed from the ring end, one form would be twisted to the left and the other to the right. It is possible that opsin may combine selectively with only one enantiomer.

As Pauling had predicted in the 1930's, the steric hindrance that necessitates the twist in the 11-*cis* isomer makes it less stable than the all-*trans* or the 9-*cis* and 13-*cis* forms. We have recently found, for example, that the 11-*cis* form contains about 1,500 calories more "free energy" per mole than the *trans* form. One has to put in about 25,000 calories per mole, however, to rotate the molecule from one form to the other. This amount of energy, which is much more than a molecule is likely to acquire through chance collisions with its neighbors, is known as the activation energy: the energy required to surmount the barrier that separates the *cis* and *trans* states.

This raises an important point. How can two parts of a molecule be rotated around a double bond? The interconversion of *cis* and *trans* isomeric forms to another requires gross departures from flatness. How can this be accomplished?

Here we must introduce the concept of the excited state. One can think of molecules as existing in two kinds of state: a "ground," or stable, state of relatively low internal energy and various less stable states of higher energy—the excited states. Molecules are raised from the ground state into one or another excited state by a sudden influx of energy, which can be in the form of heat or light. They return to the ground state by giving up their excess energy, usually as heat but occasionally as light, as in fluorescence or phosphorescence.

The orbital diagrams we have described apply to molecules in the ground state. When molecules are in an excited state, their electrons have more energy and therefore occupy different orbitals. Quantum-mechanical calculations show that an excited pi electron divides its time between the two ends of a double bond [*see bottom illustration on page 68*]. The net effect is to make the double bond in an excited molecule more like a single bond and less like a double bond. In a conjugated molecule, in which pi electrons are already delocalized, the changes in bond character are not uniform throughout the conjugated system but depend on the nature of the excitation and the structure of the molecule that is excited.

When one tries to isomerize carotenoids in the laboratory, it is usually helpful to add catalysts such as bromine or iodine. (The reader will recall that Zechmeister used iodine in his demonstrations.) Heat and light favor the existence of excited states. Bromine and iodine probably function by dissociating into atomic bromine and iodine, a process that is also favored by light. A bromine or iodine atom adds fleetingly to the double bond and converts it into a single bond, which is then momentarily free to rotate until the bromine or iodine atom has departed. The actual lifetime of the singly bonded form can be very brief indeed: the time required for one rotation around a carbon-carbon single bond is only about 10^{-12} second.

The Sensitivity of Eyes

It may seem remarkable that all animal visual systems so far studied depend on the photoisomerization of retinal for light detection. Three main branches of the animal kingdom—the mollusks, the arthropods and the vertebrates—have evolved types of eyes that differ profoundly in their anatomy. It seems that various anatomical (that is, optical) arrangements will do; apparently the photochemistry, once it had evolved, was universally accepted. Presumably the visual pigments of all animals must within narrow limits be equally sensitive to light, otherwise the more light-sensitive animals would eventually

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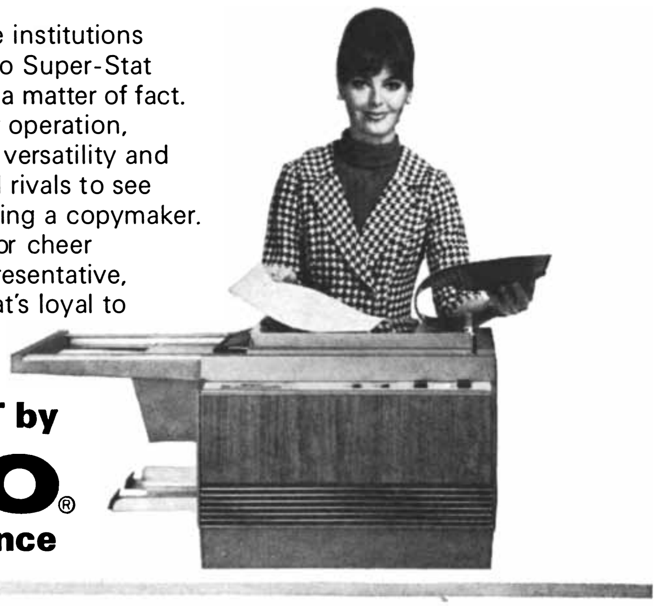

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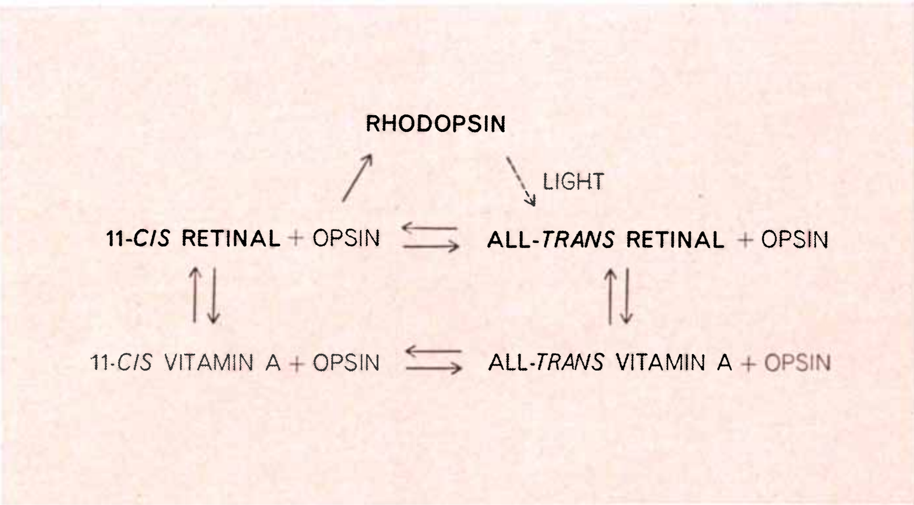


PHOTOCHEMICAL EVENTS IN VISION involve the protein opsin and isomers of retinal and its derivative, vitamin A. Opsin joined to 11-*cis* retinal forms rhodopsin. When struck by light, the 11-*cis* chromophore is converted to an all-*trans* configuration and subsequently all-*trans* retinal becomes detached from opsin. With the addition of two hydrogen atoms, all-*trans* retinal is converted to all-*trans* vitamin A. Within the eye this isomer must be converted to 11-*cis* vitamin A, thence to 11-*cis* retinal, which recombines with opsin to form rhodopsin.

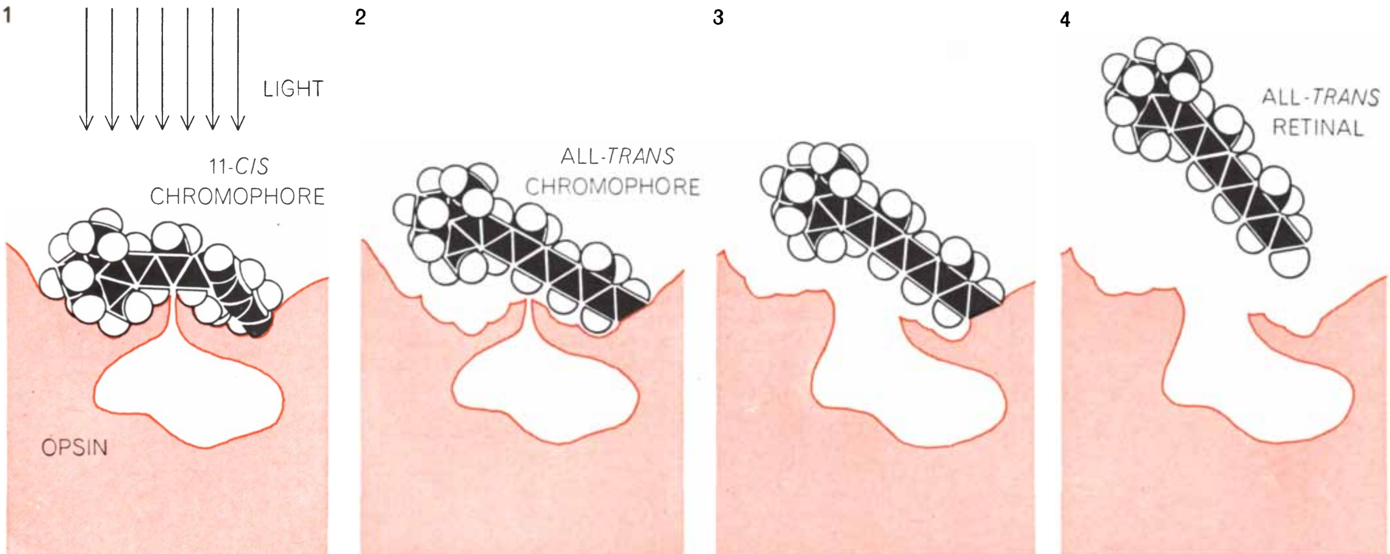
replace those whose eyes were less sensitive.

How sensitive to light is the animal retina? In a series of experiments conducted about 1940 Selig Hecht and his collaborators at Columbia University showed that the dark-adapted human eye will detect a very brief flash of light when only five quanta of light are absorbed by five rod cells. From this Hecht concluded that a single quantum is enough to trigger the discharge of a dark-adapted rod cell in the retina.

It is therefore essential that the quantum efficiency of the initial photochemical event be close to unity. In other words, virtually every quantum of light absorbed by a molecule of rhodopsin must isomerize the 11-*cis* chromophore to the all-*trans* configuration. It was shown many years ago by the British workers H. J. A. Dartnall, C. F. Goodeve and R. J. Lythgoe that an absorbed quantum has about a 60 percent chance of bleaching frog rhodopsin. One of us (Kropf) has found a similar quantum efficiency for the isomerization of the 11-*cis* retinal chromophore of cattle rhodopsin. Our work also shows that 11-*cis* retinal is more photosensitive than either the 9-*cis* or the all-*trans* isomers when they are attached as chromophores to opsin, and this may be the reason why the geometrically hindered and therefore comparatively unstable 11-*cis* isomer has evolved into the chromophore of the visual pigments.

We have also recently measured the quantum efficiency of the photoisomerization of retinal and several closely related carotenoids in solution. Retinal turns out to be considerably more photosensitive than any of them and nearly as photosensitive as rhodopsin.

Although all animal eyes seem to employ 11-*cis* retinal as their light-sensitive agent, there are slight variations in the opsins that combine with retinal, just as there are variations in other proteins, such as hemoglobin, from species to species. Within the next few years we may learn the complete amino acid sequence of one of the opsins, and thereafter we should be able to compare such sequences for two or more species. It may be many years, however, before X-ray crystallographers have established the complete three-dimensional structure of an opsin molecule and are able to describe the site that binds it to retinal. One can conjecture that the binding site will be quite similar in the various opsins, even those from animals of different phyla, but there may be surprises in store. Whatever the precise details, it is clear that evolution has produced a remarkably efficient system for translating the absorption of light into the language of biochemistry—a language whose vocabulary and syntax are built on the various ways proteins interact with one another and with smaller molecules in their environment.



MOLECULAR EVENTS IN VISION can be inferred from the known changes in the configuration of 11-*cis* retinal after the absorption of light. In these schematic diagrams the twisted isomer is shown attached to its binding site in the much larger protein molecule of opsin (*1*). After absorbing light the 11-*cis* chromophore straightens into the all-*trans* isomer (*2*). Presumably a change in the shape of opsin (*3*) facilitates the release of all-*trans* retinal (*4*). The configuration of the binding site in opsin is not yet known.

905/7

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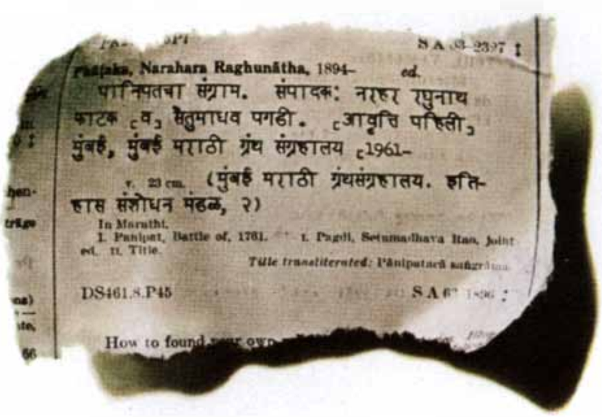

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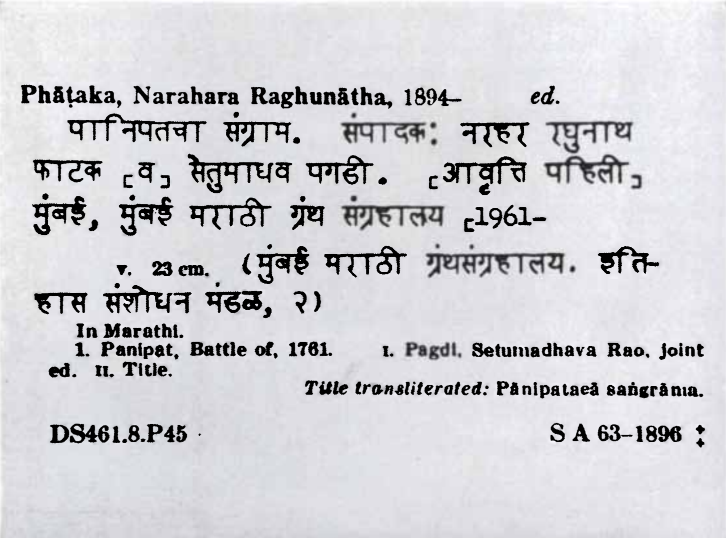
Phāṭaka, Narahara Raghunātha, 1894– *ed.*
पानिपतचा संग्राम. संपादक: नरहर रघुनाथ फाटक [व] सेतुमाधव पगडी. [आवृत्ति पहिली] मुंबई, मुंबई मराठी ग्रंथ संग्रहालय [1961–
v. 23 cm. (मुंबई मराठी ग्रंथसंग्रहालय. इतिहास संशोधन मंडळ, २)
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1. Panipat, Battle of, 1761. I. Pagdi, Setumadhava Rao, joint ed. II. Title.
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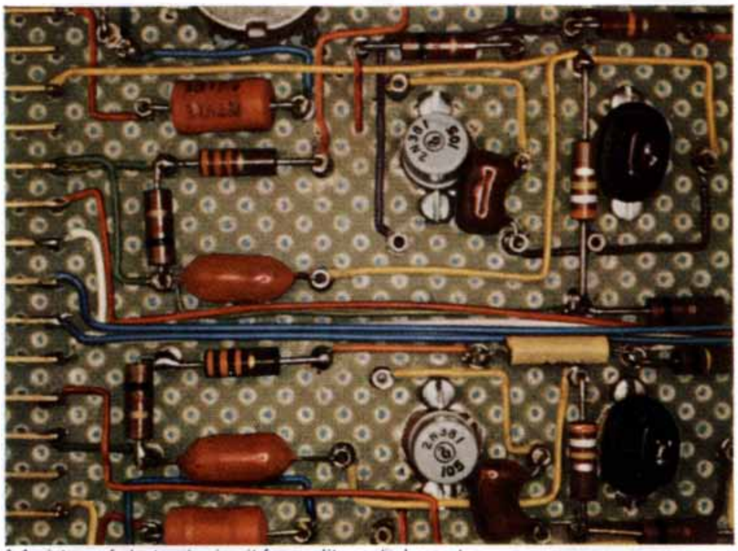
National Union Catalog entry enlarged 1.6 times.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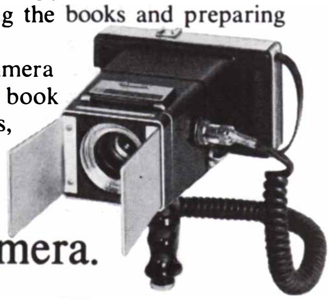

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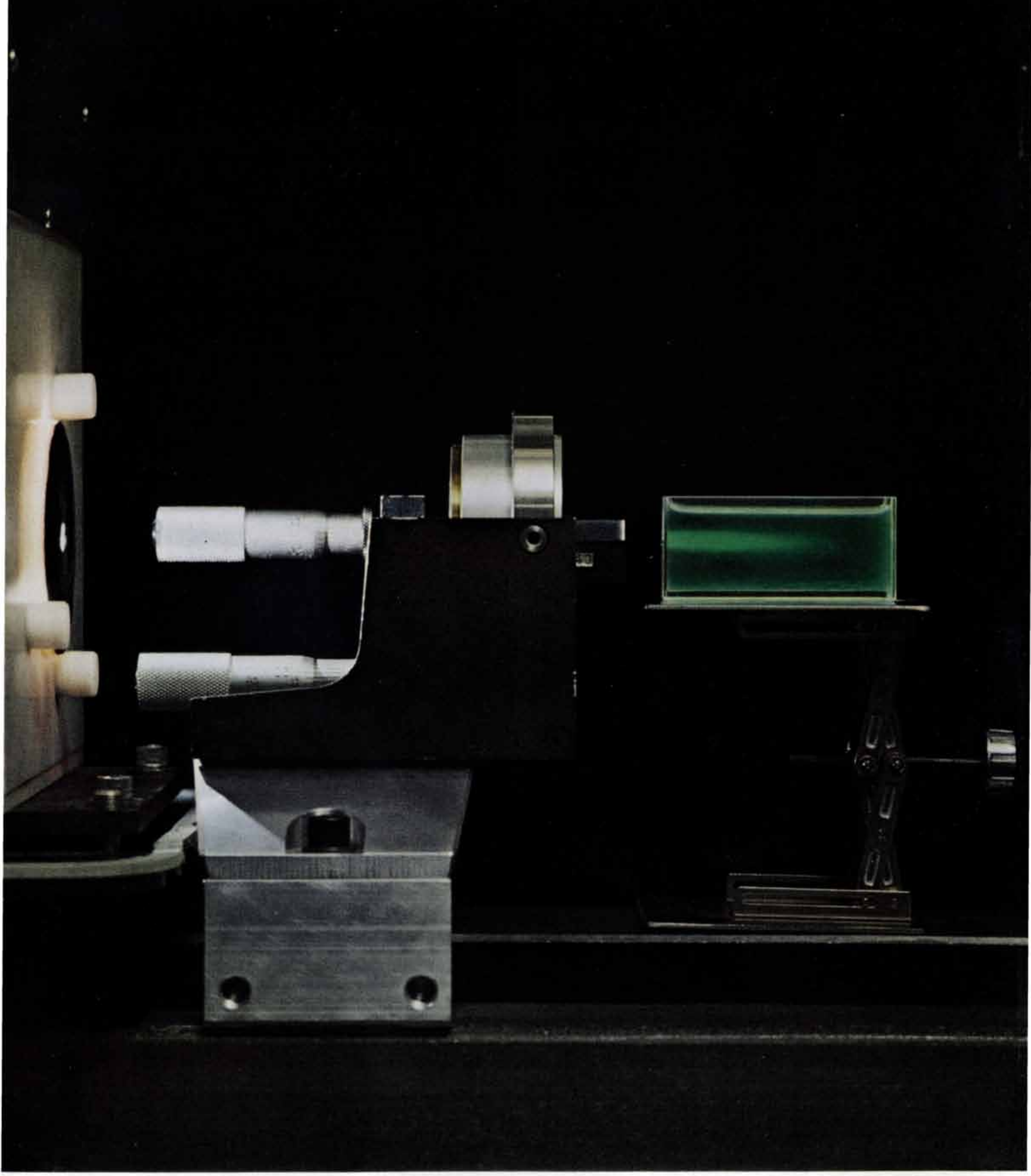


INVISIBLE BEAM of infrared radiation from a pulsed liquid laser (*inside box at left*) was made visible for this photograph by first passing it through a crystal of potassium dihydrogen phosphate (*inside mounting at center*), which halved the wavelength of the beam from 10,550 angstrom units (infrared) to 5,275 angstroms (green). Since the green beam was still highly collimated and directed only to the right, it could not be recorded directly by the camera. A shallow trough containing water and a few drops of milk was therefore placed in the path of the beam; light scattered from the particles of milk in suspension was then visible to the camera. The green color in the trough represents the accumulated effect of 15 separate bursts of light, spaced about two minutes apart. A burst consists of several pulses, each lasting between 20 and 50 nanoseconds (billionths of a second). The photograph was made at the General Telephone & Electronics Laboratories. A photograph of the entire optical bench appears at the top of the following two pages.

LIQUID LASERS

There are a number of advantages to be gained from using a liquid as the active medium in a laser rather than a solid or a gas. Such devices may soon become competitive with more conventional lasers

by Alexander Lempicki and Harold Samelson

A few years ago the laser could be aptly characterized as a solution in search of a problem. This situation is in the process of changing rapidly as new applications of lasers are announced almost daily in various areas of science, technology and medicine. All this activity has generated a growing demand for lasers with greater power, efficiency and stability. The lasers currently in use have as their active mediums either gases or solids, and a major part of the effort to overcome the deficiencies of existing laser systems has been devoted to the search for new gases and solids to serve as laser materials. This article concerns another approach altogether: the use of a liquid as the active medium in a laser.

One of the most important characteristics of a laser medium, and one that strictly limits its performance, is its degree of optical perfection, or freedom from local irregularities. Most gas systems have a high degree of optical perfection, simply because the density of the gas is uniform and at low pressures the refractive index (the tendency to bend a light beam) of the gas is not sensitive to changes in temperature. In condensed systems—solids and liquids—a high degree of optical perfection is more difficult to attain. Crystals and glasses are usually formed at high temperatures and require considerable effort and expense to be freed of the many "frozen in" imperfections that can lower their optical performance.

Liquids, of course, are not subject to such defects. On the other hand, liquids are particularly prone to large changes in refractive index brought about by changes in temperature. By circulating a liquid, however, one can effectively eliminate such temperature gradients and hence any associated variations in refractive index. Circulation entails no loss of optical quality due to variations in density, since liquids are incompressible. Furthermore, in very-high-power lasers, solids tend to crack or shatter, whereas liquids naturally do not. Finally, the cost of a solid-state laser rises rapidly with its size, which is limited in any case by the method of fabrication. No such inherent limitation exists for liquid lasers.

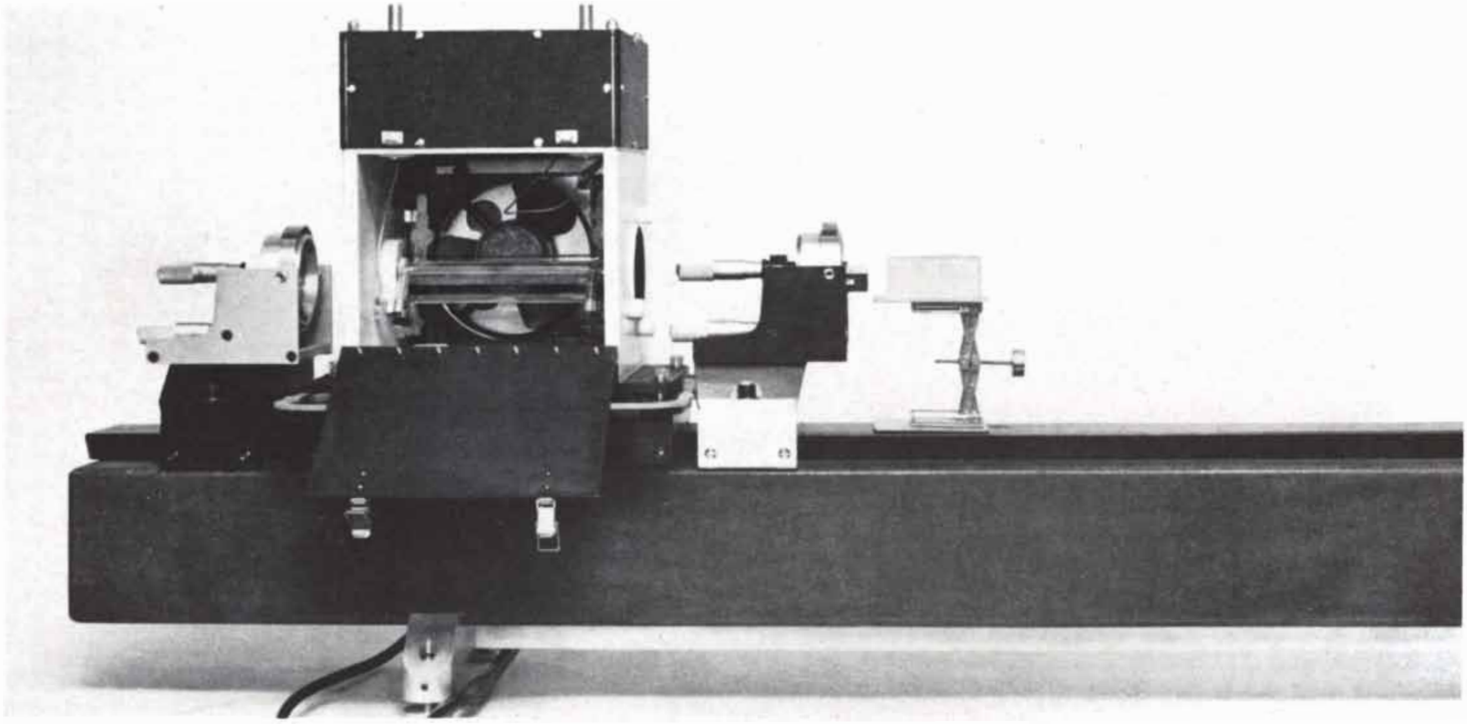
All these advantages of the liquid medium are somewhat offset by the fact that liquids generally have a much larger coefficient of expansion than solids do. Although this property can cause problems, they are not insurmountable. From these preliminary considerations alone liquid lasers would appear to be worthy of serious consideration. Recent findings have brightened this promising picture, suggesting that liquid lasers may soon become competitive in many areas with solid-state lasers.

The theoretical foundation for the laser was laid by Albert Einstein, who perceived in 1917 that an excited atom or molecule can emit a photon, or quantum of light, by either of two mechanisms. In the first process photons are emitted in the absence of any external perturbation. This process, called spontaneous emission, has a probability of occurrence that is characterized by a definite lifetime. In the second process a photon emitted spontaneously from an atom or a molecule can trigger another excited atom or molecule to emit its photon prematurely. This process, called stimulated emission, has a probability that is dependent on the density of the photons. If the density of the excited atoms and photons is high enough, the stimulated-emission process will predominate, and laser action will result. (The word "laser" is an acronym for "light amplification by stimulated emission of radiation.")

For laser action to occur one must first achieve a "population inversion," that is, the higher, or excited, states of the atoms or molecules must be more densely populated by electrons than the lower, or terminal, states are; otherwise the absorption of photons by unexcited atoms will prevent the dominance of the stimulated-emission process. In addition it is always helpful and usually necessary to enclose the laser medium in a structure that prevents the photons from leaving the scene of the action too soon. This can be accomplished by a pair of mirrors, one of which is slightly transmissive to allow the extraction of the stimulated emission to the outside world, where it can be studied or put to use.

Laser radiation is characterized by three main properties: the waves are coherent (all in step), highly monochromatic (all with the same wavelength) and capable of being propagated over long distances in the form of well-collimated beams. Since laser action is initiated by a spontaneous process, the spontaneous lifetime cannot be too long lest the reaction "breed" too slowly. Furthermore, the conversion of absorbed excitation energy to emitted light energy must be reasonably high. Because the "avalanche" of electrons from excited states to terminal states will start only when enough photons are available, it is important that photons not be absorbed by impurities or scattered by optical imperfections in the medium. In other words, the optical losses of the material must be small.

These general requirements for the onset of laser action were first formulated and expressed in a compact mathe-

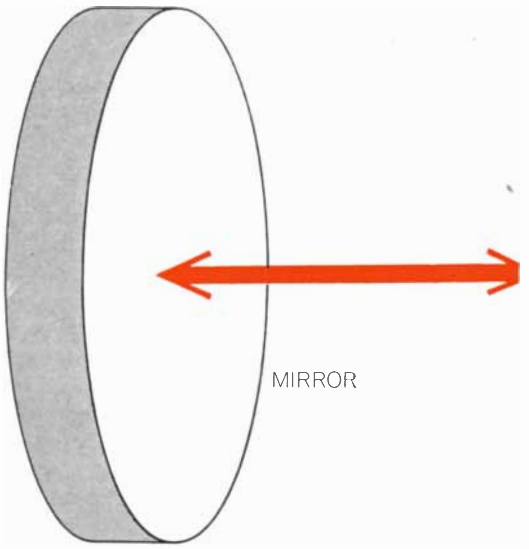


LIQUID LASER AND ASSOCIATED COMPONENTS rest on an optical bench consisting of a slab of granite four feet long. The wide glass tube containing the active liquid (a solution of neodymium ions in selenium oxychloride) can be seen through the open door of the box. The tube is surrounded by three narrower tubes containing xenon, which are used to excite the ions in the liquid. When the laser is in operation, the door is closed in order to shield the experimenters from the intense white light produced by the xenon flash tubes. The small fan at the back of the box helps to cool the laser. Just to the left of the box is a mirror that reflects

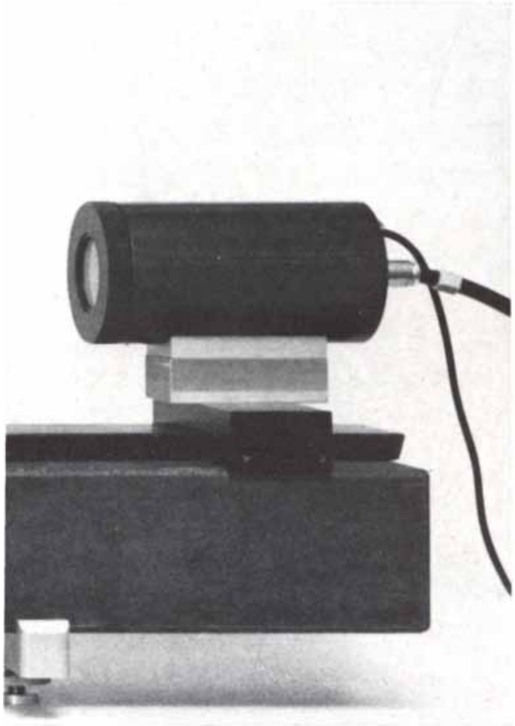
matical equation in 1958 by Arthur L. Schawlow and Charles H. Townes, then respectively at the Bell Telephone Laboratories and Columbia University [see "Optical Masers," by Arthur L. Schawlow; SCIENTIFIC AMERICAN, June, 1961]. Given the characteristics of the laser system (the width of its band of wavelengths and the lifetime of the emission, as well as the optical losses), the Schawlow-Townes equation predicts what minimum population inversion must be reached before anything spectacular is likely to happen. The knowledge of this minimum-inversion threshold is extremely important, because it is this factor that determines the minimum number of active atoms or molecules per unit volume needed for laser action; if the concentration of active particles is less than the minimum inversion threshold, nothing will happen, regardless of the other factors. The minimum-inversion factor is also used to determine how much one has to excite a laser medium in order to bring it to the point where the avalanche of electrons can start feeding on itself. Beyond this threshold stimulated emission takes over, and all the emitting atoms respond together to the electromagnetic field bouncing between the mirrors.

Schawlow and Townes thus established the criteria a luminescent system must satisfy to be considered a potential laser material. First, the emitted light should be confined to a few bands of the spectrum, the ideal case being a single narrow band, or line, of high intensity. If the band is too broad, the photons within the laser cavity would be spread over a wide range of energies and would therefore be less effective in stimulating emission. Second, the conversion efficiency of the material must be high. For example, if the excited atoms do not generate enough photons and instead dissipate their energy in the form of heat, the avalanche process will never start. Finally, the necessity of keeping the loss of photons to a minimum requires both a high degree of optical perfection in the laser material and a good alignment of the reflecting mirrors.

How does one excite a laser medium? There are several possible ways, depending on the structure of the laser and the properties of the active medium. A gas laser or a solid-state laser can be excited by passing an electric current through it, by bombarding it with electrons or by illuminating it. Although there is no fundamental reason why any of these methods could not be used with a suitable liquid, only the last method, called optical pumping, has been employed so far. In this method the active particles are pumped from their "ground" state to an excited state by the absorption of light. The most suitable pumping light may differ from material to material, but xenon flash lamps, which emit white radiation, have been widely employed for optically pumped



XENON FLASH TUBES (*white*) are used to "pump" electrons in the active liquid (*color*) from lower to higher energy states.



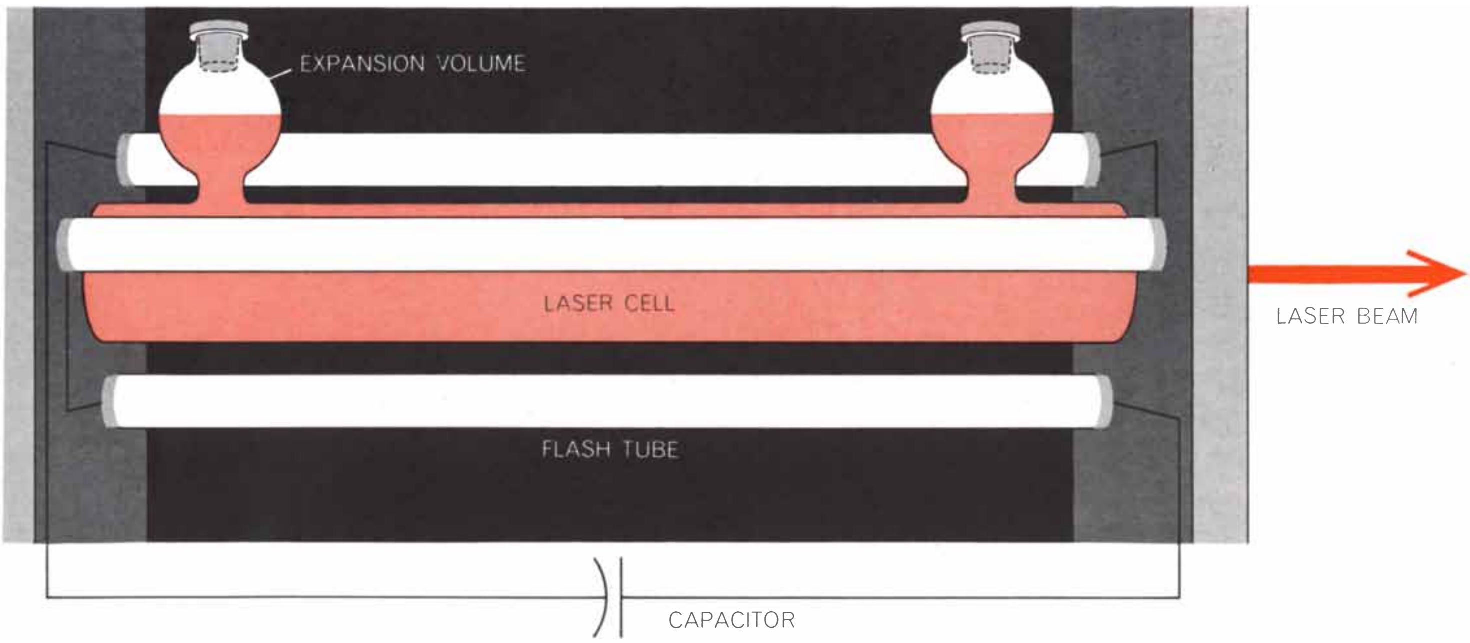
the escaping laser beam back into the active medium. Just to the right of the box is the apparatus that was used to make the photograph on page 80. At the far right is a photodetector for studying the laser radiation.

pulsed lasers. Continuously emitting lasers, on the other hand, have utilized a variety of pumping sources, including incandescent tungsten filament lamps and mercury or xenon arc lamps. The liquids studied by our group at the General Telephone & Electronics Laboratories have all been optically pumped by a conventional xenon flash source.

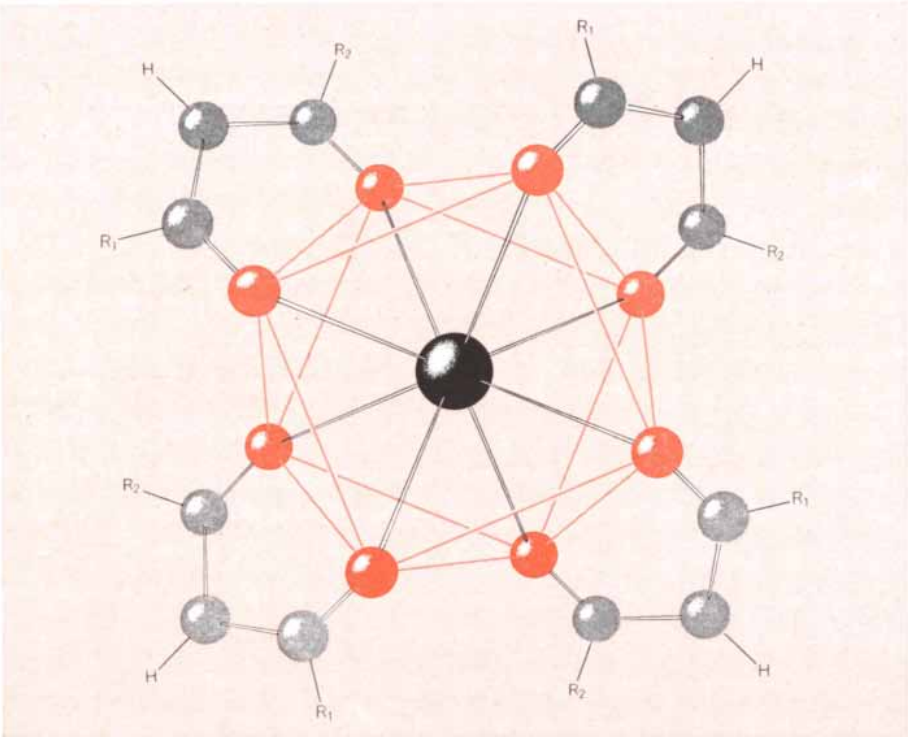
In trying to devise a liquid laser medium one must first survey materials that show luminescence in the liquid form. In the early days of lasers organic materials were preferred, largely because luminescence is a rather common phenomenon in the organic domain. Some early reports of success were later shown to be premature, and the achievement of stimulated emission from organic systems proved to be far more difficult than had been anticipated. In fact, operation of a purely organic laser was first reported only last year by Peter Sorokin and John Lankard of the International Business Machines Corporation. Their laser has a number of novel properties and will be subject to much further research. In its present form it requires the use of extremely intense, short pulses of exciting radiation, which can be obtained only from "giant pulse" ruby lasers or from flash tubes used in conjunction with specialized circuitry. These organic lasers operate in a pulsed mode and have a potentially high repetition rate. The output consists of a short burst of radiation with a high peak power. Although this class of liquid lasers is very interesting, there are special problems and properties that set it apart from other kinds of lasers. In this article we are concerned primarily with liquid lasers whose characteristics more closely parallel those of solid-state devices.

Outside the organic domain liquid luminescence is not a particularly common phenomenon. In the search for a liquid laser it was therefore natural to take a cue from the materials used in the solid state. In most of these lasers the active atoms (those that participate in the emission process) are dispersed in a host substance, which is either a crystal lattice or a glassy framework. In liquids the counterparts would be the active solute and the host solvent. In solid systems the active components have most commonly been the lanthanide, or rare-earth, ions and certain metal ions. The electrons responsible for the optical properties of the rare-earth ions are situated deep within the ion's electron cloud and are usually well shielded from external perturbing influences.

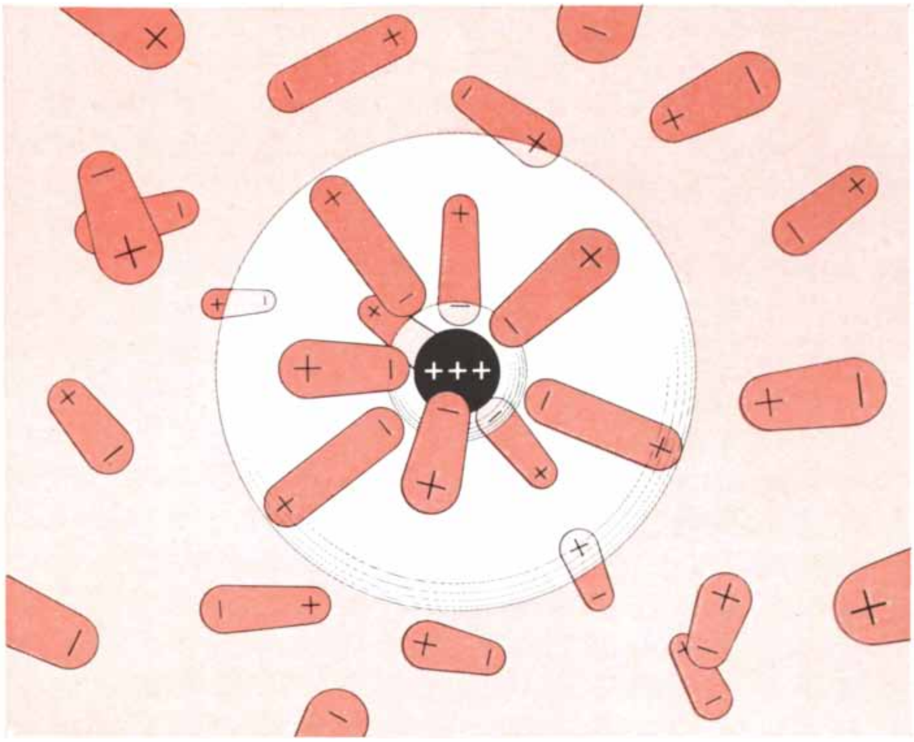
It is just this property that gives rise to the characteristically sharp line emission of such ions and accounts for their success in laser applications. It is quite natural, therefore, to consider their use in liquids. When introduced into solution as "free" ions (in the form, say, of a rare-earth halide dissolved in water), however, their fluorescence efficiency is very low. The agitation of the solvent molecules is too much even for the shielded electrons, and the absorbed energy is dissipated as heat rather than emitted as photons. In order to use these materials it is necessary to find some way to make this nonradiative dissipation of energy noncompetitive with the radiative path. For the rare-earth ions this



When an electron returns spontaneously to the lower state, the photon of light it emits can trigger another electron to emit its photon prematurely, setting off the "avalanche" process that characterizes laser action. Expansion volumes protect the laser against damage caused by the thermal shock wave generated in the liquid by the flash. Flash tubes are connected in series to a capacitor (*bottom*).



CHELATE CAGE consisting of eight oxygen atoms (*colored balls*) shields the active rare-earth ion (*black ball at center*) from the agitation of the solvent molecules (*not shown*) in one class of liquid-laser materials. In this particular organic molecule the oxygens are arranged in the form of an antiprism (*colored lines*). Each of the organic groups, called ligands, is bonded to the central rare-earth ion by two oxygen atoms, which together with three carbon atoms (*gray balls*) constitute the basic ligand chain. The groups designated R_1 and R_2 are further organic components of the ligands; in the benzoylacetonate molecule R_1 is a benzene ring (C_6H_5) and R_2 is a methyl group (CH_3), whereas in the benzoyltrifluoroacetonate molecule R_1 is a benzene ring and R_2 is a trifluoromethyl group (CF_3).



"SOLVATION SHELL," consisting of an array of inorganic solvent molecules (*color*), forms around a "free" rare-earth ion (*black*) in solution, effectively isolating it from interactions with the solvent. The solvent molecules are represented schematically here as simple elongated electric dipoles. The best liquid-laser material of this general type discovered to date is a solution of trivalent neodymium ions (Nd^{+3}) in selenium oxychloride ($SeOCl_2$).

can be accomplished by incorporating the ion into a cagelike molecule that provides additional shielding, or by giving the solvent a special structure. These two approaches to the problem of energy dissipation have led to two different classes of liquid lasers.

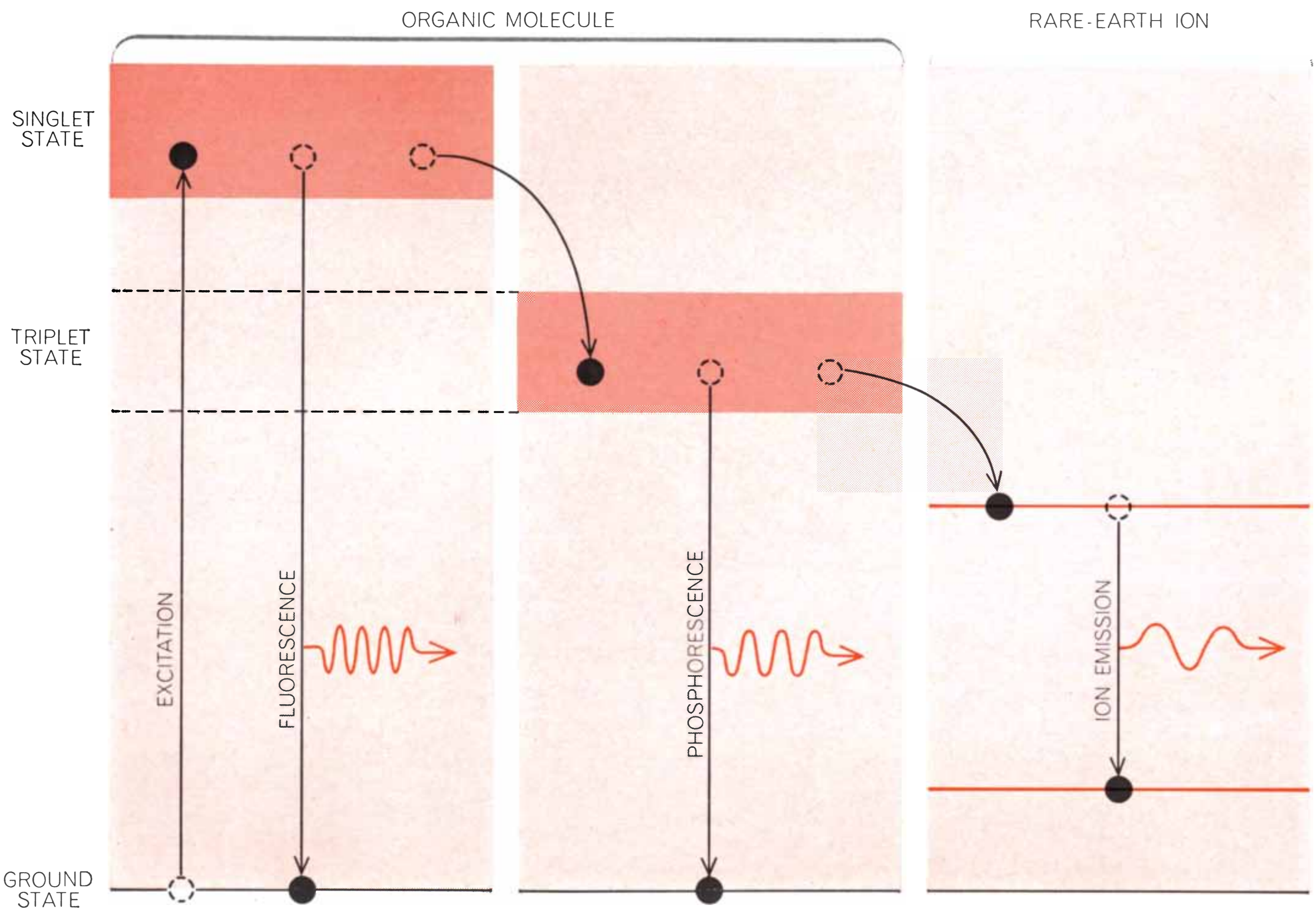
A number of cagelike structures are known to chemists; in one type, called a chelate, the rare-earth ion exhibits intense fluorescence with a comparatively sharp line spectrum. In a chelate molecule (the name is derived from the Greek word meaning claw) the rare-earth ion is bonded to a number of organic groups called ligands. The particular ligands that are effective with rare-earth ions have two points of bonding and are called bidentate. Typical among such ligands are the benzoylacetonate group (CH_3–CO–CH–CO–C_6H_5)$^-$ and the benzoyltrifluoroacetonate group (CF_3–CO–CH–CO–C_6H_5)$^-$. Each of these ligands is bonded to the rare-earth ion by two carbonyl (CO) groups. In the completed structure the ion is surrounded by the ligand oxygens, with the remainder of the organic structure providing further isolation from the solvent.

The most effective of these compounds contain four bidentate ligands, making a cage of eight oxygens in the immediate vicinity of the rare-earth ion. The total number of atoms in such a complex can easily exceed 100. An important feature of the structure is that the oxygens are placed in well-defined positions forming a polyhedron around the central ion. Several such structures are possible and have been identified; a typical one is shown in the top illustration at the left. The significant point here is the similarity between the immediate surroundings of the rare-earth ion in a chelate molecule and the situation in some crystal lattices. Although the bulky molecule interacts with the solvent, the central ion is principally "aware" of the oxygen cage and in some ways behaves as if it were in a crystal lattice.

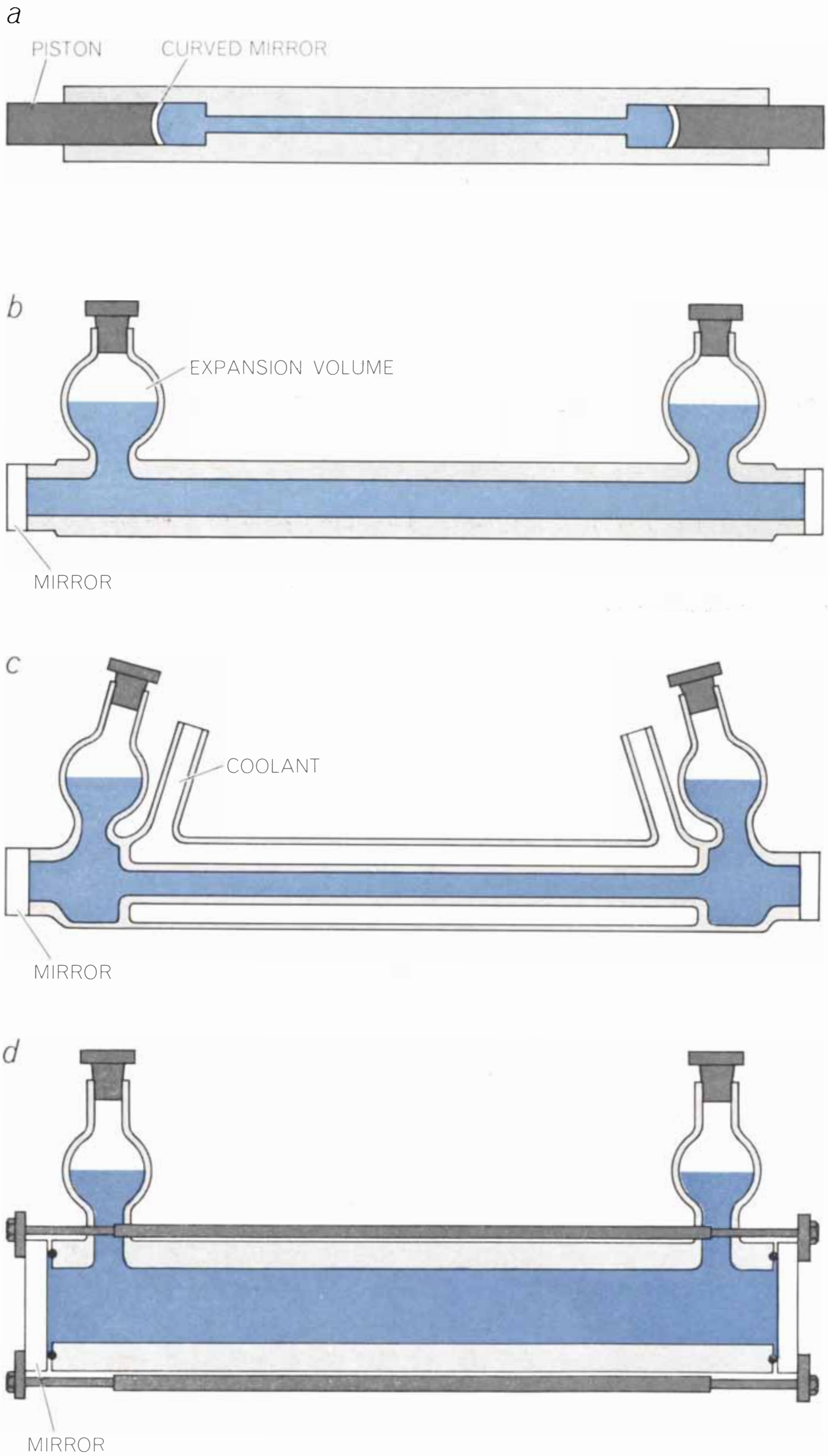
It would be misleading, however, to disregard the organic structure beyond the oxygens. In fact, it can and frequently does play a major role in promoting laser action. Each ligand can be regarded as an organic molecule with its own electronic structure and energy levels. Although organic molecules have vastly different geometries, sizes and structures, their energy-level structure is generally similar. A common characteristic is that these molecules readily absorb radiation, usually in the blue or ultraviolet region of the spectrum. Electrons raised to an excited "singlet" state by this absorption can return to the ground state directly; this gives rise to a short-lived organic fluorescence [*see illustration below*]. On the other hand, the electron may make an internal transition to a long-lived metastable state, called the "triplet" state, and then return to the ground state. This emission is called phosphorescence. Which path is ultimately dominant depends on the structure of the molecule, its surroundings and the temperature.

In particular, when the molecule happens to form a ligand to a rare-earth ion, the path involving the metastable triplet is strongly favored. Furthermore, in such a chelate structure the electron in the triplet state, instead of returning to the ground state radiatively, may transfer its energy to the rare-earth ion. For this to occur there must be a close match in energy between the ligand triplet state and the excited ion state, with the former being somewhat higher. Such an energy transfer can be extremely efficient and result in a greatly improved chance of exciting the rare-earth ion. Photons in the pumping source that would not be absorbed by the rare-earth ion itself can now be usefully employed. The pumping bands of a chelate complex are very much wider than those for the free rare-earth ion. Thus the decrease in nonradiative loss, achieved by the shielding effect of the ligand, and the improved pumping resulting from the energy transfer from the ligand greatly facilitate the attainment of population inversion.

The first liquid laser, based on a chelate structure, was successfully operated by our group at General Telephone & Electronics in January, 1963. The active component was a europium ion at the center of a cage consisting of four benzoylacetonate ligands. The solvent was a mixture of ethyl and methyl alcohols. These solutions have the property of becoming more viscous as the temperature is lowered. At −160 degrees centigrade, a convenient operating temperature for the laser, the solution is quite viscous, somewhat like thick honey, and the optical quality is excellent. Although laser action can be achieved only at low temperatures with this particular chelate, the results demonstrated that laser action can take place in a liquid and that the speculations involved in evaluating the merits of the chelates were correct. With a sufficiently intense pulse of excitation from the flash tube, the beam of red light emitted at a wavelength of 6,131 angstrom units indeed had all the properties attributable to solid-state lasers. These properties include high spectral purity, beam collimation and the characteristic "spik-



ENERGY LEVELS of the electrons in a rare-earth chelate molecule are arranged in such a way as to favor the internal transition of electrons from the first excited "singlet" state of the ligands (*left*) to a long-lived metastable "triplet" state (*center*), from which they can be transferred to a closely matched excited state of the rare-earth ion (*right*). Electrons that return to the "ground" state of the organic molecule directly from the singlet state are responsible for organic fluorescence; those that return to the ground state directly from the triplet state account for the characteristic emission called phosphorescence. The energy transfer from the organic molecule to the active rare-earth ion greatly facilitates the attainment of the "population inversion" required for the onset of laser action.



TYPICAL LIQUID-LASER CELLS have undergone several modifications in design. Cell *a* was used in early chelate lasers, which operated only at very low temperatures. Since the chelate liquid contracts considerably when it is cooled, it was necessary to devise some structure that would keep the mirrors in alignment during the contraction. This was accomplished by outfitting the cell with two close-fitting quartz pistons whose opposed interior faces were optically ground and polished. Drawn inward by surface tension, the pistons followed the contracting liquid, maintaining their alignment. Cell *b* is similar to the one installed in the inorganic liquid laser shown on pages 82 and 83. The bulbs serve as expansion volumes and are also used for filling the cell. Cell *c* is surrounded by a glass jacket through which a cooling liquid is circulated. Cell *d* is a recent demountable version of *b*. In *b*, *c* and *d* the mirrors can be either evaporated on the end windows of the cell or placed outside.

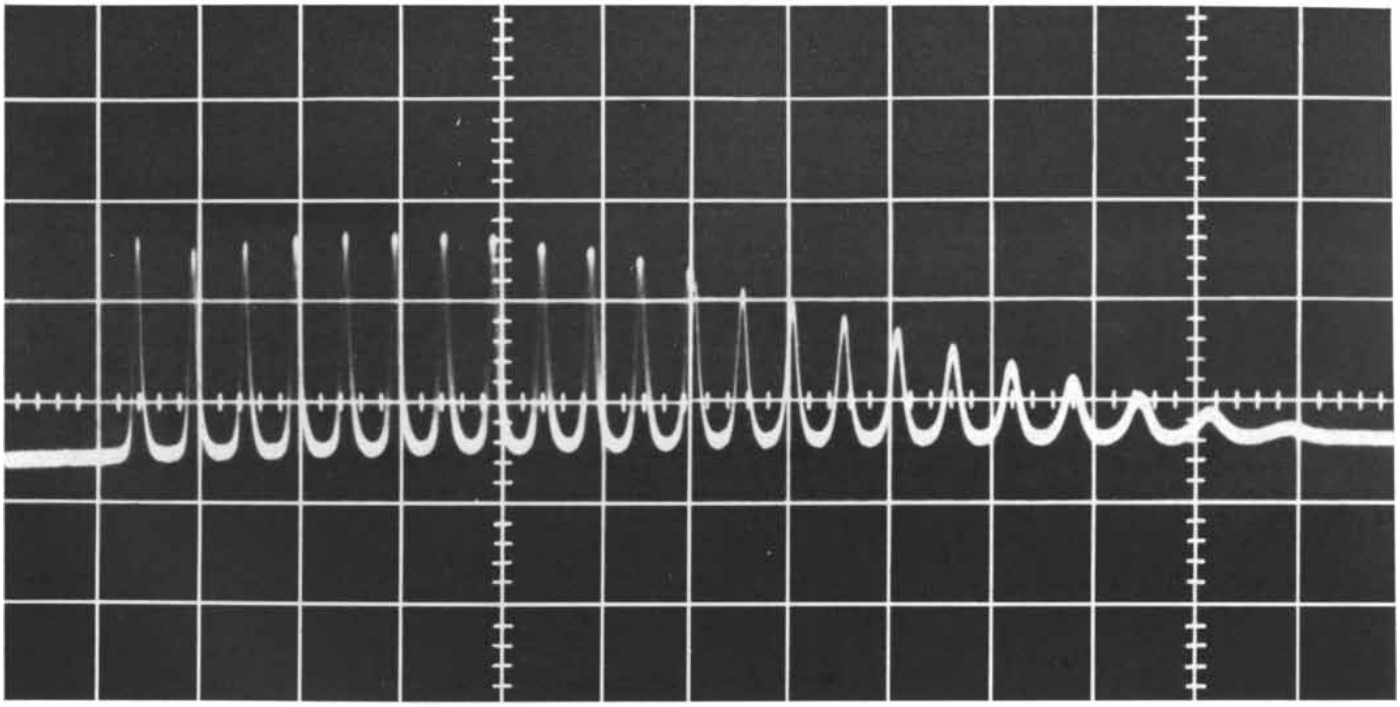
ing," or pulsation, of the output as a function of time [*see illustration on opposite page*].

There are many possibilities for constructing such chelate complexes and many different solvent combinations that can be used. Indeed, after the first demonstration of a successful chelate laser a number of other systems were introduced. A major problem was to find a chelate that retained its fluorescent intensity and structural integrity at higher temperatures, ideally at room temperature. Such a chelate, it was discovered, is formed by the ligand benzoyltrifluoroacetonate and the solvent acetonitrile. Trivalent (triply ionized) europium formed a complex with this ligand, and when it was dissolved in this solvent, it constituted a chelate laser capable of operating at room temperature.

All the chelate lasers discussed so far use ligands that belong to the general class designated as beta-diketone, in which the carbonyl group is principally responsible for the interesting spectroscopic and energy-transfer properties of the ligands. The singlet absorption of this group is so intense, however, that the exciting radiation is absorbed within a few tenths of a millimeter after entering the solution. This places a very serious limitation on the performance of a chelate laser; only a small amount of the material is involved in the laser action, and the energy and power outputs are much smaller than those of the more conventional solid-state lasers. Thus the use of beta-diketone chelate cages, although it is effective in achieving the first liquid laser, ultimately limits this device as a practical system.

To find a way out of the dilemma we were obliged to go back and seek another way to isolate the ion and prevent the nonradiative losses. This involved giving up the energy-transfer property of the beta-diketone ligands. This sacrifice would be fatal for a rare-earth ion with weak pumping bands of its own, such as europium, but it is of small consequence to other rare-earth ions, such as neodymium, which is known to "lase" in many solid materials without assistance from energy transfer.

Following this line of reasoning, Adam Heller of our group succeeded in constructing neodymium chelate complexes free of the absorption limitation and giving rise to laser action. In these chelates, however, the nonradiative losses are still large enough to limit the



CHARACTERISTIC "SPIKING," or pulsation, of the output of a pulsed laser as a function of time can be observed in this oscilloscope trace produced by a chelate liquid laser. The active medium was a europium-benzoylacetonate chelate in an alcohol solution.

performance of the resulting laser. Major advances therefore depended on a still greater reduction of these losses. To show how this was achieved we return to the more fundamental problem of the luminescence of the "free" ion in solution.

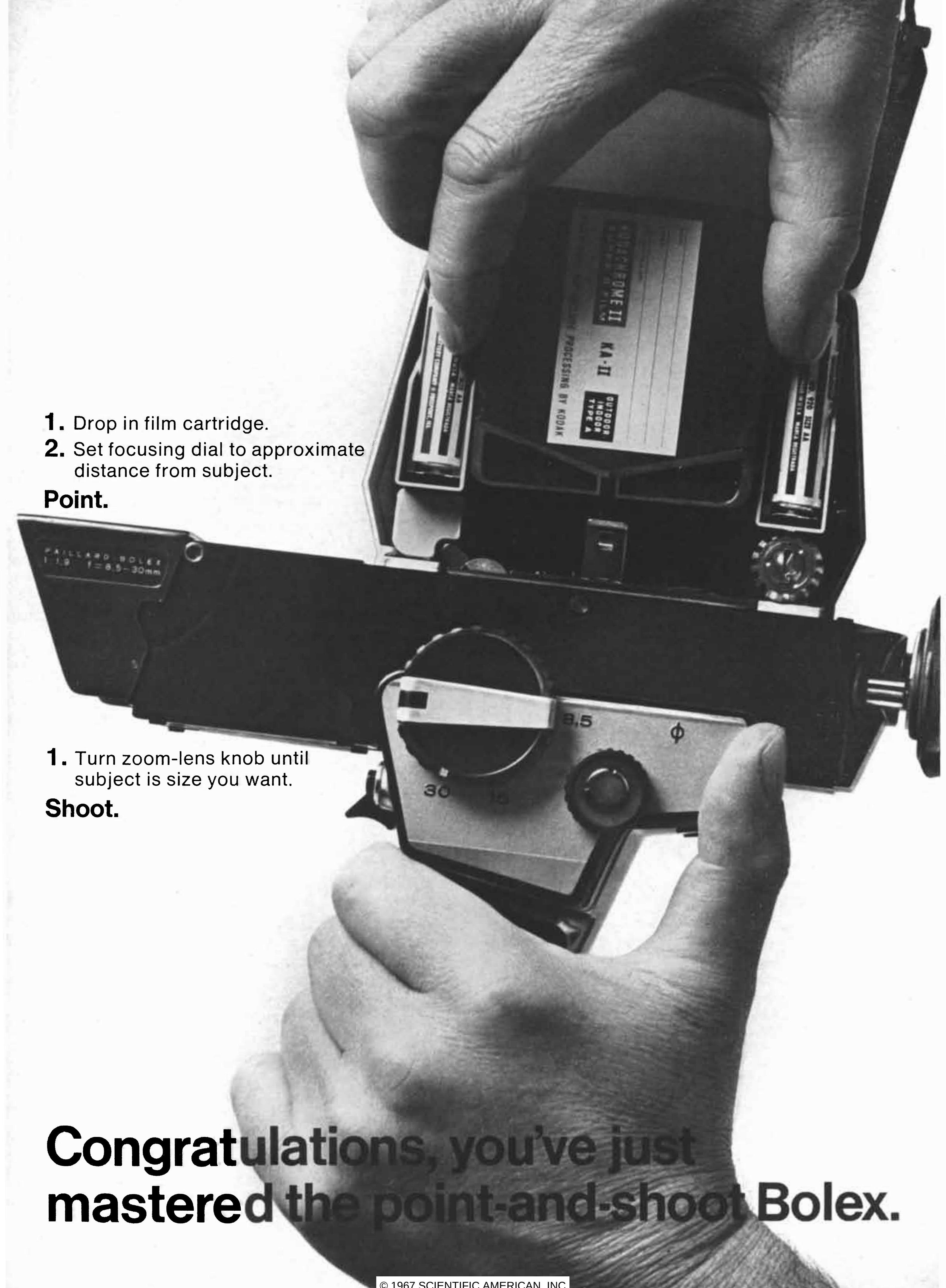
We have mentioned briefly that essentially "free" ions display rather weak luminescence, if it is detectable at all. The key word in this context is "free," and one must understand the sense in which we use the word. In chelates the ions are definitely bonded to the ligands. In solvents such as water the "free" ion is surrounded by solvent molecules that form a "solvation shell" [*see bottom illustration on page 84*]. The resulting complex is not essentially different from a chelate, inasmuch as it can have considerable stability and a well-defined geometry. The low efficiency of luminescence in such systems (for instance neodymium ions solvated by water) must therefore be attributed to a deactivation of the ion by the solvation shell. Instead of radiating as photons the excitation energy of the ion is somehow dissipated into heat, or—what is synonymous—into vibrational motions of the shell and outlying solvent molecules.

A detailed study of this process led Heller to understand how the nonradiative loss could be controlled and minimized. The interchange of energy between the ion and the solvent can be pictured as a disappearance of a single large quantum of electronic energy localized on the ion and a simultaneous appearance of a number of smaller vibrational quanta localized somewhere in the solvation shell or beyond. The probability of such nonradiative losses depends on the number of the vibrational quanta that must be created and decreases rapidly as this number increases. This effect can be demonstrated by substituting deuterium oxide, or heavy water, for ordinary water. Because of the increase of mass the vibrational quantum of energy associated with the deuterium-oxygen bonds is lowered and more quanta must be excited to deactivate the ion. The result is a definite increase in luminescent yield.

The energy of the vibration is primarily determined by the lightest atom in the bonding group. It occurred to Heller that nonradiative losses could be prevented by the use of solvents having no hydrogen or deuterium atoms at all. This requirement alone seriously limits the number of choices; it eliminates virtually all organic solvents. Further requirements are even more restrictive: the solvent must be transparent to the emission wavelength and should be transparent to most of the pumping radiation. In addition the solvent must have a high dielectric constant in order to dissolve sufficient amounts of the active ionic compounds.

The liquid selenium oxychloride ($SeOCl_2$) has met all these requirements. In its pure form it is a nearly colorless, highly toxic liquid with a density comparable to that of glass, a low refractive index and a high dielectric constant. By itself it is capable of dissolving only limited amounts of substances such as neodymium oxide and neodymium chloride. The solubility of these substances can, however, be greatly increased by adding such compounds as tin tetrachloride ($SnCl_4$) or antimony pentachloride ($SbCl_5$). Mixtures of these compounds with selenium oxychloride form very strong aprotic acids (acids that do not contain protons, or hydrogen ions); these acids can then chemically react with the neodymium compound. In the dissolution of neodymium oxide the highly polar selenium oxychloride molecules presumably form a solvation shell around the trivalent neodymium ion. Since the vibrational energy is inversely proportional to the square root of the mass, and since the lightest atom in the system is oxygen (16 times heavier than hydrogen), the vibrational energies are likely to be about four times lower than in hydrogen-containing solvents.

In this system the ion is effectively isolated from interactions with the solvent, and the nonradiative dissipation of its electronic excitation energy is greatly reduced. Early observations indeed showed that trivalent neodymium


1. Drop in film cartridge.
2. Set focusing dial to approximate distance from subject.
Point.
1. Turn zoom-lens knob until subject is size you want.
Shoot.
Congratulations, you've just mastered the point-and-shoot Bolex.
KA-II
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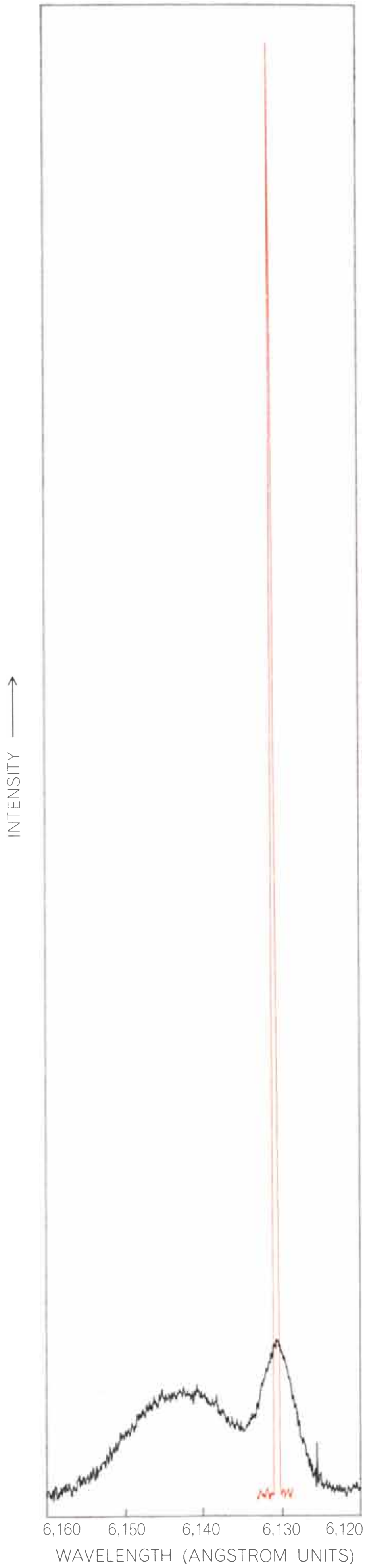
15

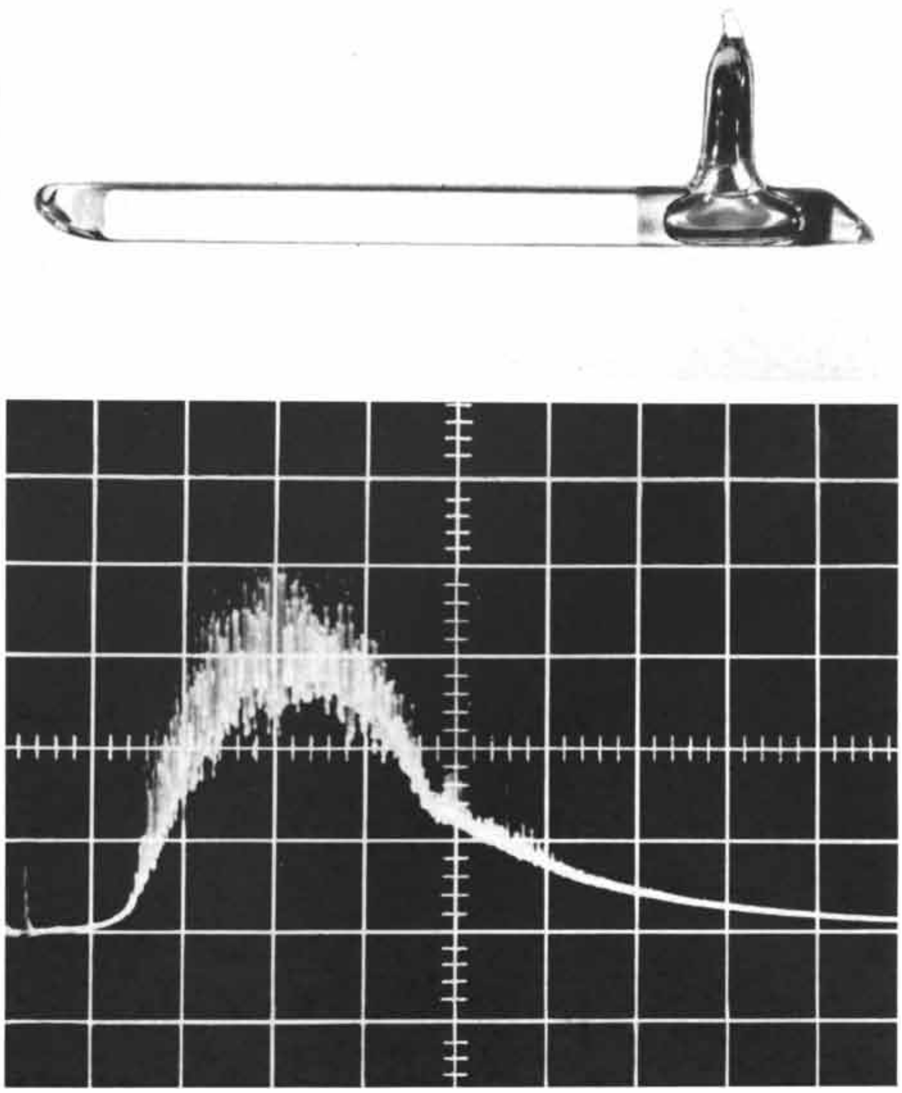
in selenium oxychloride exhibits an extremely intense fluorescence. The principal line emission of this ion, which occurs at 10,550 angstroms in the infrared region of the spectrum, was shown at room temperature to exceed in intensity even the line emissions found in high-quality laser crystals and glasses. The width of the spectral line in this fluorescence is significantly broader than the lines observed in crystals but narrower than those in glasses. Perhaps even more important, the absorption bands used for optical pumping are broader than the absorption bands of crystals and comparable to the bands of glasses.

The remarkable spectroscopic properties of the material indicated that it could be incorporated into a comparatively simple laser cell. This proved to be the case: the solution contained in a simple Pyrex glass tube crudely sealed at both ends showed the characteristic laser spiking [*see illustration on next page*]. An input energy of only 30 joules to the flash tube was required to attain the threshold of laser action. No mirrors were necessary because total internal reflection (due to the fact that the solution has a higher index of refraction than glass) trapped enough radiation for laser action to result.

A laser cell with no mirrors has a limited usefulness because the stimulated radiation leaks out of the cell in all directions and does not form a collimated beam. To achieve such a beam one must use precision-made cells with properly aligned mirrors. The performance of a number of six-inch cells with a quarter-inch inside diameter was evaluated and found to be quite comparable to the performance of commercial glass laser rods of similar dimensions. Output energies of several joules per pulse are readily obtainable; the peak power of individual spikes reaches 10 to 20 megawatts. Furthermore, the spectral output is far purer than those characteristic of glass lasers. This performance is particularly impressive if one compares



SPECTRAL OUTPUT characteristic of laser action is graphically illustrated by these two curves, one of which shows the fluorescence spectrum of a chelate laser just below the threshold for laser action (*black*), whereas the other shows the spectrum just above the threshold (*color*). The spectral output of the laser suddenly shrinks to a narrow, intense line at 6,131 angstroms.

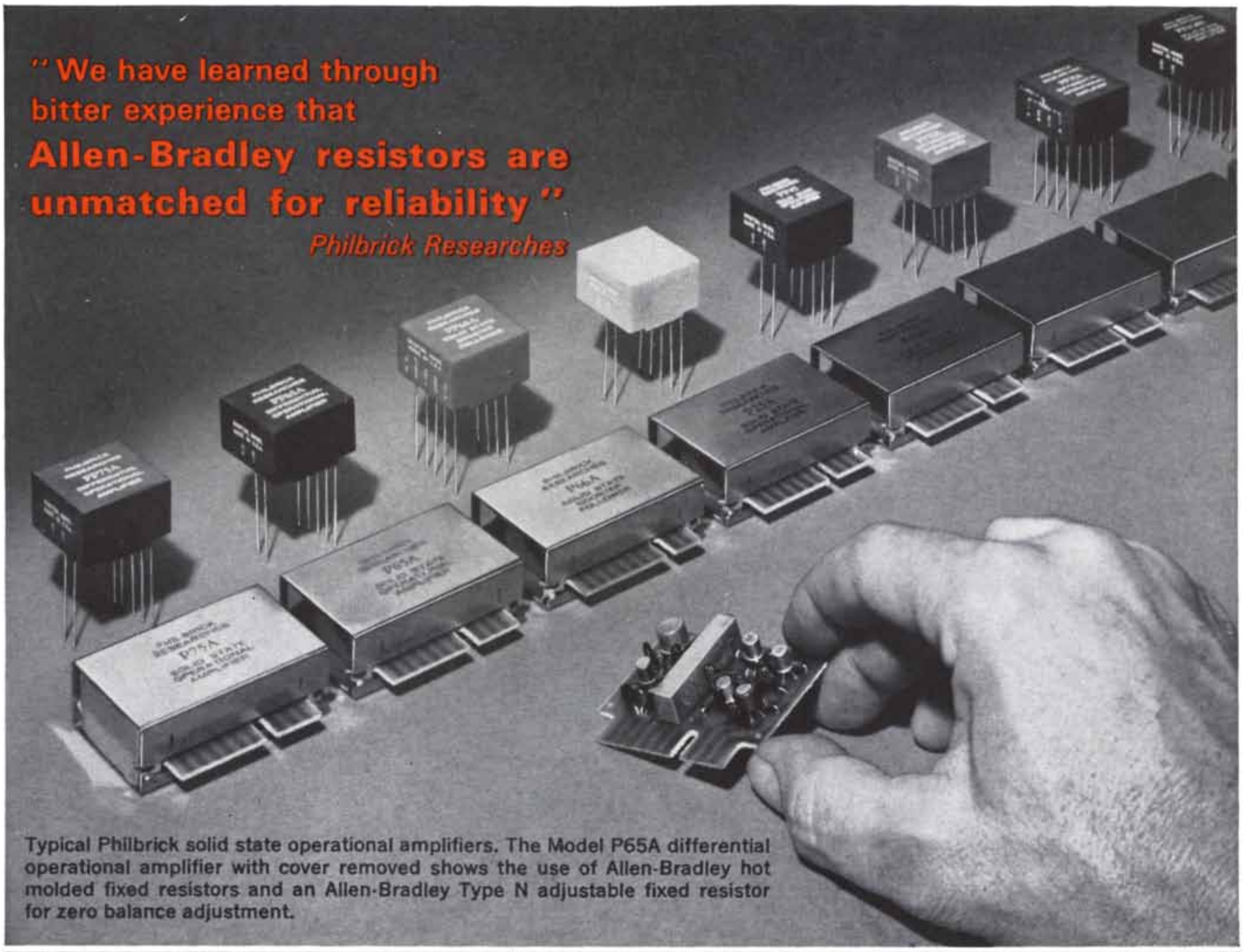


SIMPLEST TYPE of liquid-laser cell consists of a Pyrex tube with its ends flame-sealed to minimize reflection (*top*). Laser action takes place in the absence of the usual end mirrors, as shown by the characteristic spiking on the oscilloscope trace of the laser's output (*bottom*). The laser cell is filled with a solution of neodymium ions in selenium oxychloride.

it with that of the chelate laser, whose output and efficiency are respectively at least 1,000 and 10,000 times lower.

From this result it appears that a liquid medium with nearly ideal fluorescence properties has finally been found. This, however, completes only the first part of the task. Among the many problems that remain the foremost is the problem of the thermal expansion coefficient of liquids, which is about 1,000 times larger than it is in solids. A thermal shock wave generated in the medium by the flash can lead to disastrous consequences for the cell. The simple expedient of providing volumes for expansion at both ends is effective, but better designs are being developed. Heating of the liquid caused by the exciting flash is also accompanied by a change of refractive index, which distorts the path of the rays and thereby leads to losses in the cavity. Here circulation of the liquid may prove to be of great importance, particularly for lasers that are operated continuously or at high pulse rates.

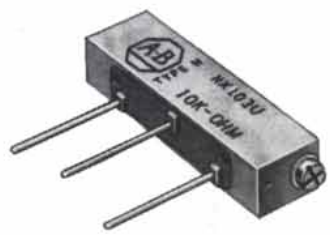
It is in the class of "free" ion liquid lasers that the advantages and disadvantages of the liquid state in laser technology are most likely to receive a critical test. The achievement of continuous operation and high-energy, high-power pulsed operation appears to be only a matter of time. Liquid lasers have thus reached a stage of development at which they promise to be competitive with the more conventional lasers. In short, a new way has been found; now the whole technology of using the liquid medium and exploiting its advantages must be developed.



Typical Philbrick solid state operational amplifiers. The Model P65A differential operational amplifier with cover removed shows the use of Allen-Bradley hot molded fixed resistors and an Allen-Bradley Type N adjustable fixed resistor for zero balance adjustment.

HOT MOLDED FIXED RESISTORS are available in all standard EIA and MIL-R-11 resistance values and tolerances, plus values above and below standard limits. Shown actual size.

The need for a yearly production capacity of well over a billion units is a testimonial to the uniformity and reliability of all Allen-Bradley hot molded resistors.



Type N hot molded adjustable fixed resistor rated 1/3 watt at 50°C ambient. Available with nominal resistance values from 100 ohms to 2.5 megohms with tolerances of ±10% and ±20%.

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Allen-Bradley Type N adjustable fixed resistors likewise use a solid hot molded resistance track. Adjustment is so smooth, it approaches infinite resolution—and settings remain fixed. Being noninductive, Type N controls can be used at high frequency, where wire-wound units would be completely unsatisfactory.

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Geological Subsidence

In many parts of the world the pumping of oil, gas or water out of the ground has caused the land to sink. Where oil or gas are involved the subsidence can be forestalled by pumping in water

by Sullivan S. Marsden, Jr., and Stanley N. Davis

Mankind levels hills, changes the courses of rivers and converts marshes into dry land, but his alterations of the landscape rarely approach the large-scale geological operations of nature itself. In the 20th century, however, some of man's activities quite unintentionally have begun to produce geological effects of an extensive and alarming character. One of the most far-reaching is geological subsidence, or sinking of lands, that results from tapping the earth for water and petroleum.

The phenomenon was first noticed in Texas in the early 1920's. At the edge of Galveston Bay an area of several square miles subsided by three feet or more, cracks appeared in the ground and the Gaillard Peninsula sank below the surface of the bay. The cause was not difficult to discover: the affected area was above the Goose Creek oil field, where many millions of barrels of petroleum were rapidly being drawn from the underlying strata.

The Goose Creek subsidence was only a small sample of events that were to

SUBSIDENCE OF LAND formed a depression around municipal buildings in Long Beach, Calif. Because of the subsidence the area acted as a catchment basin for rainwater, which had to be pumped out. The sinking resulted from the withdrawal of fluids from an oil field under the city. Long Beach has now repaired the damage with fill and halted subsidence with subsurface injections of water.

follow elsewhere. The most dramatic and damaging effects became apparent at Long Beach, Calif., in the 1940's and 1950's. Above the extremely active Wilmington oil field in that area (then the third largest field in the U.S.) the ground sank until it had become a bowl up to 26 feet deep over an area of 22 square miles. The slow subsidence of the land ruined buildings, cracked city pavements, twisted railroad tracks, wrecked bridges, sheared off oil wells and did extensive damage to a power plant and the Long Beach Naval Shipyard; all told it produced damage amounting to upward of $100 million.

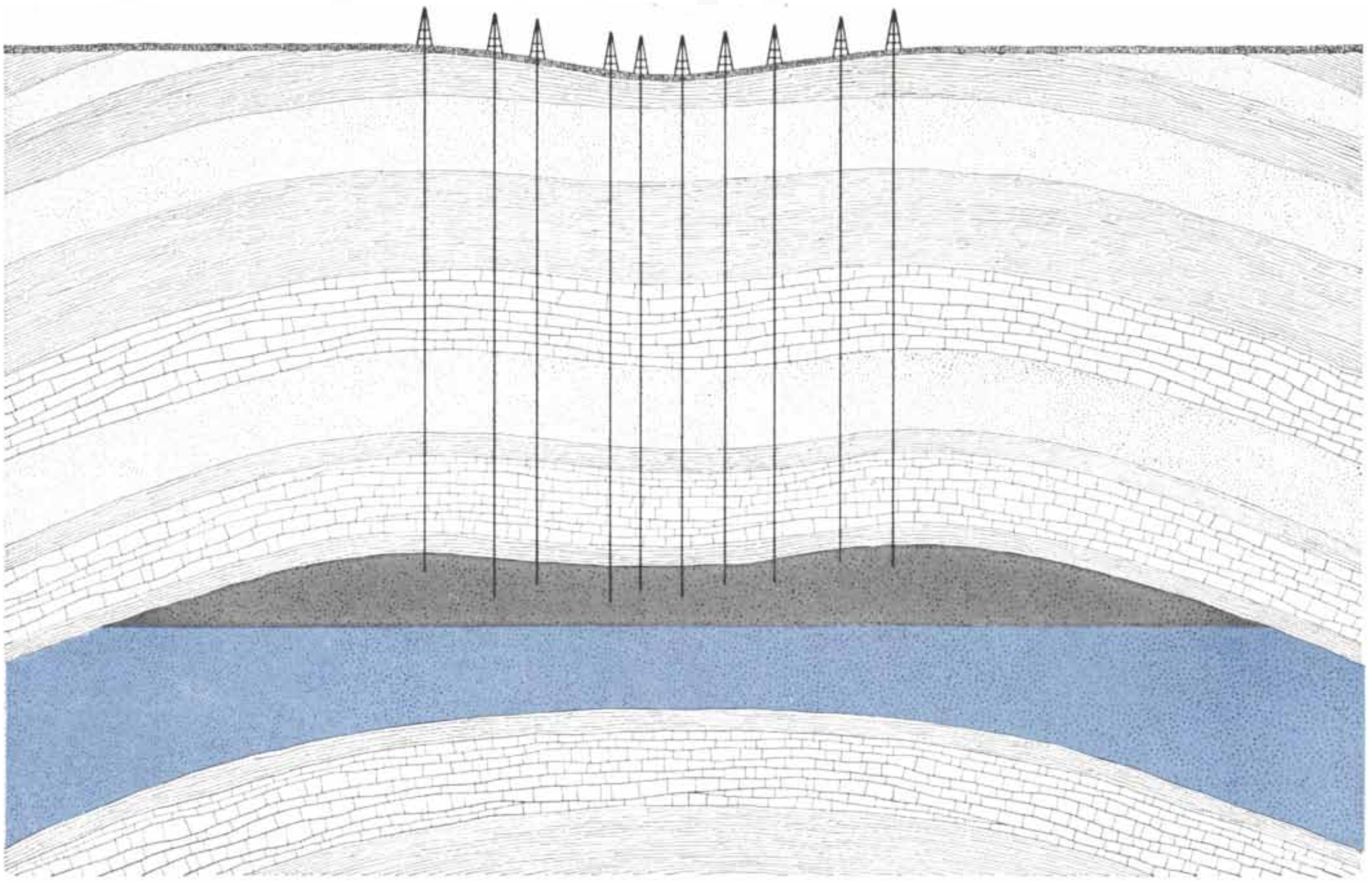
Long Beach is an example of subsidence concentrated in a comparatively small area; there are other places where the sinking affects a large region. The largest areas of land subsidence known are in California's San Joaquin Valley. Three such areas have been found there, one covering about 1,400 square miles, another 800 square miles and the third 300 square miles. They are the result of four decades of intensive pumping of underground water for irrigation in the valley. The ground in these areas is now sinking at rates of up to a foot per year, and in some places the land has fallen to more than 20 feet below its former level.

Pockets and regions of subsidence attributable to the same basic cause (withdrawal of fluid from underground pools) are now known to be widespread over the earth. They have become troublesome in Mexico City and Tokyo, in the oil fields of Venezuela and in many other populated places. Las Vegas, Los Angeles, Houston and London are among the well-known cities that have detected evidence of land sinking in recent years. There is reason to believe that subsidence is far more common around the world than is generally realized; no doubt it goes unreported in many places where the sinking so far has done no damage.

Since subsidence is obviously a growing problem, becoming intensified as man draws more and more deeply on the stocks of water and fossil fuels below the earth's surface, it behooves us to examine its causes in detail and to institute measures of prevention. There are ways to forestall or arrest the sinking of the land; they have been applied at Long Beach and elsewhere. The entire matter is now being studied by petroleum engineers, hydrologists, geophysicists and other specialists.

The liquid or gas tapped by a well is generally drawn from a stratum of porous rock whose pores are filled with the fluid under pressure. If the rock is well consolidated (that is, if its grains are well cemented together), it will usually continue to support the weight of the rock-and-earth overburden after the fluid is withdrawn. If, however, the fluid-holding rock is a poorly consolidated, easily molded sandstone, once the supporting pressure of the fluid has been withdrawn from its pores the pressure of the overburden compacts the rock, and the ground above subsides by the amount by which the rock is compressed. Other factors besides the mechanical strength of the fluid-containing rock may play a part in determining whether or not subsidence will occur after the withdrawal of fluid. Subsidence is more likely if soft, clayey material (which is easily compacted) is present in or next to the fluid stratum.

As the first step toward controlling subsidence it is essential, of course, to detect its occurrence as early as possible and to locate the strata where compaction is taking place. This is not an easy



GEOLOGICAL SITUATION in an area of subsidence caused by removal of oil shows an oil-containing stratum (*black*) lying above a stratum containing water (*color*). Subsidence can occur when oil is withdrawn if any strata that contain oil are readily compacted.

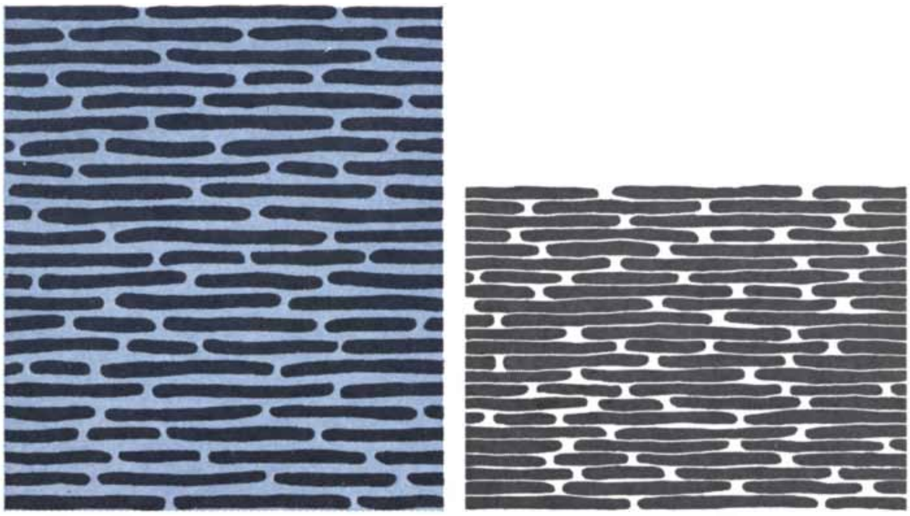
matter; special techniques have had to be devised in order to obtain accurate measurements of what is happening below the earth's surface.

There is a simple method of watching for subsidence at the surface. Firmly anchored posts ("bench marks") are set out in a grid pattern over a wide area, and their relative positions and elevations are examined from time to time with surveying instruments. Any change in the elevation or contour of the land will then be revealed by shifts in the marker configuration. This method, however, merely indicates the degree of the subsidence; to investigate its causes one must measure phenomena in the subsurface.

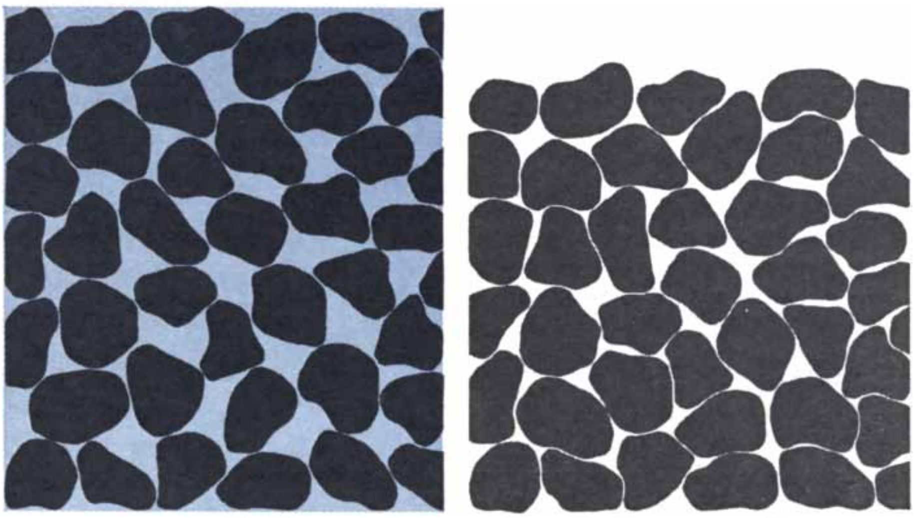
Several techniques have been used to detect and measure the shrinking or collapse of underground strata. One is to lower a firing mechanism into a well and shoot bullets of radioactive material into the rock at measured intervals down the hole. With these markers in place a gamma ray detector is periodically lowered into the well on a cable to determine if the distances between the radioactive markers have changed; a lessening of the distance between two bullets indicates that the stratum containing the bullets has become compacted.

Other, more precise methods are employed to obtain accurate measurements of the amount of compaction. Some of these depend on measurement of the vertical compression of the steel-pipe casing that lines a well. If the casing is cemented to the rock surrounding the well, vertical compression of the rock will shorten the pipe lengths. The shortening can be measured by marking the pipe with radioactive pellets embedded at intervals along its length. Or it can be measured by means of a magnetic device. The casing consists of a string of 30- or 40-foot "joints" (pipe lengths). At the collar joining two pipe lengths the magnetic flux is different from the flux along the length of the pipe. Consequently a magnetometer can locate the successive collars and thus provide an accurate measurement of any shortening of individual pipe lengths. The method can detect a shortening of as little as half an inch in a 40-foot joint.

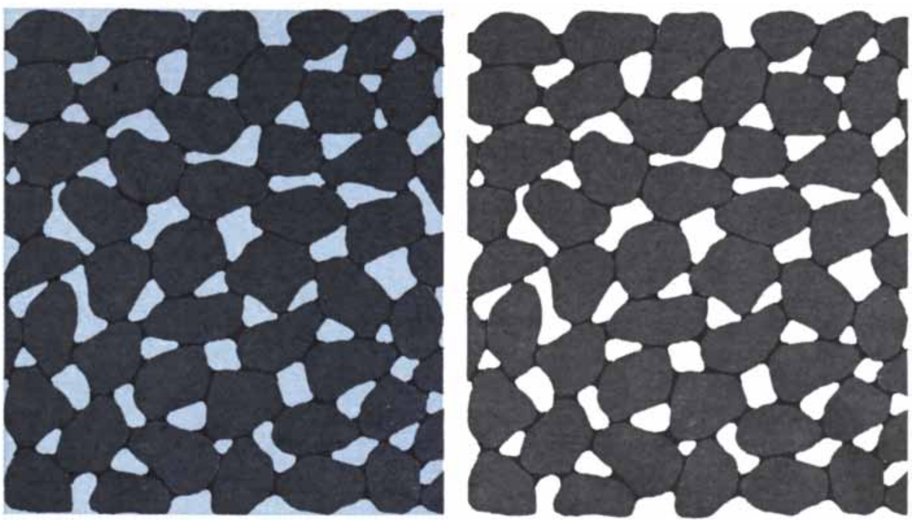
Still another technique, which has been employed for some time by the U.S. Geological Survey, furnishes a continuous record of subsidence. It is based on the use of a cable reaching from the surface to a weight anchored deep underground; the cable is free to move at its upper end and provides a remarkably precise measurement of any compaction



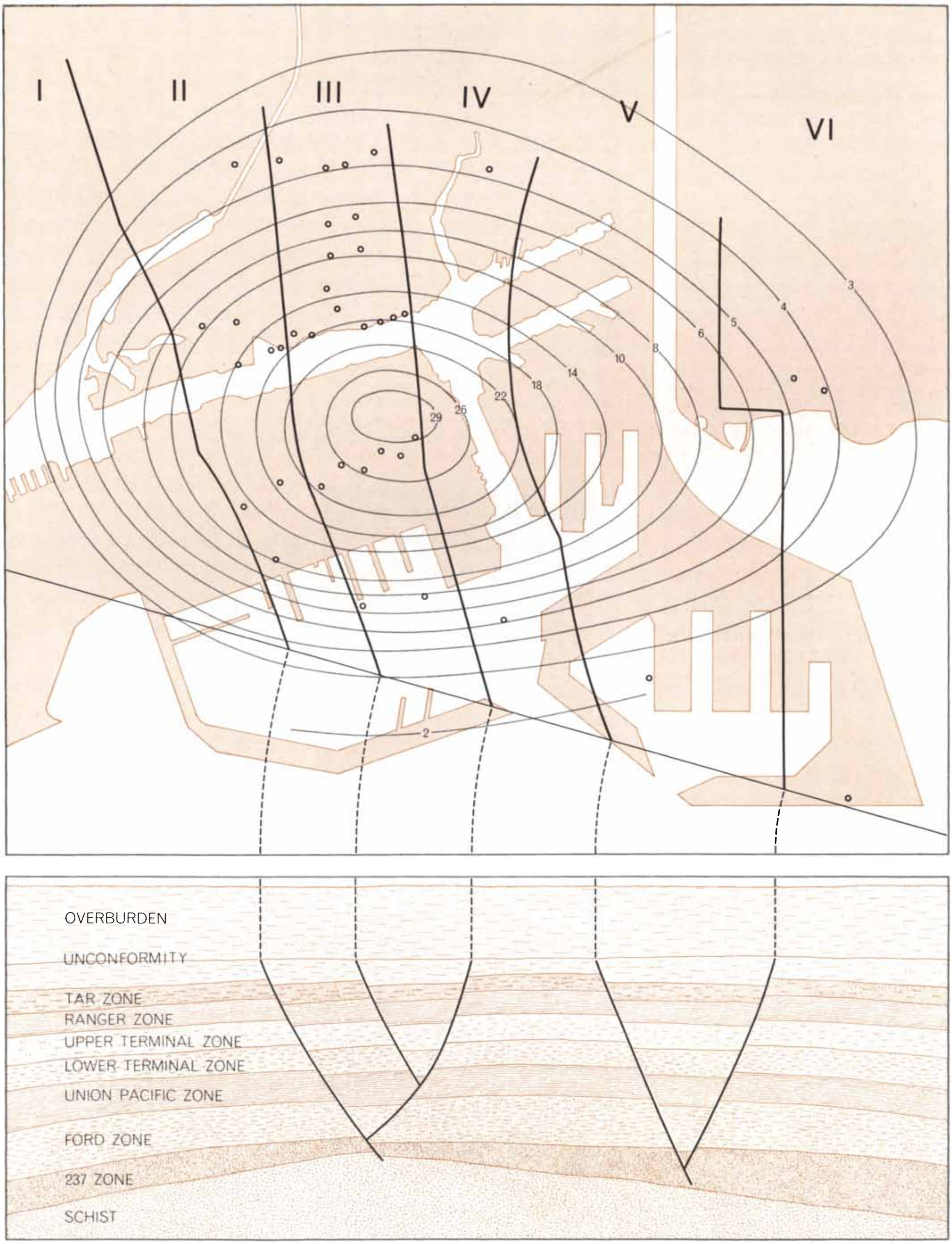
CLAY-RICH ZONES in or around the strata that yield oil, gas or water can be the source of considerable subsidence. Before the withdrawal of fluid (*left*) clay particles are kept separated by the fluid and by the pressure applied to it by the overlying land. When fluid is withdrawn (*right*), a claylike soil is more likely than most others to undergo compaction.



POORLY CONSOLIDATED ROCKS also can lead to subsidence when fluid is withdrawn, although the subsidence will be less because the rock is stronger than clay. In such rock the individual grains are weakly held together and will be compressed by additional pressure.



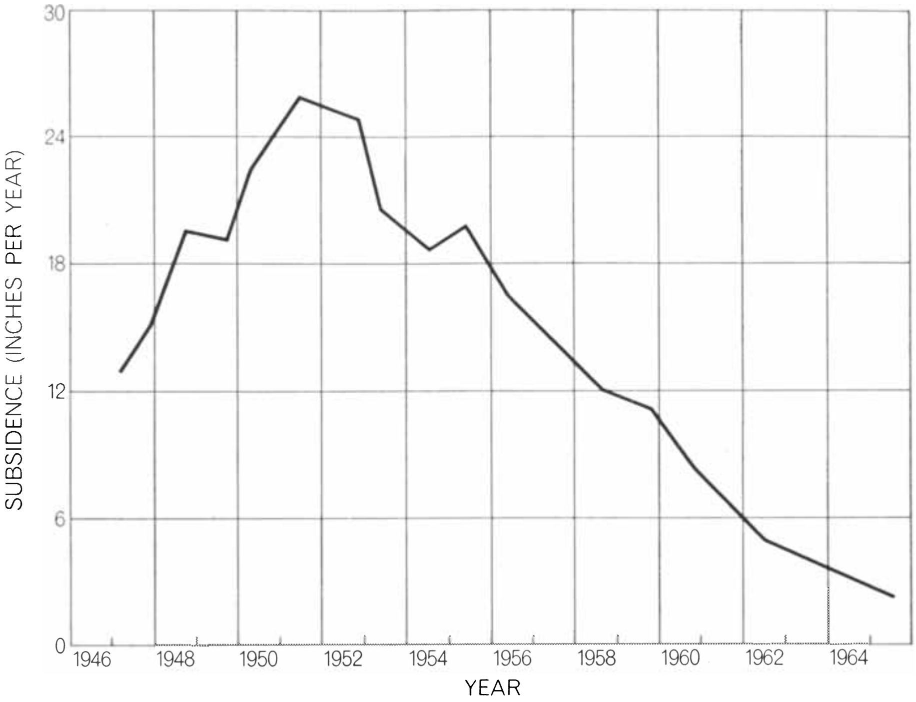
WELL-CONSOLIDATED ROCKS, in which individual grains are held together strongly, retain their structure even if fluid or gas is removed and give rise to little or no subsidence.



LONG BEACH SITUATION indicates why subsidence there has caused extensive damage. A region of the city that includes a naval shipyard, a plant generating electricity and several other large installations lies above a highly productive oil field. The geological strata under the city include several fault zones, such as those bounding sections I through VI. Hence the withdrawal of oil has led to subsidence, the extent of which is shown in feet on the elliptical lines. To counteract the subsidence the city and the oil companies have started injection of seawater to replace oil that is withdrawn. The open circles show the location of the injection wells.

that takes place between the fixed anchor and the surface [*see illustration on next page*]. The record is so sensitive that when amplified it can reveal a subsidence as small as a tenth of a millimeter. Applied in several wells at various depths in a given area, it can provide a rather detailed picture of the compaction at specific levels.

Our group at Stanford University has recently developed devices that make it possible to obtain very accurate measurements of distortions of the surface soil that take place above active oil fields or underground water reservoirs that are being pumped. Employing floats, quartz rods and transducers, the instruments measure vertical and horizontal strains and tilts of the land. They can measure ground movements of less than a tenth of a micron.



RECORD OF SUBSIDENCE in Long Beach is charted. By 1957 the city's expenditures for repairs of facilities damaged by subsidence had reached $90 million. The program to counteract subsidence by injections of water to increase underground pressures began in 1953.

What can be done to avoid or control subsidence? Let us consider particular cases.

The Wilmington oil field in the Long Beach area was discovered in 1936. By 1951 it was still producing 140,000 barrels of oil per day, and in addition considerable amounts of salt water were being drained from the underground strata. The affected land was sinking at the rate of two feet per year in some parts of the field and, as we have noted, by 1957 it had formed a depressed bowl that in one place was 26 feet deep. In the downtown area of Long Beach the subsidence amounted to two to six feet. Since much of the area on which the city and its surroundings had been built was filled-in tideland, standing only a few feet above sea level, the subsidence became a major threat to the entire community and its structures, including the Naval Shipyard, harbor improvements, roads, railroads, power lines, buildings and so on. Dikes had to be erected, land filled and bridges and buildings raised, repaired or rebuilt. As the cost of the damage mounted (reaching a total of $90 million by 1957 and threatening to become much more), the U.S. Department of Justice sought an injunction to shut down the oil field and filed suit to compel the city, the state and the oil producers to pay for the damages.

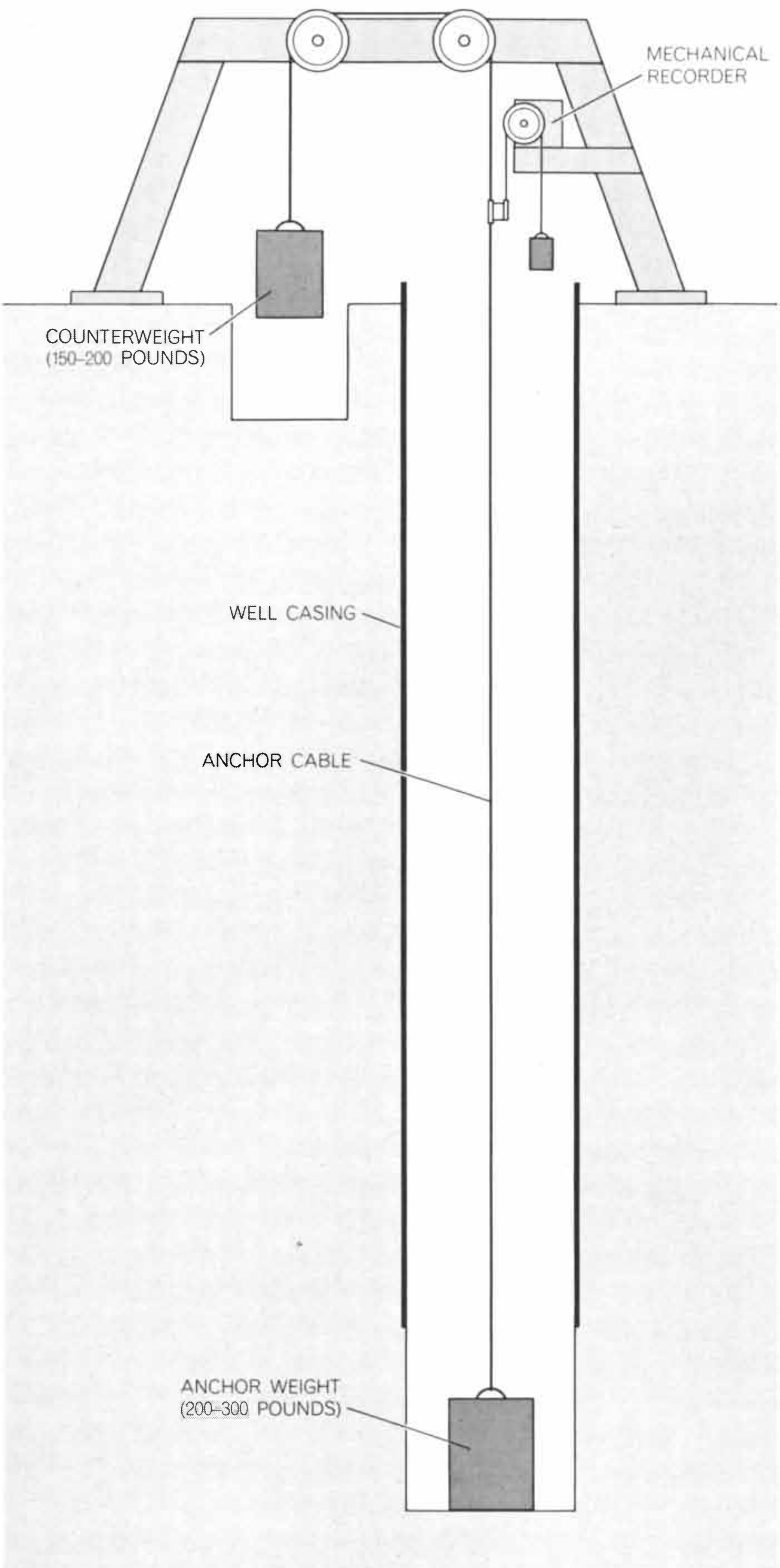
Something had to be done to arrest the land subsidence. The oil companies decided to try the device of flooding the depleted oil-bearing strata with seawater. This tactic is commonly used in oil fields to obtain secondary recovery of oil: the pumping of water under pressure into rocks from which oil is no longer flowing often serves to drive much of the remaining oil out through the original wells. For various reasons earlier attempts to apply the method had not worked well in California oil fields. A test in the Wilmington field now showed, however, that it could be used successfully there; indeed, that it could more than double the output of a given pool.

The Wilmington waterflooding project became the largest of its kind in the world. The necessary legislation was enacted; engineering studies were made; financing was arranged; the companies joined in a cooperative agreement for unitization of the field, and extensive installations were built. The installations include nine major brine plants that pump filtered seawater at pressures of 1,500 to 2,000 pounds per square inch through pipelines to several hundred injection wells that deliver the water to the oil-sand strata. These wells now inject more than half a million barrels of brine per day and soon will be increased to a delivery capacity of more than a million barrels.

The waterflooding accomplished two objectives: (1) it reduced the land subsidence to a steadily decreasing rate and (2) it raised the field's oil production, which had been declining, to something like 100,000 barrels per day. What is more, it has produced another large dividend for the oil companies. The offshore areas in the Pacific near Long Beach are known to be rich in oil sands. Because of the fear of subsidence the voters of Long Beach had refused to lease offshore drilling rights to tap this oil. The success of the waterflooding program, however, induced the city to approve such leases, on condition that the water-injection method would be employed from the beginning to prevent subsidence. Groups of oil companies began to drill offshore several months ago, and by the end of this year the tapping of the new area is expected to make Wilmington the No. 1 oil-producing field in the U.S.

Japan offers two other interesting examples of land subsidence. Compared with Japan's great natural hazards—typhoons, volcanoes and earthquakes—subsidence is a relatively minor problem, but it does cause serious concern and has already resulted in substantial damage.

The city of Niigata, on the northwestern shore of Honshu, the main island, is underlain by a large deposit of natural gas. The gas is dissolved in salt water in the underground strata, and since its solubility in water is rather low, large quantities of water must be taken from the strata to obtain a substantial amount of the gas. Because Japan's fuel resources are scarce, the gas field at Niigata was actively exploited after World War II, in spite of the comparatively high cost of producing its useful methane. By 1961



COMPACTION RECORDER keeps track of subsidence. Compaction of ground above the anchor weight causes the support frame (*top*) to sink. The large and small counterweights attached to the frame keep the cables under tension as the frame sinks. The smaller counterweight drives a recording pen, which is independently driven horizontally to record time.

the tapping of this field had produced an alarming amount of subsidence, as the strata containing the brine and gas consist of poorly consolidated rock. Parts of the city had sunk to below sea level.

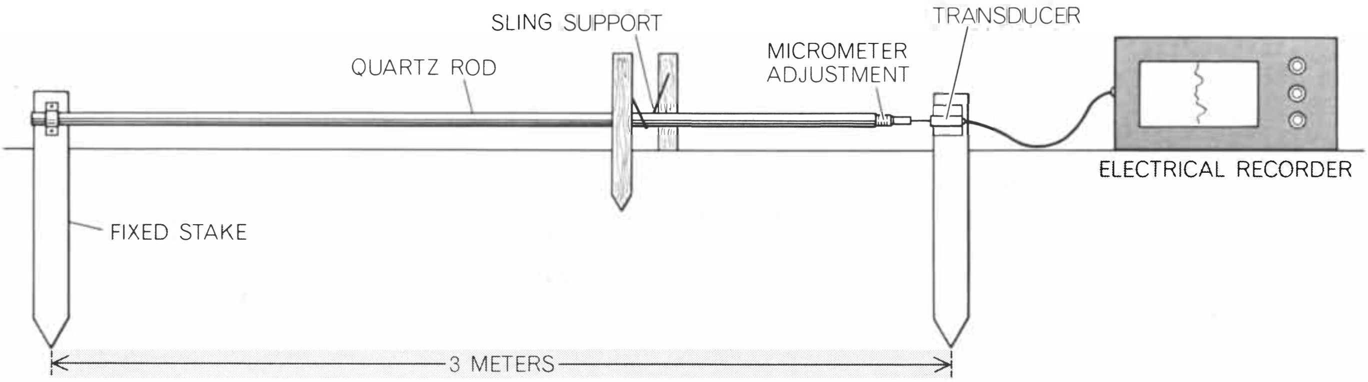
The city built dikes and drastically limited the production of gas; for various reasons reinjection of water was not practicable. Then in 1964 the city was struck by a major earthquake, which breached the dikes and resulted in severe flooding of the area of subsidence. Another result was an abrupt land subsidence, amounting to a foot or more, in parts of the city. The physical effect was something like the one produced when a container of sand is hit sharply: the blow causes the sand grains to settle into a more compact arrangement, and the earthquake shock similarly compacted the loose material in the subsurface. Conspicuous signs of the sudden subsidence were visible in Niigata after the quake: well casings were left sticking a foot or so above the ground, some at a tilted angle. Ironically enough, most of the damage from the sudden land collapse was to the pipelines of the gas-producing system!

In the Koto ward of Tokyo, an area in the northeastern section of the city, it was noticed some years ago that the land was sinking around building foundations and the wellhead equipment of water wells. These wells draw water from shallow strata of loose, claylike material; since the building foundations and well pipes are anchored in rock that lies below the tapped strata, the settling of the latter strata made it appear that the buildings and pipes were rising out of the ground. The subsidence, progressing at the rate of about six inches per year, affected an area of about 40 square miles, and by 1961 some 15 square miles had sunk below sea level. Dikes had to be built along the northern edge of Tokyo Bay and the Sumida and Arakawa rivers to prevent this section of the city from being flooded. A threat of catastrophe hangs over the area, however, because it could well be inundated by a flooding typhoon or by a tidal wave following a strong earthquake.

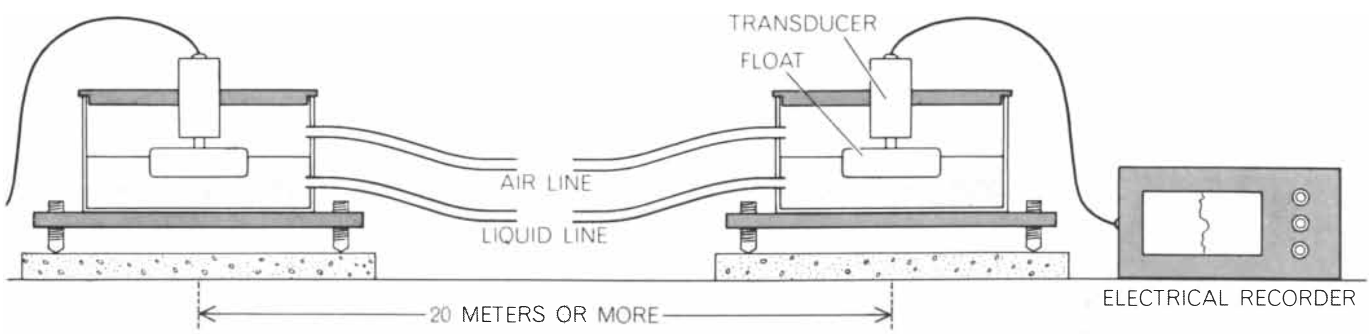
The arid San Joaquin Valley of California is so dependent on underground water that it accounts for about 20 percent of all the well water pumped in the U.S. Most of its wells tap deep water-bearing zones consisting of sand and coarse silt. As we have noted, the removal of water over the past four decades has produced three large areas of subsidence in the valley, the most extensive of which is in western Fresno County between the city of Los Banos and Kettleman City. Studies by the U.S. Geological Survey have shown that land subsidence is closely correlated with lowering of the water level in wells. It has been found, through sensitive measurements, that the land will begin to sink within a few minutes after water is pumped from wells and that the sinking stops when the pumping is halted. As a general rule the amount of land subsidence in such areas is on the order of one foot for every 20 to 30 feet of lowering of the water level in the wells. In the San Joaquin Valley the water levels in wells have fallen by at least 50 feet, and in some areas by more than 400 feet, in the past 40 years. Because of the continuous subsidence topographical maps in the valley have had to be revised repeatedly.

Land subsidence in the valley has been costly in damage to the wells themselves, because the well casings are usually destroyed. Each well represents an investment of $10,000 to $30,000 or more, and it is estimated that more than $1 million a year is lost in well destruction caused by subsidence. The most costly problem created by subsidence, however, is not well failure but the effects on irrigation canals. The agricultural productivity of the San Joaquin Valley depends on a network of large canals, which is continually being expanded. The slope of these canal beds is ordinarily only three-tenths of a foot per mile, and a slight tilting due to land subsidence can therefore stop or reverse the gravity flow of water. It then becomes necessary to raise the water level to drive the water through the canals; this requires the raising of the walls of the canals, which in turn necessitates the raising or reconstructing of bridges, pipeline crossings and other structures. The canals now being built are designed with walls high enough to allow for future subsidence.

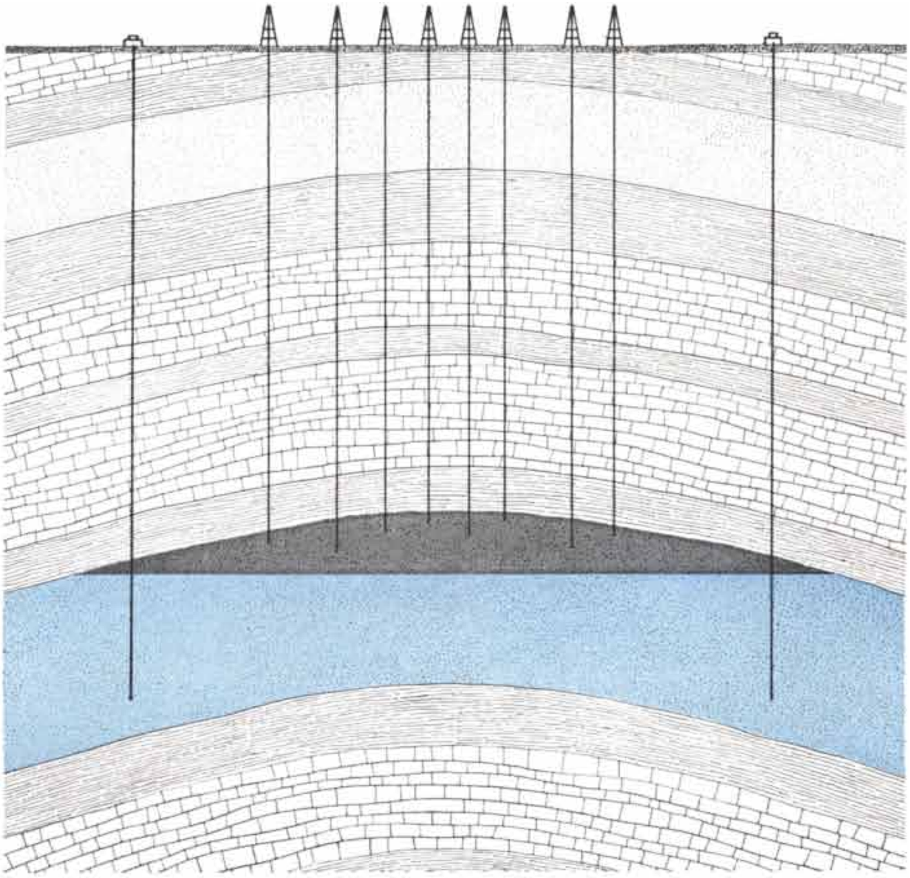
In parts of the San Joaquin Valley, as in many other regions of the world, certain natural causes contribute to land subsidence. One of these is the presence of highly organic soil—muck or peat—at the surface. As this soil dries out and becomes oxidized, it gradually shrinks. In the northern part of the San Joaquin Valley the subsidence of such lands has been so substantial that they are now more than 10 feet below sea level and must be protected by dikes. Another condition that leads to land subsidence is the existence of certain soils that have a high porosity. In these soils, which are commonly derived from mudflows, the individual grains are held together with a dry clay film that prevents them from consolidating. When such a soil becomes saturated with water, however, the clay



STRAIN RECORDER is also used to detect ground movements related to subsidence. The left end of the quartz rod is fixed; the right end is free to move horizontally. The micrometer adjustment, fastened to the rod, touches the transducer, which measures the relative movement of the free end of the rod. Short-term horizontal strains of less than .1 micron can be measured with the apparatus.



TILTMETER records changes in ground elevation. The relative elevation of the liquid in the two containers is measured by the floats and transducers. The air line and the liquid line keep the pressures of air and liquid in the two containers equal. The apparatus can measure elevation changes of less than .1 micron. Recorders for the transducers and for temperature are not depicted.



WATER-INJECTION TECHNIQUE, carried out in a region geologically similar to the one in the illustration on page 94, can prevent or deter subsidence. Once subsidence has occurred, however, injection of water (*color*) will not significantly raise the subsided land.

loses strength and the soil structure collapses. Unusually heavy rains or water leaking into the soil from canals and pipelines may therefore bring about a dramatic collapse of the land. In some areas along the western edge of the San Joaquin Valley porous soil of this type extends down to depths of 150 feet, and subsidence of as much as 20 feet has been observed. Since an immense new irrigation canal is being built through these areas, the builders are taking the precaution of saturating and settling the soil before they lay the concrete lining of the canal.

In London the withdrawal of underground water by means of wells has produced noticeable subsidence in sections of the city. In Mexico City some areas have suffered subsidence at the rate of more than a foot per year, and the pumping of underground water in the central part of the city is now prohibited. In Houston troublesome cracks, attributed to land subsidence, have appeared in various parts of the city, including the runways of the principal airport. In some cases the vertical difference between one side of a crack and the other is several inches.

In Los Angeles the disastrous breakup of the Baldwin Hills reservoir dam in 1963, which caused a flood that cost five lives and $15 million in damage, is believed by some people to have been caused by a crack in the ground that originated from land subsidence. Los Angeles, by the way, is now applying the lesson learned at Long Beach. The city is allowing exploitation of oil fields that underlie its downtown areas, but it is requiring the oil companies to inject water into these fields as they withdraw the oil.

Land subsidence is a highly complex problem. Much has been learned from the investigations of emergency situations, where expensive damage has already occurred or has been found to be imminent. We need to find out a great deal more, however, particularly with regard to means of predicting the exact location, extent and duration of subsidence from a given pattern of pumping subsurface fluids. The problem calls not only for expanded field measurements but also—and perhaps even more important—investigations by means of controlled, small-scale experiments. These efforts will yield faster answers by telescoping the time scale and will provide accurate quantitative information about the variables involved in land subsidence.

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AGGIES

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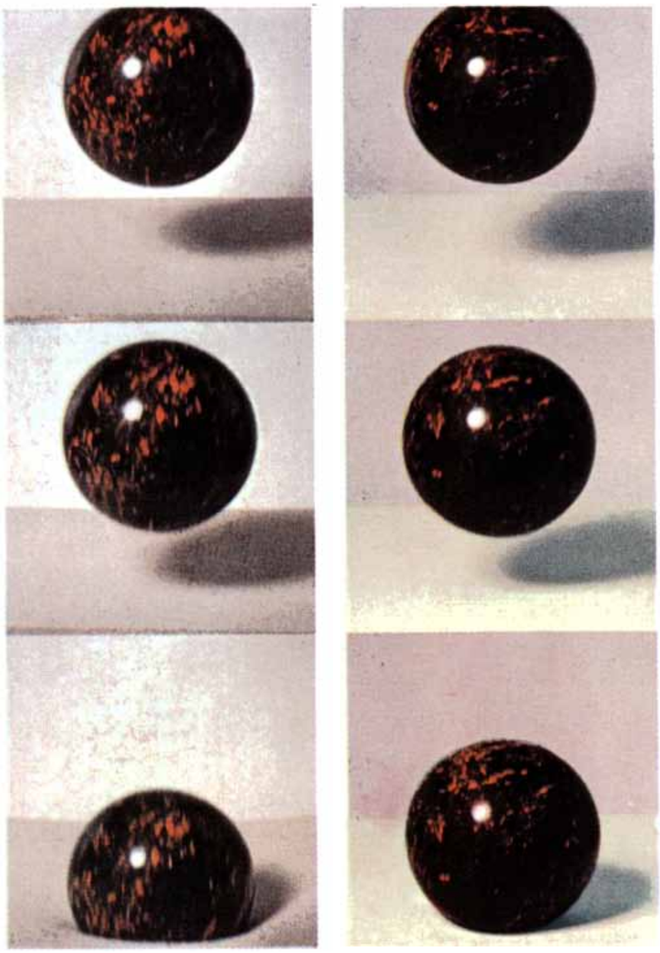


Contrary to expectations, the softer foam rubber is not as shock absorbent as the stiffer Ensolite. A 16-lb. bowling ball dropped three feet onto two inches of material builds up 51 G's of force with foam rubber, only 29 G's with Ensolite.

Uniroyal holds more patents than any other rubber company.

BUTTERFLY EGGS (*top*) stand upright on a leaf of clover, the egg-laying site selected by the gravid female. Clover is the food plant preferred by this species: *Colias philodice,* the clouded sulphur. After hatching (*bottom*), growing clouded sulphur larvae feed on the plant preselected for them by the parent. When they metamorphose, they too will seek out clover as an egg-laying site.

BUTTERFLIES AND PLANTS

The hungry larvae of butterflies are selective in choosing the plants they eat. This reflects the fact that the evolution of both plants and the animals that feed on them is a counterpoint of attack and defense

by Paul R. Ehrlich and Peter H. Raven

Anyone who has been close to nature or has wandered about in the nonurban areas of the earth is aware that animal life sometimes raises havoc with plant life. Familiar examples are the sudden defoliation of forests by hordes of caterpillars or swarms of locusts and the less abrupt but nonetheless thorough denudation of large areas by grazing animals. A visitor to the Wankie National Park of Rhodesia can see a particularly spectacular scene of herbivore devastation. There herds of elephants have thinned the forest over hundreds of square miles and left a litter of fallen trees as if a hurricane had passed through.

Raids such as these are rare, and the fertile regions of the earth manage to remain rather green. This leads most people, including many biologists, to underestimate the importance of the perennial onslaught of animals on plants. Detailed studies of the matter in recent years have shown that herbivores are a major factor in determining the evolution and distribution of plants, and the plants in turn play an important part in shaping the behavior and evolution of herbivores.

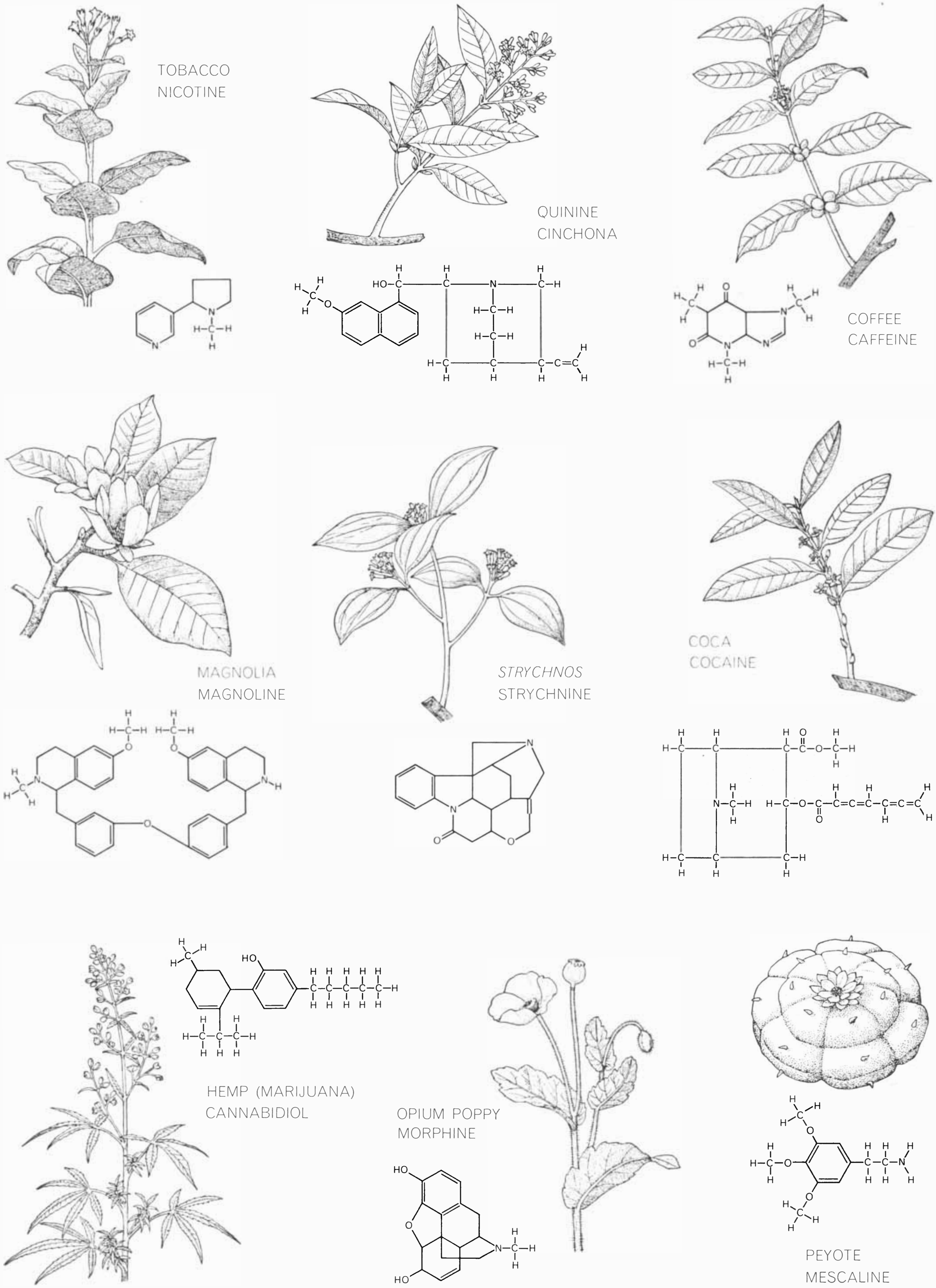
The influence of herbivores on plants is usually far from obvious, even when it is most profound. In Australia huge areas in Queensland used to be infested with the spiny prickly-pear cactus, which covered thousands of square miles of the area and made it unusable for grazing herds. Today the plant is rare in these areas. It was all but wiped out by the introduction of a cactus moth from South America, which interestingly enough is now hardly in evidence. When one searches scattered remaining clumps of the cactus, one usually fails to find any sign of the insect. The plant survives only as a fugitive species; as soon as a clump of the cactus is discovered by the moth it is devoured, and the population of moths that has flourished on it then dies away. A similar situation is found in the Fiji Islands. There a plant pest of the genus *Clidemia* was largely destroyed by a species of thrips brought in from tropical America, and the parasitic insect, as well as the plant, has now become rare in Fiji.

The interplay of plant and animal populations takes many forms—some direct, some indirect, some obvious, some obscure. In California the live oak is disappearing from many areas because cattle graze on the young seedlings. In Australia a native pine that was decimated by rabbits has made a dramatic comeback since the rabbit population was brought under control by the myxomatosis virus. Australia also furnishes a striking example of how the evolution of a plant can be influenced by the presence or absence of certain animals. The plant involved is the well-known acacia. In Africa and tropical America, where grazing mammals abound, the acacia species are protected by thorns that are often fearsomely developed. Until recently there were comparatively few grazing mammals in Australia, and most of the acacia plants there are thornless, apparently having lost these weapons of their relatives on other continents.

By far the most important terrestrial herbivores are, of course, the insects. They have evolved remarkably efficient organs for eating plants: a great variety of mouthparts with which to pierce, suck or chew plant material. They eat leaves from the outside and the inside, bore through stems and roots and devour flowers, fruits and seeds. In view of the abundance, variety and appetites of the insects, one may well wonder how it is that any plants are left on the earth. The answer, of course, is that the plants have not taken the onslaught of the herbivores lying down. Some of their defenses are quite obvious: the sharp spines of the cactus, the sharp-toothed leaves of the holly plant, the toxins of poison ivy and the oleander leaf, the odors and pungent tastes of spices. The effectiveness of these weapons against animal predators has been demonstrated by laboratory experiments. For example, it has been shown that certain leaf-edge-eating caterpillars normally do not feed on holly leaves but will devour the leaves when the sharp points are cut away.

The plant world's main line of defense consists in chemical weapons. Very widespread among the plants are certain chemicals that apparently perform no physiological function for the plants themselves but do act as potent insecticides or insect repellents. Among these are alkaloids, quinones, essential oils, glycosides, flavonoids and raphides (crystals of calcium oxalate). Long before man learned to synthesize insecticides he found that an extract from chrysanthemums, pyrethrin, which is harmless to mammals, is a powerful killer of insects.

Particularly interesting are the alkaloids, a heterogeneous group of nitrogenous compounds found mainly in flowering plants. They include nicotine, caffeine, quinine, marijuana, opium and peyote. Considering the hallucinogenic properties of the last three drugs, it is amusing to speculate that the plants bearing them may practice "chemopsychological warfare" against their enemies! Does an insect that has fed on a fungus containing lysergic acid diethylamide (LSD) mistake a spider for its mate? Does a zebra that has eaten a



ALKALOIDS give the plants that contain them protection from predators; nine such plants are illustrated. The authors note that plant alkaloids can disturb a herbivore's physiology and that hallucinogenic alkaloids may be "chemopsychological" weapons.

plant rich in alkaloids become so intoxicated that it loses its fear of lions? At all events, there is good reason to believe eating plant alkaloids produces a profound disturbance of animals' physiology.

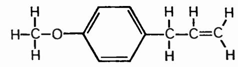
Of all the herbivores, the group whose eating habits have been studied most intensively is the butterflies—that is to say, butterflies in the larval, or caterpillar, stage, which constitutes the major part of a butterfly's lifetime. Around the world upward of 15,000 species of butterflies, divided taxonomically into five families, have been identified. The five families are the Nymphalidae (four-footed butterflies), the Lycaenidae (blues, metalmarks and others), the Pieridae (whites and yellows), the Papilionidae (including the swallowtails, the huge bird-wings of the Tropics and their relatives) and the Libytheidae (a tiny family of snout butterflies). The Nymphalidae and Lycaenidae account for most (three-fourths) of the known genera and species.

A caterpillar is a formidable eating machine: by the time it metamorphoses into a butterfly it has consumed up to 20 times its dry weight in plant material. The numerous species vary greatly in their choice of food. Some are highly selective, feeding only on a single plant family; others are much more catholic in their tastes, but none feeds on all plants indiscriminately. Let us examine the food preferences of various groups and then consider the evolutionary consequences.

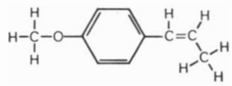
One group that is far-ranging in its taste for plants is the Nymphalinae, a subfamily of the Nymphalidae that comprises at least 2,500 species and is widespread around the world. The plants that members of this group feed on include one or more genera of the figwort, sunflower, maple, pigweed, barberry, beech, borage, honeysuckle, stonecrop, oak, heather, mallow, melastome, myrtle, olive, buttercup, rose, willow and saxifrage families. Another group that eats a wide variety of plants is the Lycaeninae, a subfamily of the Lycaenidae that consists of thousands of species of usually tiny but often beautifully colored butterflies. The Lycaeninae in general are catholic in their tastes, and among their many food plants are members of the pineapple, borage, pea, buckwheat, rose, heather, mistletoe, mint, buckthorn, chickweed, goosefoot, morning glory, gentian, oxalis, pittosporum and zygophyllum families.

What determines the caterpillars' food preferences? We learn a great deal about this subject by examining the diets of those butterfly species that are particularly selective in their choice of plants. One large group of swallowtails, for example, confines its diet mainly to plants of the Dutchman's-pipe family. Another feeds only on the "woody Ranales," a group of primitive angiosperms that includes the magnolias, the laurels and many tropical and subtropical plants. A third group of swallowtails is partial to plants of the citrus and parsley families; the striped caterpillars of these butterflies, which extrude two bright orange scent horns when they are disturbed, are familiar to gardeners, who often see them feeding on parsley, dill, fennel and celery plants. The caterpillars of the white butterfly group (a subfamily of the Pieridae) feed primarily on caper plants in the Tropics and on plants of the mustard family in temperate regions. Similarly, the monarch butterfly and its relatives (a subfamily of the Nymphalidae) confine their diet primarily to plants of the milkweed and dogbane families.

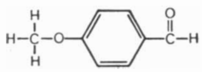
METHYL CHAVICOL



ANETHOLE



ANISIC ALDEHYDE



PLANTS OF TWO FAMILIES, citrus (*top*) and parsley (*bottom*), produce the same three essential oils attractive to the larvae of black swallowtail butterflies. The chemical kinship between these plant families suggests a closer ancestral tie than had been suspected.

Analysis of the plant selections by the butterfly groups has made it clear that their choices have a chemical basis, just as parasitic fungi choose hosts that meet their chemical needs. Vincent G. Dethier, then at Johns Hopkins University, noted some years ago that plants of the citrus and parsley families, although apparently unrelated, have in common certain essential oils (such as methyl chavicol, anethole and anisic aldehyde) that presumably account for their attractiveness to the group of swallowtails that feeds on them. Dethier found that caterpillars of the black swallowtail would even attempt to feed on filter paper soaked in these substances. The

FIVE BUTTERFLIES protected by their unpalatability are illustrated with their preferred plants. They are *Thyridia themisto* and one of the nightshades (*a*), *Battus philenor* and Dutchman's-pipe (*b*), *Danaus plexippus* and milkweed (*c*), *Heliconius charitonius* and passion flower (*d*) and *Pardopsis punctatissima* and a representative of the violet family (*e*).

same caterpillars could also be induced to feed on plants of the sunflower family (for example goldenrod and cosmos), which contain these oils but are not normally eaten by the caterpillars in nature.

The chemical finding, incidentally, raises an interesting question about the evolutionary relationship of plants. The sunflower, citrus and parsley families have been considered to be very different from one another, but their common possession of the same group of substances suggests that there may be a chemical kinship after all, at least between the citrus and the parsley family. Chemistry may therefore become a basis for reconsideration of the present classification system for plants.

In the case of the cabbage white butterfly larva the attractive chemical has been shown to be mustard oil. The pungent mustard oils are characteristic of plants of the caper and mustard families (the latter family includes many familiar food plants, such as cabbages, Brussels sprouts, horseradish, radishes and watercress). The whites' larvae also feed occasionally on plants of other families that contain mustard oils, including the garden nasturtium. The Dutch botanist E. Verschaeffelt found early in this century that these larvae would eat flour, starch or even filter paper if it was smeared with juice from mustard plants. More recently the Canadian biologist A. J. Thorsteinson showed that the larvae would eat the leaves of plants on which they normally do not feed when the plants were treated with mustard oil glucosides.

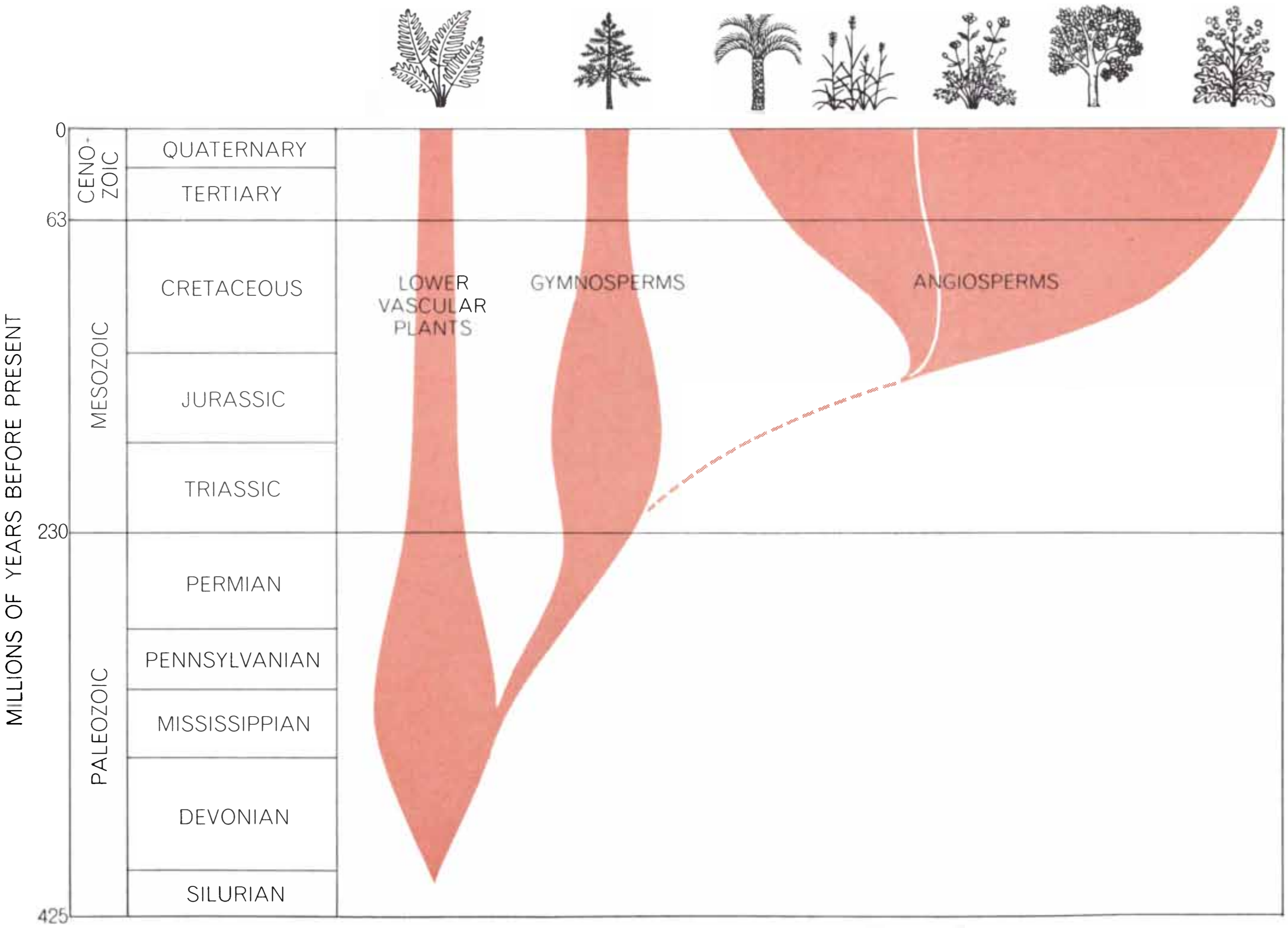
In contrast to the attractive plants, there are plant families on which butterfly larvae do not feed (although other insects may). One of these is the coffee family. Although this family, with some 10,000 species, is probably the fourth largest family of flowering plants in the world and is found mainly in the Tropics, as the butterflies themselves are, butterfly larvae rarely, if ever, feed on these plants. A plausible explanation is that plants of the coffee family are rich in alkaloids. Quinine is one example. Other plant families that butterflies generally avoid eating are the cucurbits (rich in bitter terpenes), the grape family (containing raphides) and the spiny cactus family.

One of the most interesting findings is that butterflies that are distasteful to predators (and that are identified by conspicuous coloring) are generally narrow specialists in their choice of food. They tend to select plants on which other butterfly groups do not feed, notably plants that are rich in alkaloids. It seems highly probable that their use of these plants for food has a double basis: it provides them with a feeding niche in which they have relatively little competition, and it may supply them with the substances, or precursors of substances, that make them unpalatable to predators. The distasteful groups of butterflies apparently have evolved changes in physiology that render them immune to the toxic or repellent plant substances and thus enable them to turn the plants' chemical defenses to their own advantage. Curiously, the butterfly species that mimic the coloring of the distasteful ones are in general more catholic in their feeding habits; evidently their warning coloration alone is sufficient to protect them.

The fact that some butterflies' diets are indeed responsible for their unpalatability has been demonstrated recently by Lincoln P. Brower of Amherst College and his co-workers. They worked with the monarch butterfly, whose larvae normally feed on plants of the milkweed family. Such plants are rich in cardiac glycosides, powerful poisons that are used in minute quantities to treat heart disease in man. When adult butterflies of this species are offered to hand-reared birds (with no previous experience with butterflies), the butterflies are tasted and then promptly rejected, as are further offerings of either the monarch or its close mimic, the viceroy. Recently Brower succeeded in spite of great difficulties in rearing a generation of monarch butterflies on cabbage and found that the resulting adults were perfectly acceptable to the birds, although they were refused by birds that had had previous experience with milkweed-fed monarchs.

The concept of warfare between the plants and the butterflies leads to much enlightenment on the details of evolutionary development on both sides. On the plants' side, we can liken their problem to that of the farmer, who is obliged to defend his crops from attack by a variety of organisms. The plants must deploy their limited resources to protect themselves as best they can. They may confine their growing season to part of the year (limiting their availability to predators); they may be equipped with certain mechanical or chemical defenses; some develop a nutrient-poor sap or nutritional imbalances that make them an inefficient or inadequate source of food. The herbivorous insects, for their part, reply with specializations to cope with the special defenses, as a hunter uses a high-powered rifle to hit deer or bear, a shotgun to hit birds or a hook to catch fish. No butterfly larva (or other herbivore) possesses the varieties of physical equipment that would allow it to feed on all plants; in order to feed at all it must specialize to some degree. Some of the specializations are extremely narrow; certain sap-sucking insects, for example, have developed filtering mechanisms that trap the food elements in nutrient-poor sap, and some of the caterpillars possess detoxifying systems that enable them to feed on plants containing toxic substances.

By such devices herbivores of one kind or another have managed to breach the chemical defenses of nearly every group of plants. We have already noted several examples. The mustard oils of the mustard and caper plant families,



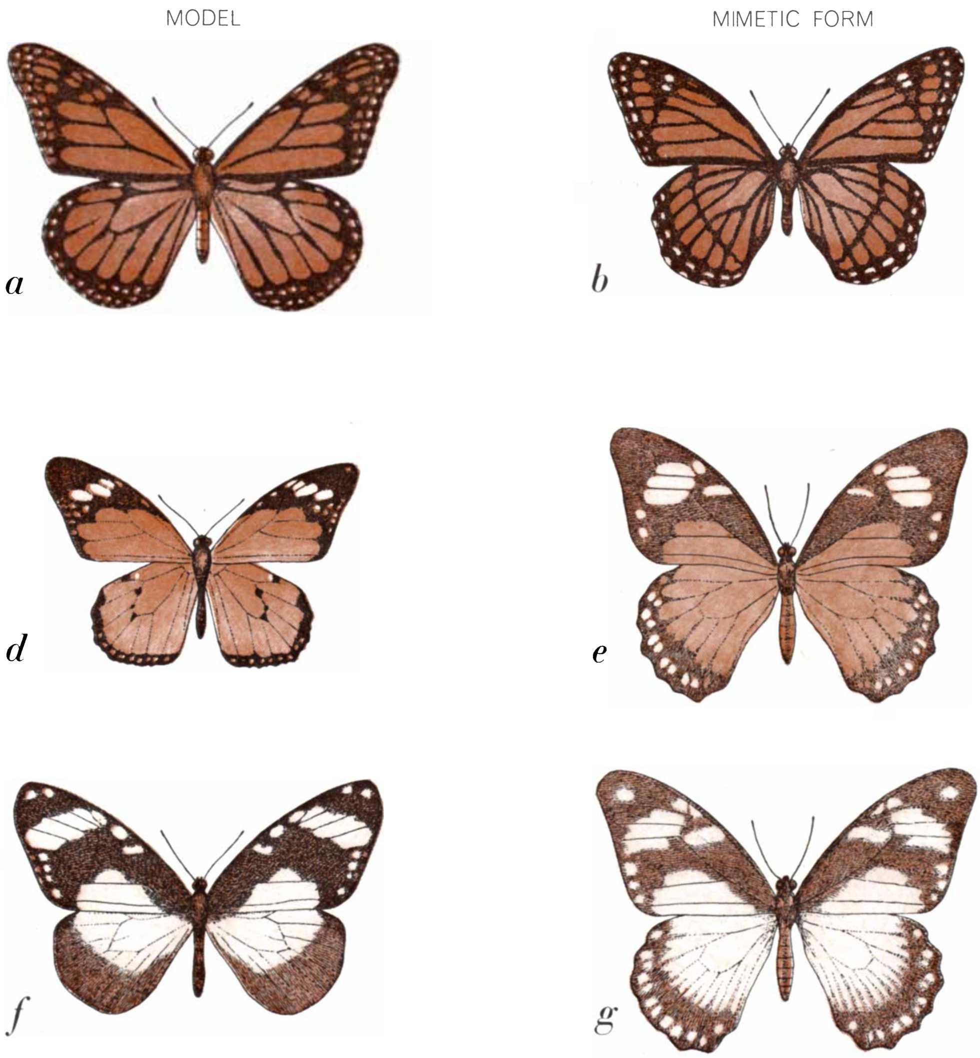
RECORD OF EVOLUTION within the plant kingdom shows that among the vascular plants the gymnosperms (*center*) declined as the angiosperms (*right*) became abundant. The authors attribute this to the acquisition of chemical defenses by the angiosperms.

for instance, serve to make these plants unpalatable to most herbivores, but the white butterflies and certain other insects have become so adapted to this defense mechanism that the mustard oils actually are a feeding stimulus for them. O. L. Chambliss and C. M. Jones, then at Purdue University, showed that a bitter, toxic substance in fruits of the squash family that repels honeybees and yellow jackets is attractive to the spotted cucumber beetle. Incidentally, this substance has been bred out of the cultivated watermelon, as any picnicker who has had to wave yellow jackets away from the watermelon can testify. By selecting against this bitter taste man has destroyed one of the natural protective mechanisms of the plant and must contend with a much wider variety of predators on it than the watermelon had to in the wild.

An important aspect of the insects' chemical adaptability is the recent finding that insects that feed on toxic plants are often immune to man-made insecticides. They evidently possess a generalized detoxifying mechanism. H. T. Gordon of the University of California at Berkeley has pointed out that this is commonly true of insects that are in the habit of feeding on a wide variety of plants. He suggests that through evolutionary selection such insects have evolved a high tolerance to biochemical stresses.

What can we deduce, in the light of the present mutual interrelations of butterflies and plants, about the evolutionary history of the insects and flowering plants? We have little information about their ancient history to guide us, but a few general points seem reasonably clear.

First, we can surmise that the great success of the angiosperm plants (plants

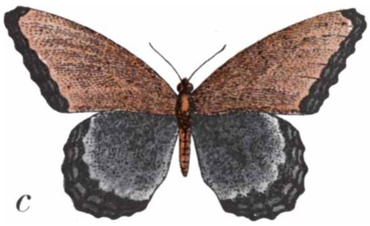


UNPALATABLE BUTTERFLIES, whose disagreeable taste originates with the plants they ate as larvae, are often boldly marked and predators soon learn to avoid them. The three "models," so called because unrelated species mimic them, are the monarch, *Danaus* (*a*), another Danaine, *D. chrysippus* (*d*) and a third Danaine, *Amauris* (*f*). Their imitators are the viceroy, *Limenitis* (*b*), one form of *Papilio dardanus* (*e*) and another form of *P.*

with enclosed seeds), which now dominate the plant world since most of the more primitive gymnosperm lines have disappeared, is probably due in large measure to the angiosperms' early acquisition of chemical defenses. One important group of protective secondary plant substances, the alkaloids, is found almost exclusively in this class of plants and is well represented in those groups of angiosperms that are considered most primitive. Whereas other plants were poorly equipped for chemical warfare, the angiosperms were able to diversify behind a biochemical shield that gave them considerable protection from herbivores.

As the flowering plants diversified, the insect world also underwent a tremendous diversification with them. The intimate present relation between butterflies and plants leaves no doubt that the two groups evolved together, each

NONMIMETIC FORM



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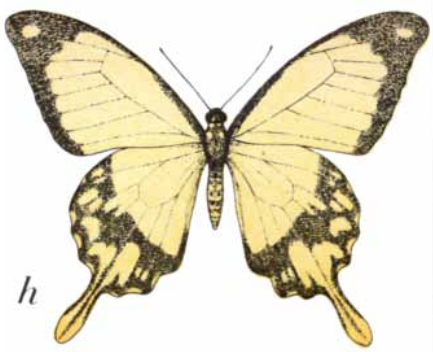
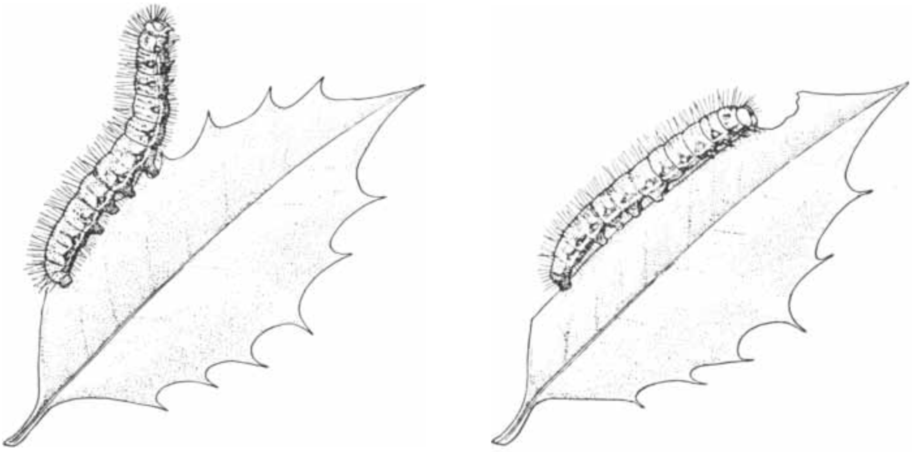


h

dardanus (g). Mimicry is not a genus-wide phenomenon: L. *astyanax* (c), a relative of the viceroy, is nonmimetic. So is a third form of P. *dardanus* (h), whose cousins (e, g) mimic two of the Danaine models.



TOOTHED EDGE of the holly (*left*) normally protects it from leaf-edge eaters, such as the tent caterpillar. After the leaf's teeth are trimmed (*right*) the insect readily devours it.

influencing the development of the other. In all probability the butterflies, which doubtless descended from the primarily nocturnal moths, owe their success largely to the decisive step of taking to daytime feeding. By virtue of their choice of food plants all butterflies are somewhat distasteful, and Charles L. Remington of Yale University has suggested that this is primarily what enabled them to establish themselves and flourish in the world of daylight. The butterflies and their larvae did not, of course, overwhelm the plant world; on the contrary, in company with the other herbivores they helped to accelerate the evolution of the plants into a great variety of new and more resistant forms.

From what little we know about the relationships between other herbivore groups and their associated plants, we can assume that the butterfly-plant association is typical of most herbivore-plant pairings. This information gives us an excellent starting point for understanding the phenomenon that we might call "communal evolution," or coevolution. It can help, for example, to account for the great diversity of plant and insect species in the Tropics compared with the much smaller number of species in the temperate zones. The abundance of plant-eating insects in the Tropics, interacting with the plants, unquestionably has been an important factor, perhaps the most important one, in promoting the species diversity of both plants and animals in those regions. Indeed, the interaction of plants and herbivores may be the primary mechanism responsible for generating the diversity of living forms in most of the earth's environments.

Since the welfare, and even the survival, of mankind depend so heavily on the food supply and on finding ways to deal with insects without dangerous contamination of the environment with insecticides, great benefits might be derived from more intensive study of plant-herbivore associations. With detailed knowledge of these associations, plants can be bred for resistance to insects. Crop plants might be endowed with bred-in repellents, and strains of plants containing strong attractants for pests might be planted next to the crops to divert the insects and facilitate their destruction. New methods of eliminating insects without danger to man might be developed. Carroll M. Williams of Harvard University and his co-workers have discovered, for example, that substances analogous to the juvenile hormone of some insects are present in tissues of the American balsam fir. Since the juvenile hormone acts to delay metamorphosis in insects, plants bred for such substances might be used to interfere with insect development. It is even possible that insects could be fought with tumor-inducing substances: at least one plant alkaloid, nicotine, is known to be a powerful carcinogen in vertebrates.

Such methods, together with techniques of biological control of insects already in use and under development, could greatly reduce the present reliance on hazardous insecticides. The insects have shown that they cannot be conquered permanently by the brand of chemical warfare we have been using up to now. After all, they had become battle-hardened from fighting the insecticide warfare of the plants for more than 100 million years. By learning from the plants and sharpening their natural weapons we should be able to find effective ways of poisoning our insect competitors without poisoning ourselves.

Memory and Protein Synthesis

If a goldfish is trained to perform a simple task and shortly thereafter a substance that blocks the manufacture of protein is injected into its skull, it forgets what it has been taught

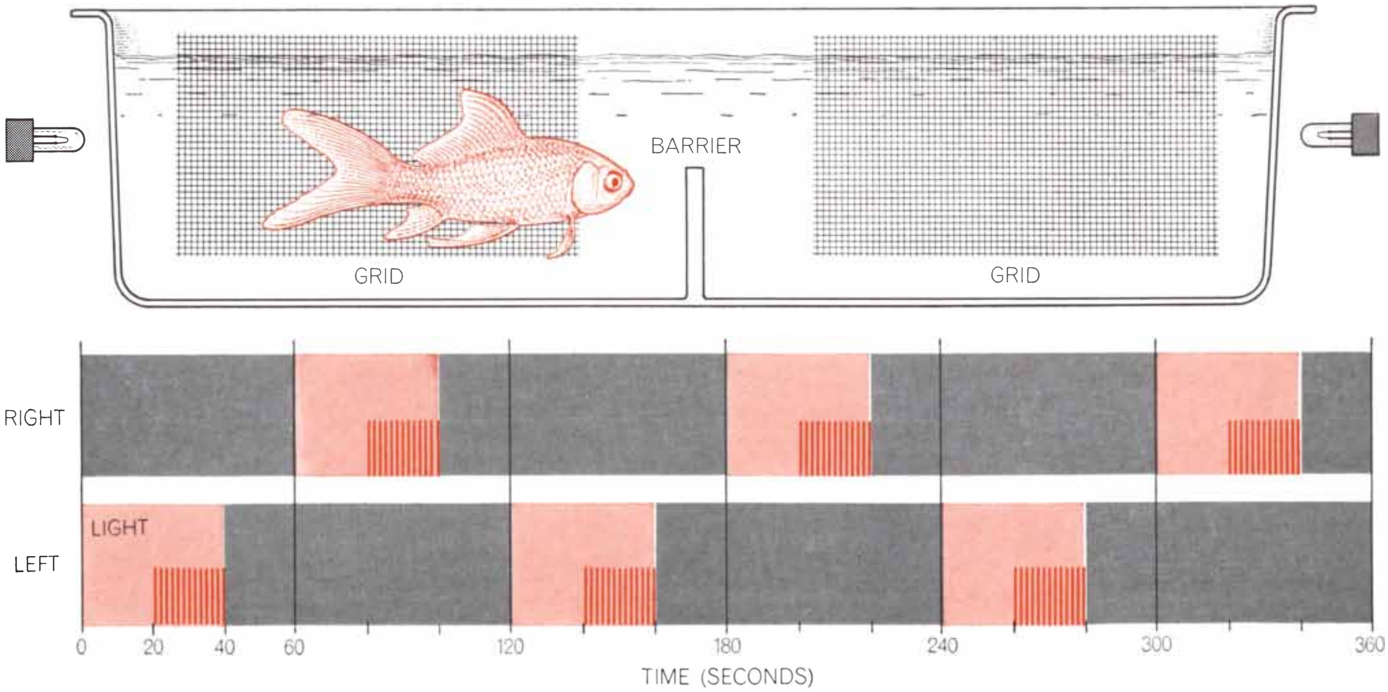
by Bernard W. Agranoff

What is the mechanism of memory? The question has not yet been answered, but the kind of evidence needed to answer it has slowly been accumulating. One important fact that has emerged is that there are two types of memory: short-term and long-term. To put it another way, the process of learning is different from the process of memory-storage; what is learned must somehow be fixed or consolidated before it can be remembered. For example, people who have received shock treatment in the course of psychiatric care report that they cannot remember experiences they had immediately before the treatment. It is as though the shock treatment had disrupted the process of consolidating their memory of the experiences.

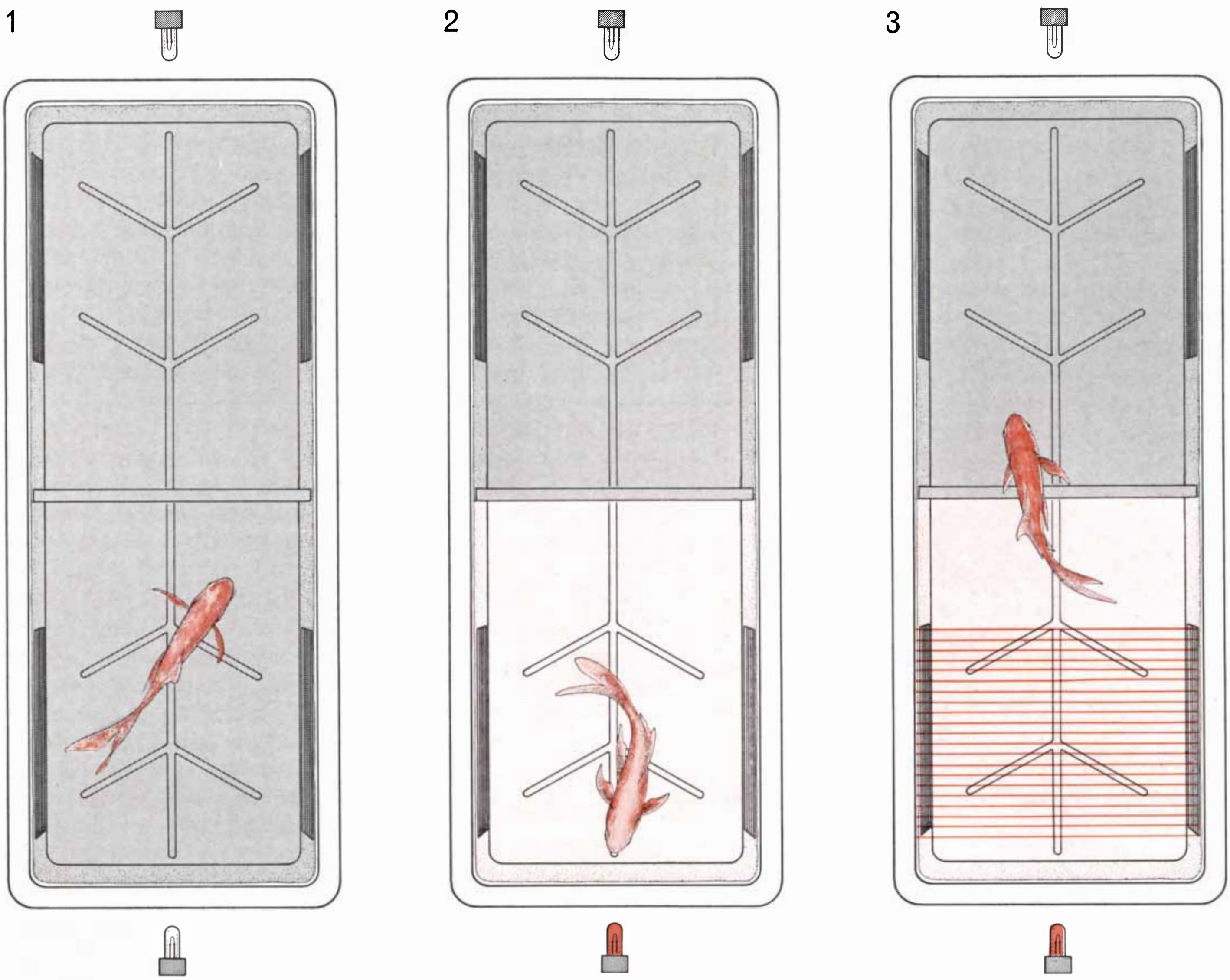
In our laboratory at the University of Michigan we have demonstrated that there is a connection between the consolidation of memory and the manufacture of protein in the brain. Our experimental animal is the common goldfish (*Carassius auratus*). Basically what we do is train a large number of goldfish to perform a simple task and at various times before, during and after the training inject into their skulls a substance that interferes with the synthesis of protein. Then we observe the effect of the injections on the goldfish's performance.

Why seek a connection between memory and protein synthesis? For one thing, enzymes are proteins, and enzymes catalyze all the chemical reactions of life. It would seem reasonable to expect that memory, like all other life processes, is dependent on enzyme-catalyzed reactions. What is perhaps more to the point, the manufacture of new enzymes is characteristic of long-term changes in living organisms, such as growth and the differentiation of cells in the embryo. And long-term memory is by definition a long-term change.

The investigation of a connection between memory and protein synthesis is made possible by the profound advances in knowledge of protein synthesis that have come in the past 10 years. A molecule of protein is made from 20 differ-



TRAINING TANK the author used was designed so that goldfish learned to swim from the light end to the dark end. A learning trial began with the illumination of the left end of the tank (*chart at bottom*), followed after a pause by mild electric shocks (*colored vertical lines*) from grids at that end. At first a fish would swim over the central barrier in response to shock; then increasingly the fish came to respond to light cue alone as sequence of light, shock and darkness was alternately repeated at each end of the tank.



GOLDFISH LEARN in successive trials to solve the problem the shuttle box presents. Following 20 seconds of darkness (*1*) the end of the box where the fish is swimming is lighted for an equal period of time (*2*). The fish fails to respond, swimming over the barrier

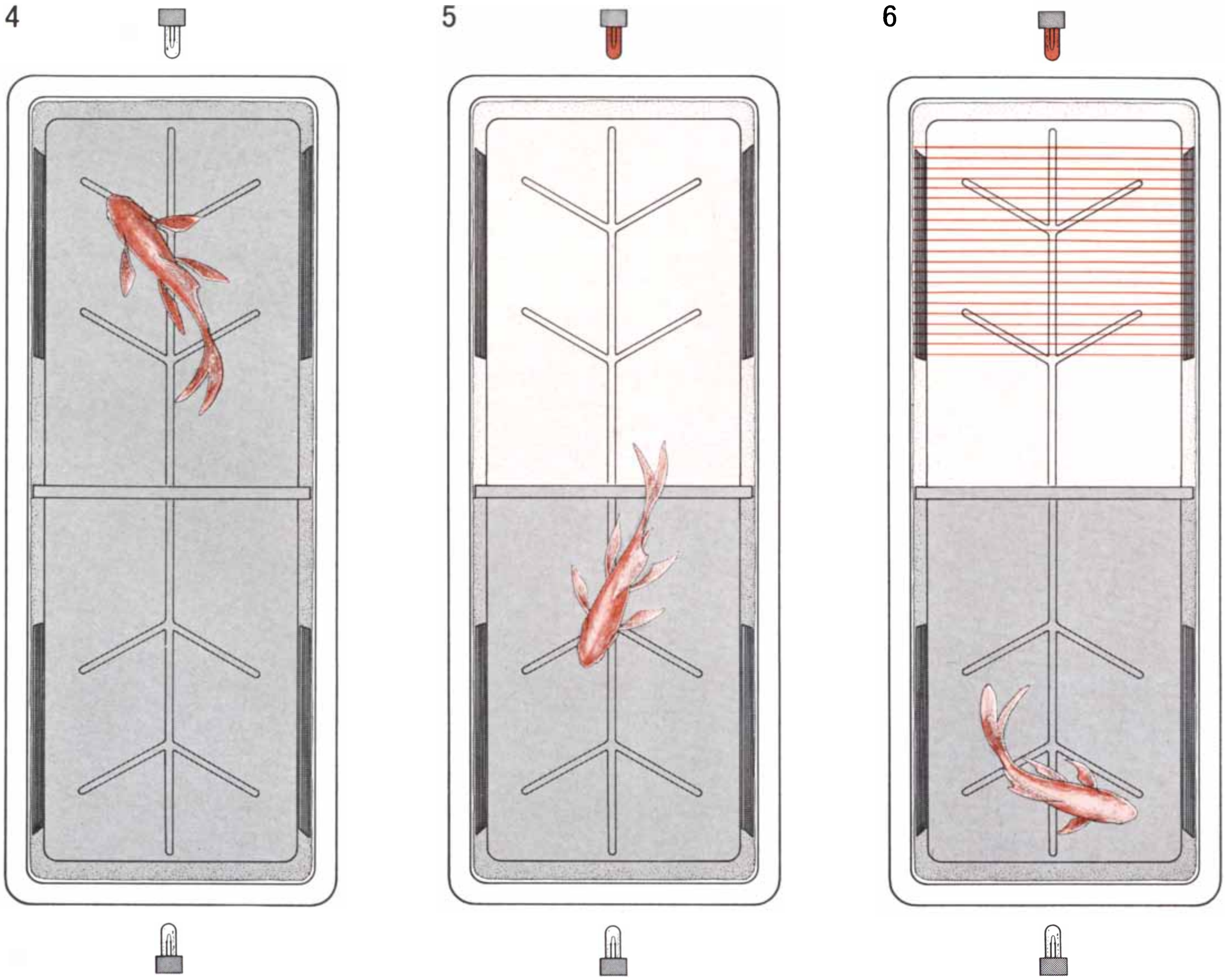
ent kinds of amino acid molecule, strung together in a polypeptide chain. The stringing is done in the small bodies in the living cell called ribosomes. Each amino acid molecule is brought to the ribosome by a molecule of transfer RNA, a form of ribonucleic acid. The instructions according to which the amino acids are linked in a specific sequence are brought to the ribosome by another form of ribonucleic acid: messenger RNA. These instructions have been transcribed by the messenger RNA from deoxyribonucleic acid (DNA), the cell's central library of information.

With this much knowledge of protein synthesis one can begin to think of examining the process by interfering with it in selective ways. Such interference can be accomplished with antibiotics. Whereas some substances that interfere with the machinery of the cell, such as cyanide, are quite general in their effects, antibiotics can be highly selective. Indeed, some of them block only one step in cellular metabolism. As an example, the antibiotic puromycin simply stops the growth of the polypeptide chain in the ribosome. This it does by virtue of the fact that its molecule resembles one end of the transfer RNA molecule with an amino acid attached to it. Accordingly the puromycin molecule is joined to the growing end of the polypeptide chain and blocks its further growth. The truncated chain is released attached to the puromycin molecule.

Numerous workers have had the idea of using agents such as puromycin to block protein synthesis in animals and then observing the effects on the animals' behavior. Among them have been C. Wesley Dingman II and M. B. Sporn of the National Institutes of Health, who injected 8-azaguanine into rats; T. J. Chamberlain, G. H. Rothschild and Ralph W. Gerard of the University of Michigan, who administered the same substance to rats, and Josefa B. Flexner, Louis B. Flexner and Eliot Stellar of the University of Pennsylvania, who injected puromycin into mice. Such experiments encouraged us to try our hand with the goldfish.

We chose the goldfish for our experiments because it is readily available and can be accommodated in the laboratory in large numbers. Moreover, a simple and automatically controlled training task for goldfish had already been developed by M. E. Bitterman of Bryn Mawr College. One might wonder if a fish has such a thing as long-term memory; in the opinion of numerous psychologists and anglers there can be no doubt of it.

Our training apparatus is called a shuttle box. It is an oblong plastic tank



only after the shock period heralded by light has begun (*3*). When the same events are repeated at the other end of the box (*4, 5 and 6*), the fish shown here succeeds in crossing the barrier during the 20 seconds of light that precede the period of intermittent shock.

divided into two compartments by a barrier that comes to within an inch of the water surface [*see illustration on page 115*]. At each end of the box is a light that can be turned on and off. On opposite sides of each compartment are grids by means of which the fish can be given a mild electric shock through the water.

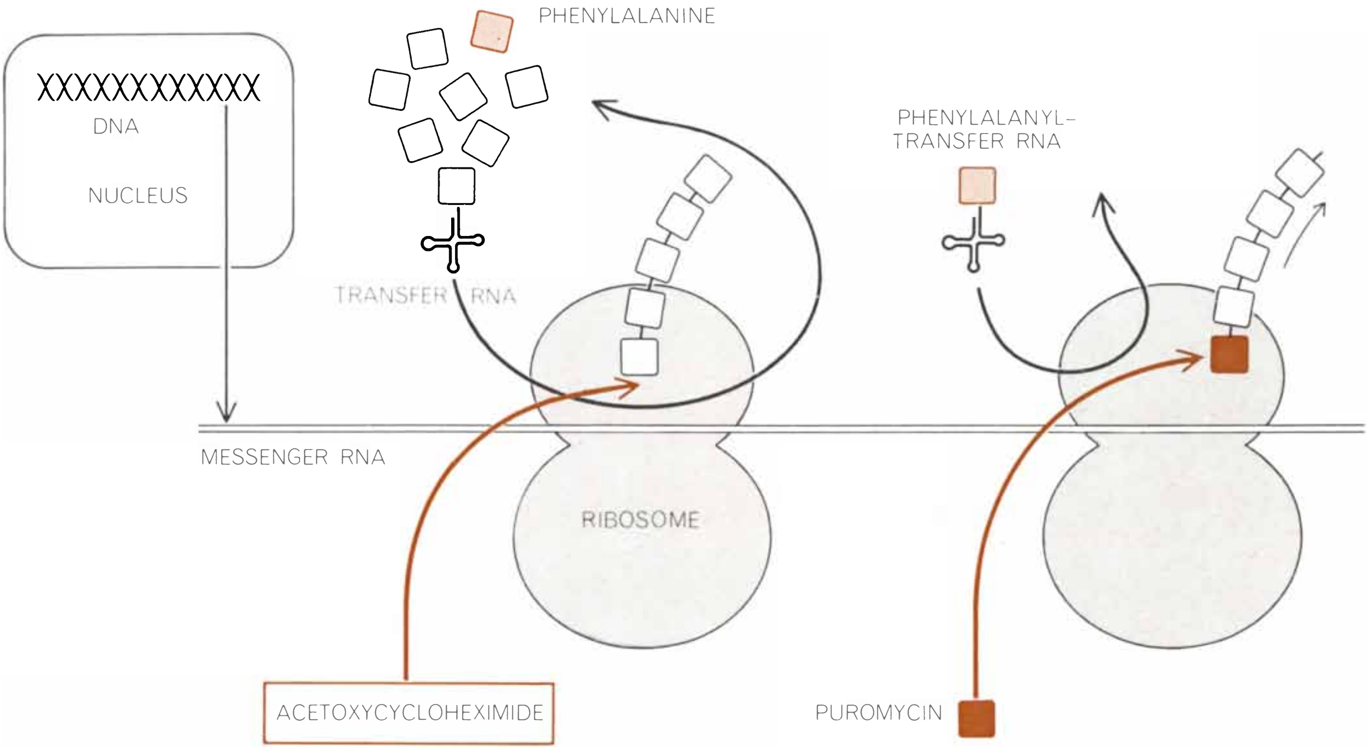
The task to be learned by the fish is that when it is in one compartment and the light goes on at that end of the box, it should swim over the barrier into the other compartment. In our initial experiments we left the fish in the dark for five minutes and then gave it five one-minute trials. Each trial consisted in (1) turning on the light at the fish's end of the box, (2) 20 seconds later intermittently turning on the shocking grids and (3) 20 seconds after that turning off both the shocking grids and the light. If the fish crossed the barrier into the other compartment during the first 20 seconds, it *avoided* the shock; if it crossed the barrier during the second 20 seconds, it *escaped* the shock.

An untrained goldfish almost always escaped the shock, that is, it swam across the barrier only when the shock began. Whether the fish escaped the shock or avoided it, it crossed the barrier into the other compartment. Then, after 20 seconds of darkness, the light at that end was turned on to start the second trial. Thus the fish shuttled back and forth with each trial. If a fish failed to either avoid or escape, it missed the next trial. Such missed trials were rare and generally came only at the beginning of training.

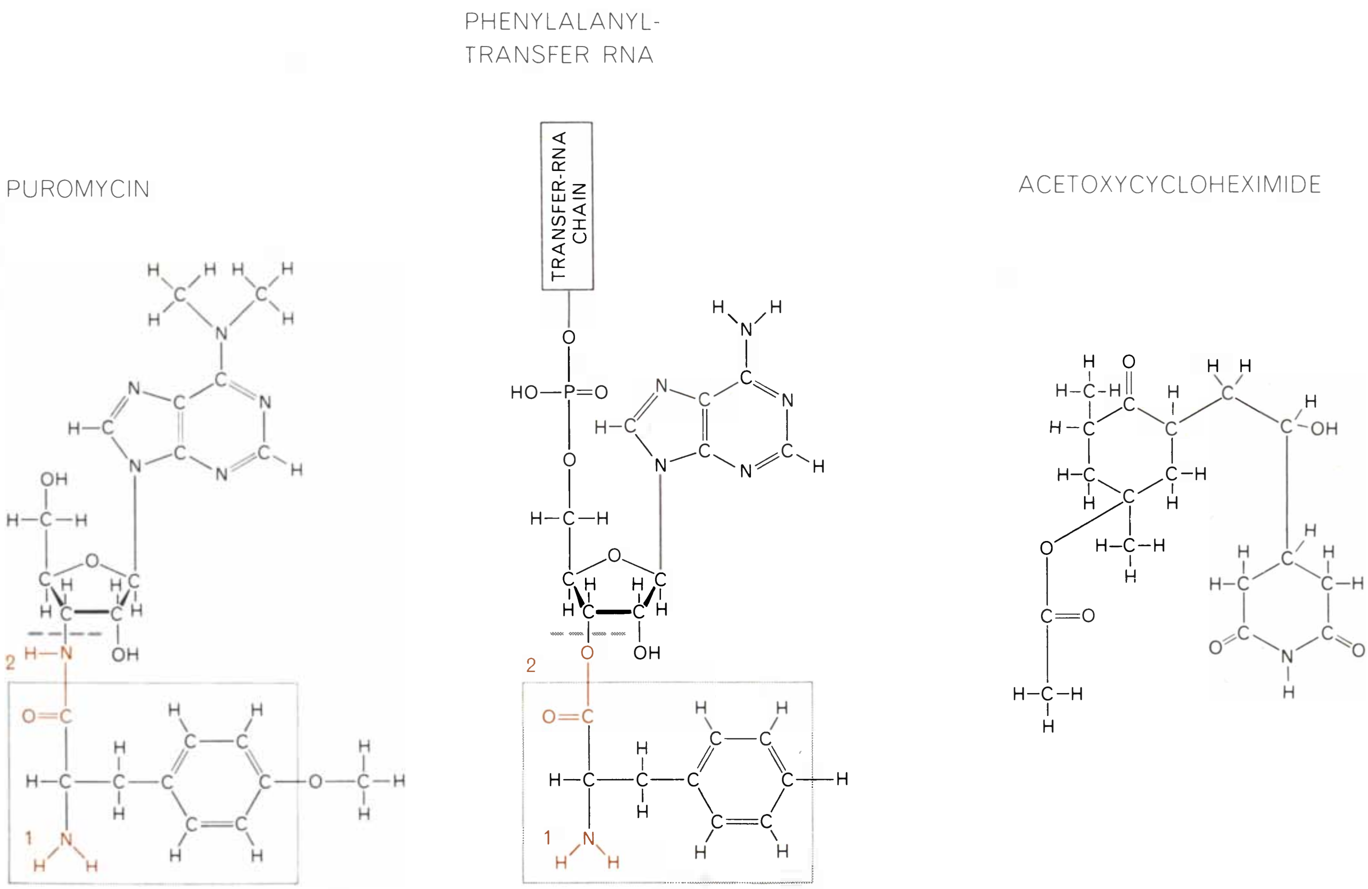
In these experiments the goldfish went through five consecutive cycles of five minutes of darkness followed by five training trials; accordingly they received a total of 20 trials in 40 minutes. They were then placed in individual "home" tanks—plastic tanks that are slightly smaller than the shuttle boxes—and kept there for three days. On the third day they were returned to the shuttle box, where they were given 10 more trials in 20 minutes.

The fish readily learned to move from one compartment to the other when the light went on, thereby avoiding the shock. Untrained fish avoided the shock in about 20 percent of the first 10 trials and continued to improve with further trials. If they were allowed to perform the task day after day, the curve of learning flattened out at about 80 percent correct responses.

What was even more significant for our experiments was what happened when we changed the interval between the first cycle of trials and the second, that is, between the 20th and the 21st of the 30 trials. If the second cycle was



PROTEIN-BLOCKING AGENTS can interrupt the formation of molecules at the ribosome, where the amino acid units of protein are linked according to instructions embodied in messenger ribonucleic acid (mRNA). One agent, acetoxycycloheximide, interferes with the bonding mechanism that links amino acids brought to the ribosome by transfer RNA (tRNA). Puromycin, another agent, resembles the combination of tRNA and the amino acid phenylalanine. Thus it is taken into chain and prematurely halts its growth.



MOLECULAR DIAGRAMS show the resemblance between puromycin and the combination phenylalanyl-tRNA. In both cases the portion of the molecule below the broken line is incorporated into a growing protein molecule, joining at the free amino group (*1*). But in puromycin the CONH group (*2*), unlike the corresponding group (COO) of phenylalanyl, will not accept another amino acid and the chain is broken. Acetoxycycloheximide does not resemble amino acid but slows rate at which the chain forms.

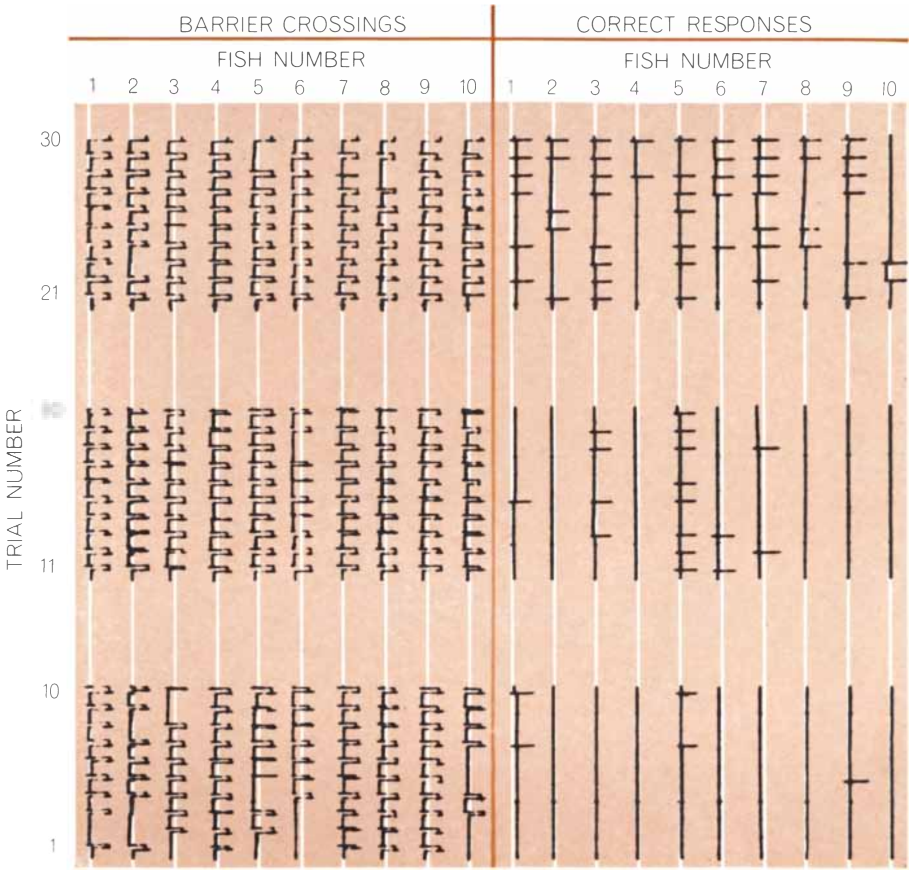
begun a full month after the first, the fish performed as well as they did on the third day. If the second cycle was begun on the day after the first, the fish performed equally well, as one would expect. In short, the fish had perfect memory of their training.

We found that we could predict the training scores of groups of fish on the third day on the basis of their scores on the first day. This made it easier for us to determine the effect of antibiotics on the fish's memory: we could compare the training scores of fish receiving antibiotics with the predicted scores. Since we conducted these initial experiments we have made several improvements in our procedure. We now record the escapes and avoidances automatically with photodetectors, and we have arranged matters so that a fish does not miss a trial if it fails to escape. We have altered the trial sequence and the time interval between the turning on of the light and the turning on of the shocking grid. The results obtained with these improved procedures are essentially the same as our earlier ones.

The principal antibiotic we use in our experiments is puromycin, whose effect on protein synthesis was described earlier. We inject the drug directly into the skull of the goldfish with a hypodermic syringe. A thin needle easily penetrates the skull; 10 microliters of solution is then injected over the fish's brain (not into it). In an early series of experiments we injected 170 micrograms of puromycin in that amount of solution at various stages in our training procedures.

We found that if the puromycin was injected immediately after training, memory of the training was obliterated. If the same amount of the drug was injected an hour after training, on the other hand, memory was unaffected. Injection 30 minutes after training produced an intermediate effect. Reducing the amount of puromycin caused a smaller loss of memory.

After the injection the fish seemed to swim normally. We were therefore encouraged to test whether or not puromycin interferes with the changes that occur in the brain as the fish is being trained. This we did by injecting the fish before their initial training. We found that they learned the task at a normal rate, that is, their improvement during the first 20 trials was normal. Fish tested three days later, however, showed a profound loss of memory. This indicated to us that puromycin did not block the short-term memory demonstrated during



TRACE FROM RECORDER shows the performances of 10 goldfish in 30 trials. Each horizontal row represents a trial, beginning at the bottom with trial 1. A blip (*left side*) indicates that a fish either escaped or avoided the shock; a dash in the same row (*right*) signifies an avoidance, that is, a correct response for the trial. These fish learned at the normal rate.

learning but did interfere with the consolidation of long-term memory. And since an injection an hour after training has no effect on long-term memory, whereas an injection immediately after training obliterates it, it appears that consolidation can take place within an hour.

One observation puzzled us. The animals had received their initial training during a 40-minute period, 20 minutes of which was spent in the dark. Puromycin could erase all memory of this training; none of the memory was consolidated. Yet the experiment in which we injected puromycin 30 minutes after training had shown that more than half of the memory was consolidated during that period. How was it that no memory at all was consolidated at least toward the end of the 40-minute training period? To be sure, the fish that had been injected 30 minutes after the training period had been removed from the shuttle boxes and placed in their home tanks. But what was different about the time spent in the shuttle box and the time spent in the home tank that memory could be consolidated in the home tank but could not be in the shuttle box?

Roger E. Davis of our laboratory undertook further experiments to clarify the phenomenon. He found that fish that were allowed to remain in the shuttle box for several hours after training and were then returned to their home tank showed no loss of memory when they were tested four days later. On the other hand, fish that were allowed to remain in the shuttle box for the same length of time and were then injected with puromycin and returned to their home tank had a marked memory loss! In other words, the fish in the first group did not consolidate memory of their training until after they had been placed in their home tank. It appears that simply being in the shuttle box prevents the fixation of memory. Subsequent studies have led us to the idea that memory fixation is blocked when the organism is in an environment associated with a high level of stimulation. This effect indicates that the formation of memory is environment-dependent, just as the consolidation of memory is time-dependent.

We conclude from all these experiments that long-term memory of training in the goldfish is formed by a puromycin-sensitive step that begins after training and requires that the animal be removed from the training environment. The initial acquisition of information by the fish is puromycin-insensitive and is a qualitatively different process. But what does the action of puromycin on memory formation have to do with its known biochemical effect: the inhibition of protein synthesis?

We undertook to establish that puromycin blocks protein synthesis in the goldfish brain under the conditions of our experiments. This we did in the following manner. First we injected puromycin into the skull of the fish. Next we injected into the abdominal cavity of the fish leucine that had been labeled with tritium, or radioactive hydrogen. Now, leucine is an amino acid, and if labeled leucine is injected into a goldfish's abdominal cavity, it will be incorporated into whatever protein is being synthesized throughout the goldfish's body. By measuring the amount of labeled leucine incorporated into protein after, say, 30 minutes, one can determine the rate of protein synthesis during that time.

We compared the amount of labeled leucine incorporated into protein in goldfish that had received an injection of puromycin with the amount incorporated in fish that had received either no injection or an injection of inactive salt solution. We found that protein synthesis in the brain of fish that had been injected with puromycin was deeply inhibited. The effects of different doses of puromycin and the length of time it took the drug to act did not, however, closely correspond to what we had observed in our experiments involving the behavioral performance of the goldfish. In retrospect this result is not surprising. Various experiments, including our own, had shown that the rate of memory consolidation can be altered by changes in the conditions of training. Moreover, the rate of leucine incorporation can be affected by complex physiological factors.

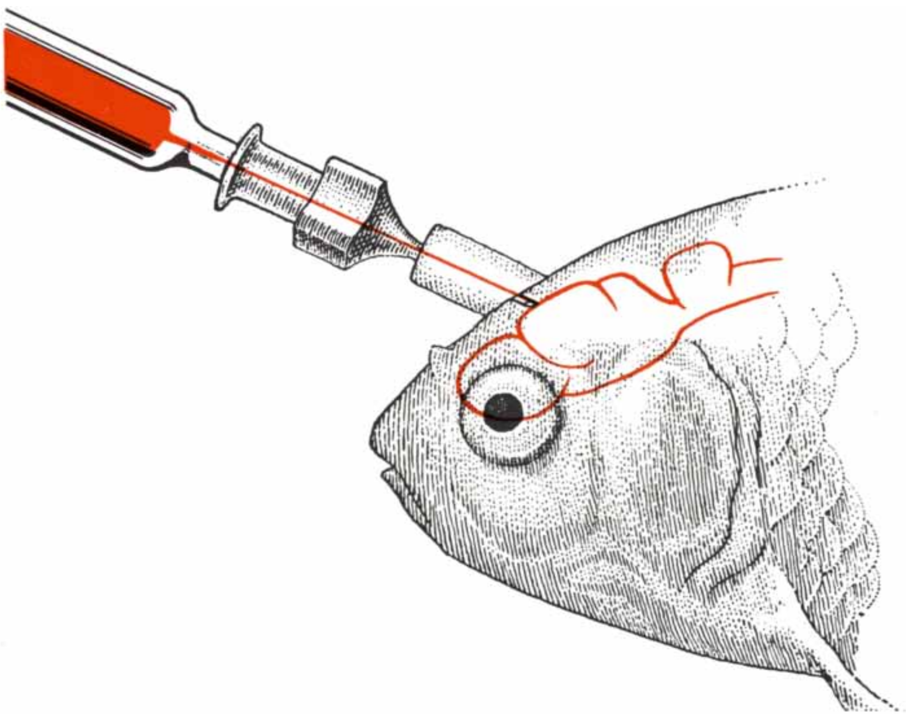
Another way to check whether or not puromycin exerts its effects on memory by inhibiting protein synthesis would be to perform the memory experiments with a second drug known to inhibit such synthesis. Then if puromycin blocks long-term memory by some other mechanism, the second drug would have no effect on memory. It would be even better if the second drug did not resemble puromycin in molecular structure, so that its effect on protein synthesis would not be the same as puromycin's. Such a drug exists in acetoxycycloheximide. Where puromycin blocks the growth of the polypeptide chain by taking the place of an amino acid, acetoxycycloheximide simply slows down the rate at which the amino acids are linked together. We found that a small amount of this drug (.1 microgram, or one 1,700th the weight of the amount of puromycin we had been using) produced a measurable memory deficit in goldfish. Moreover, it commensurately inhibited the synthesis of protein in the goldfish brain.

These experiments suggest that protein synthesis is required for the consolidation of memory, but they are not conclusive. Louis Flexner and his colleagues have found that puromycin can interfere with memory in mice. On the other hand, they find that acetoxycycloheximide has no such effect. They conclude that protein is required for the expression of memory but that experience acts not on protein synthesis directly but on messenger RNA. The conditions of their experiments and the fact that they are working with a different animal do not allow any ready comparison with our experiments.

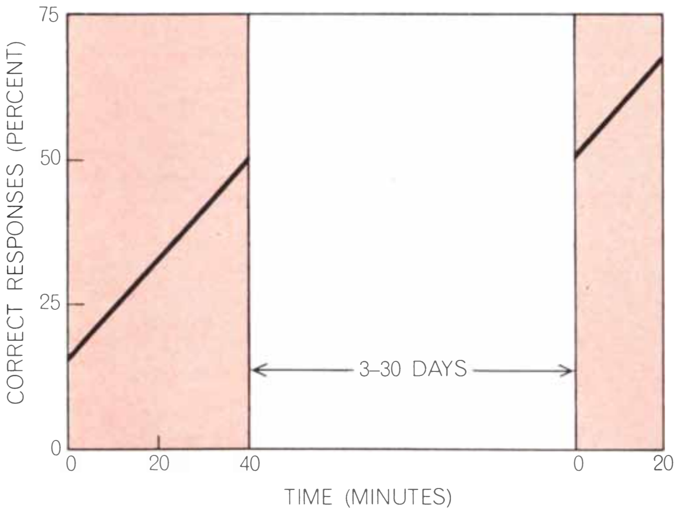
Our studies of the goldfish have led us to view learning and memory as a form of biological development. One may think of the brain of an animal as being completely "wired" by heredity; all possible pathways are present, but not all are "soldered." It may be that in short-term memory, pathways are selected rapidly but impermanently. In that case protein synthesis would not be required, which may explain why puromycin has no effect on short-term memory. If the consolidation of memory calls for more permanent connections among pathways, it seems reasonable that protein synthesis would be involved. The formation of such connections, of course, would be blocked by puromycin and acetoxycycloheximide.

Another possibility is that the drugs block not the formation of permanent pathways but the transmission of a signal to fix what has just been learned. There is some evidence for this notion in what happens to people who suffer damage to certain parts of the brain (the mammillary bodies and the hippocampus). They retain older memories and are capable of new learning, but they cannot form new long-term memories. Experiments with animals also provide some evidence for a "fix" signal. We are currently doing experiments in the hope of determining which of these hypotheses best fits the effects of puromycin and acetoxycycloheximide on memory in the goldfish.

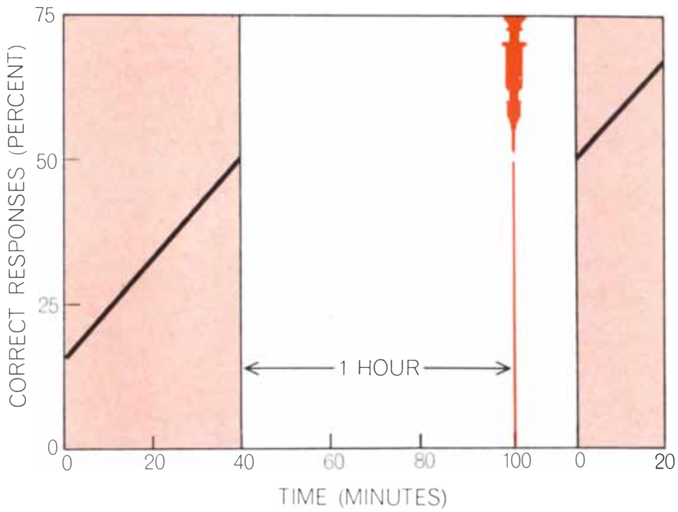
Quite apart from our own work, it has been suggested by others that it is possible to transfer patterns of behavior



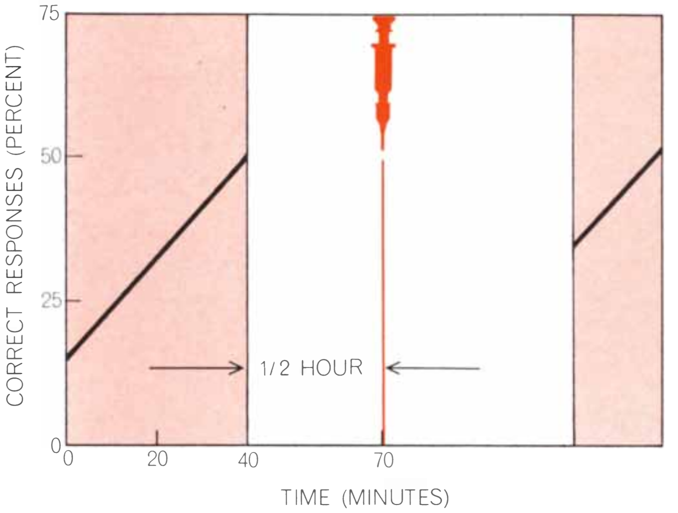
ANTIBIOTIC WAS INJECTED through the thin skull of a goldfish and over rather than into the brain. The antibiotic was puromycin, which inhibits protein synthesis. Following its injection the fish were able to swim normally. They could then be tested for memory loss.



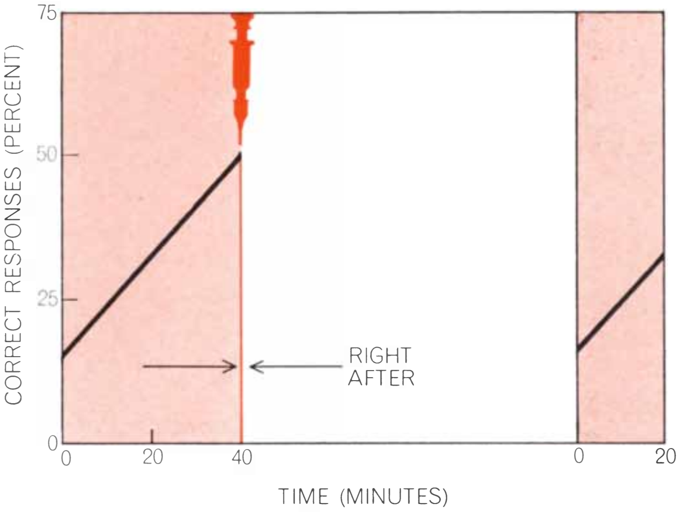
NORMAL LEARNING RATE of goldfish in 30 shuttle-box trials is shown by the black curve. Whether the last 10 trials were given three days after the first 20 (the regular procedure) or as much as a month later, fish demonstrated the same rate of improvement.



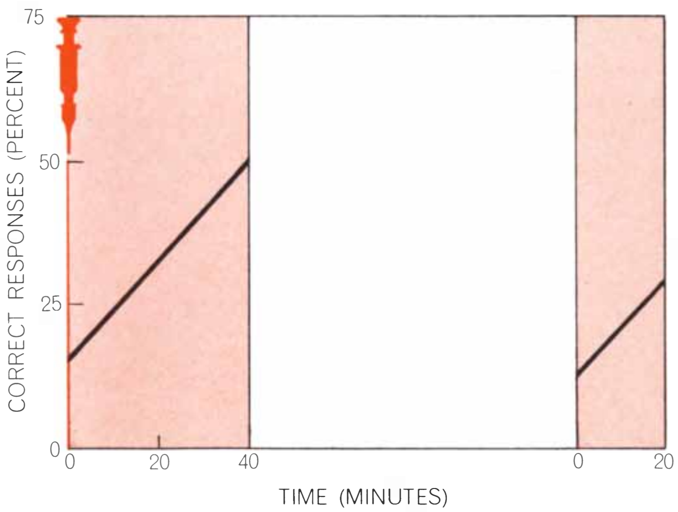
INJECTION WITH PUROMYCIN one hour after completion of 20 learning trials did not disrupt memory. Goldfish given the antibiotic at this point scored as well as those in the control group in the sequence of 10 trials that followed three days afterward.



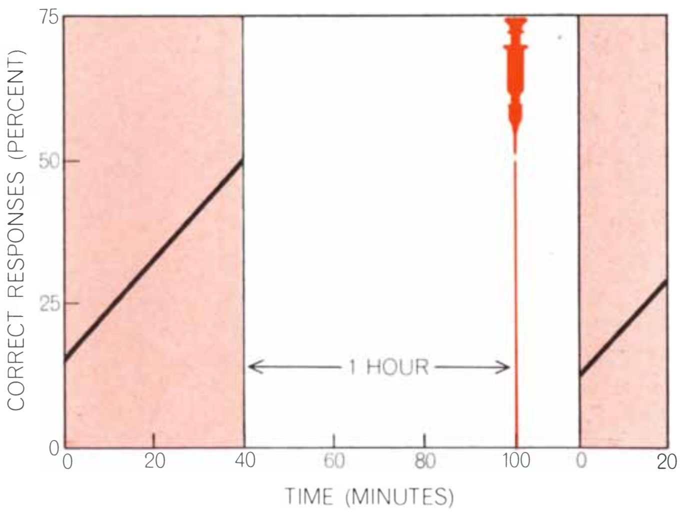
INJECTION HALF AN HOUR AFTER the first 20 trials cut the level of correct responses to half the level without such injection.



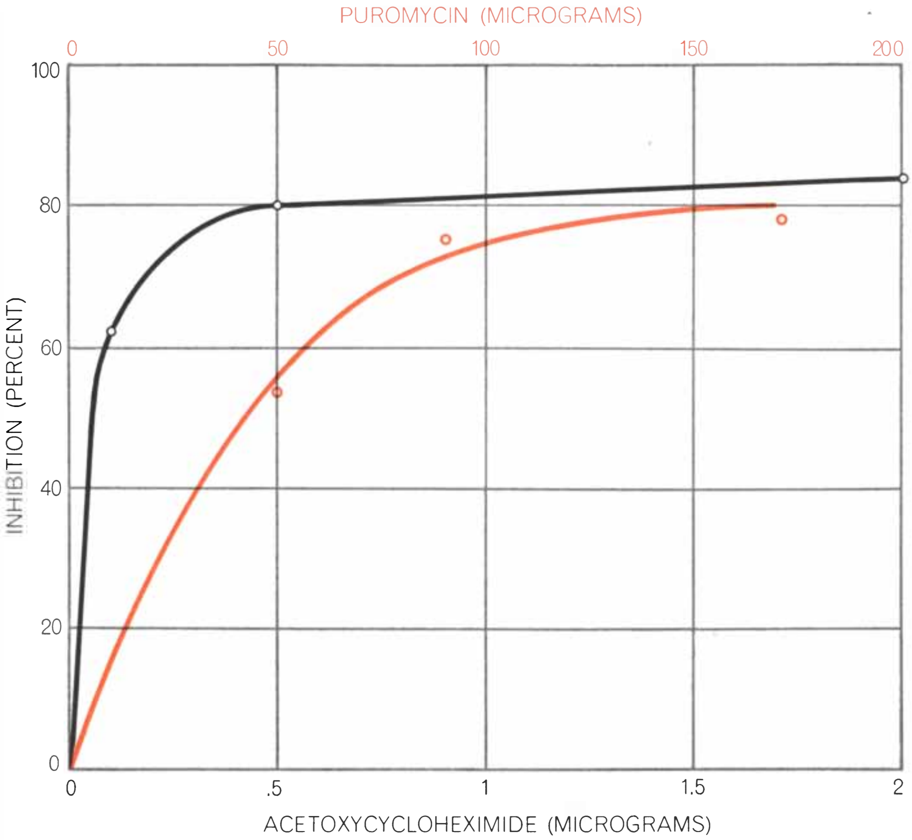
INJECTION IMMEDIATELY AFTER the first 20 trials erased all memory of training. The fish scored at the untrained level.



INJECTION PRIOR TO TRAINING did not affect the rate at which goldfish learned to solve the shuttle-box problem. But puromycin given at this point did suppress the formation of long-term memory, as shown by the drop in the scores three days afterward.



ENVIRONMENTAL FACTOR in the formation of lasting memory was seen when fish remained in training (instead of "home") tanks during the fixation period. Under these conditions fixation did not occur. Puromycin given at end of period still erased memory.



SLOWED PROTEIN SYNTHESIS in the brain of goldfish is induced both by acetoxycycloheximide (*black line*) and the antibiotic puromycin (*colored line*), agents that block the fixation of memory. The author tested the effect on goldfish of various quantities of the two drugs; acetoxycycloheximide was found several hundred times more potent than puromycin.

from one animal to another (even to an animal of a different species) by injecting RNA or protein from the brain of a trained animal into the brain (or even the abdominal cavity) of an untrained one. If such transfers of behavior patterns can actually be accomplished, they imply that memory resides in molecules of RNA or protein. Nothing we have learned with the goldfish argues for or against the possibility that a behavior pattern is stored in such a molecule.

It can be observed, however, that there is no precedent in biology for such storage. What could be required would be a kind of somatic mutation: a change in the cell's store of information that would give rise to a protein with a new sequence of amino acids. It seems unlikely that such a process could operate at the speed required for learning.

It might also be that learning and memory involve the formation of short segments of RNA or protein that somehow label an individual brain cell. Richard Santen of our laboratory has calculated (on the basis of DNA content) the number of cells in the brain of a rat: it comes to 500 million. With this figure one can calculate further that a polypeptide chain of seven amino acids, arranged in every possible sequence, could provide each cell in the rat's brain with two unique markers.

The concept that each nerve cell has its own chemical marker is supported by experiments on the regeneration of the optic nerve performed by Roger W. Sperry of the California Institute of Technology. If the optic nerve of a frog is cut and the two ends of the nerve are put back together rotated 180 degrees with respect to each other, the severed fibers of the nerve link up with the same fiber as before. This of course suggests that each fiber has a unique marker that in the course of regeneration enables it to recognize its mate.

Is it possible, then, that a cell "turned on" by the learning process manufactures a chemical marker? And could such a process give rise to a substance that, when it is injected into another animal, finds its way to the exact location where it can effectuate memory? Thus far the evidence put forward in support of such ideas has not been impressive. In this exciting period of discovery in brain research clear-cut experiments are more important than theories. Certain long-term memories held by investigators in this area may be more of a hindrance than a help in exploring all its possibilities.

RECENT FINDINGS

RESEARCH LABORATORIES

Ford

Observation of molecular vibrations in tunneling

Physicists from the Scientific Research Staff at Ford Motor Company recently developed a device to demonstrate a new phenomenon in solid state physics.

The device, called a Solid State Spectrometer, represents a significant development in our ability to detect microscopic amounts of chemical materials.

The phenomenon, known as inelastic electron tunneling, is capable of seeing minute amounts of molecular material which are in the adsorbed state, having attached themselves to the surface of a thin, insulating film. Experiments have shown that less than a single layer of these impurities can be detected.

In the experiment, an electron current is passed through the thin film on which the impurities have been adsorbed. The ability of the film to pass current was measurably affected by the presence of the impurity molecules.

Tunneling electrons were found to interact with vibrational states of molecules included at a metal-oxide interface. There were increases in the conductance G of the junction occurring at various characteristic voltages V. These voltages correspond to vibrational frequencies v of molecules contained in the junction, i.e., $eV=hv$.

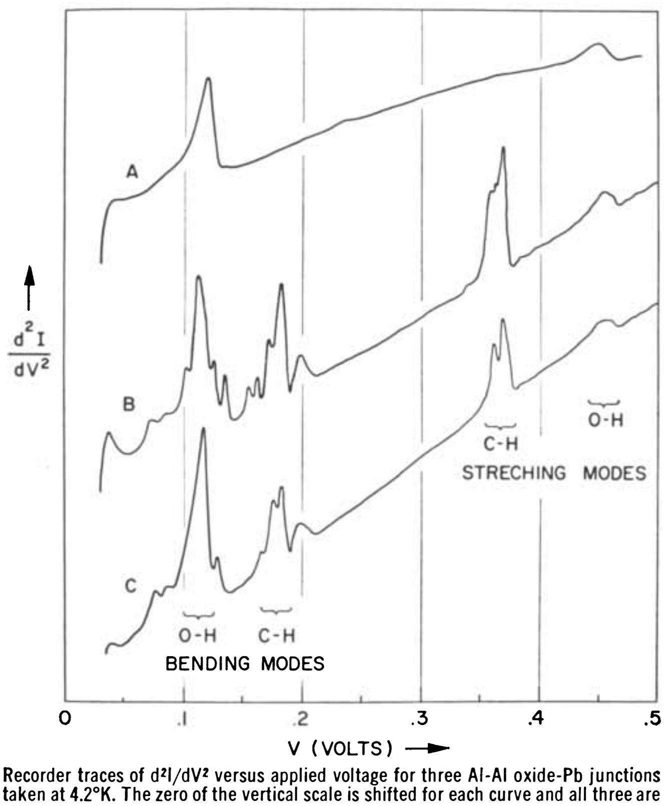
These increases represent changes in G of about 1% and correspond to the onset of new tunneling channels paralleling the bulk of the tunneling current. The characteristic voltages occur when molecular impurities are introduced in the junction, usually after formation of the oxide insulating barrier and before deposition of the top metal film. Coverage is estimated to be of the order of one monolayer.

A spectrum was obtained that was characteristic of the particular molecular species. The spectra reflect the internal molecular vibrations.

Traditional methods of obtaining this information have used infrared light of varying wave length to probe the sample. In this new method, electrons take the place of light waves and the voltage applied to drive current through the insulating film takes the place of wave length.

Compared to infrared absorption, electrons are effected more than a thousand times more efficiently in this method, which accounts for its high sensitivity.

Besides providing a new analytical tool, the Solid State Spectrometer permits experimentation on molecules in the adsorbed state, which will be of importance to the field of surface chemistry. It also represents an advance in understanding the basic processes related to electron tunneling in the solid state.



Recorder traces of d^2I/dV^2 versus applied voltage for three Al-Al oxide-Pb junctions taken at 4.2°K. The zero of the vertical scale is shifted for each curve and all three are normalized to the same arbitrary units. The largest peaks represent increases of 1% of G. Also indicated are intervals associated with the energy of IR active molecular vibrational modes. Curve A is obtained from a "clean" junction. Curves B and C are obtained from junctions exposed to propionic acid ($CH_3(CH_2)COOH$) and acetic acid (CH_3COOH) respectively. The spectra are independent of voltage polarity.

PROBING DEEPER FOR BETTER IDEAS

Ford

MATHEMATICAL GAMES

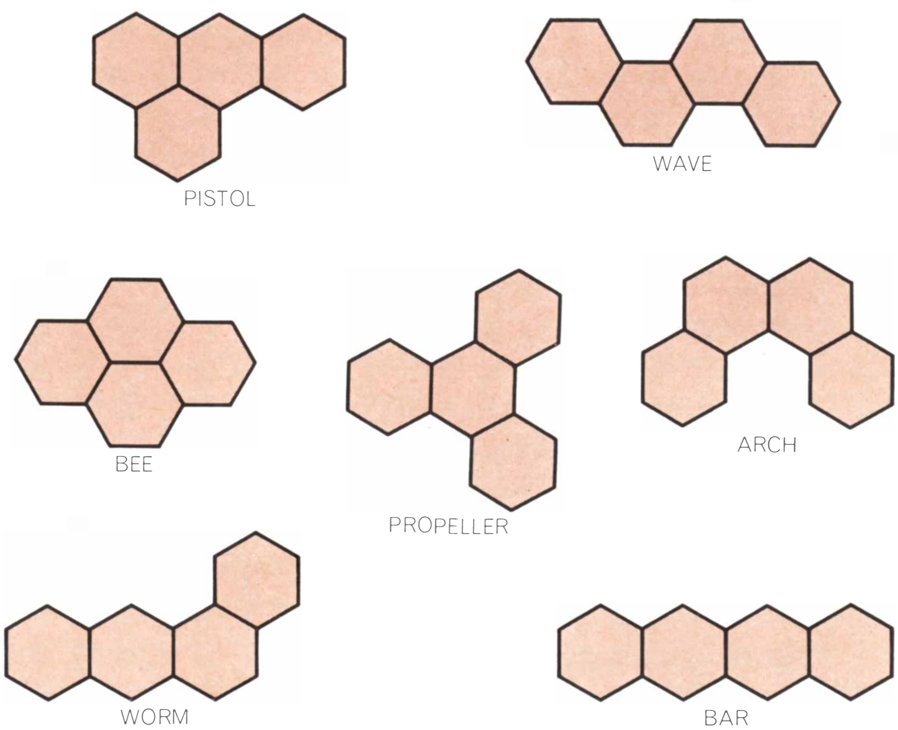
The polyhex and the polyabolo, polygonal jigsaw puzzle pieces

by Martin Gardner

The usual jigsaw puzzle is almost devoid of mathematical interest: the pieces are fitted together by trial and error, and if one has enough determination and patience, the pattern is eventually completed. But if the pieces have simple polygonal shapes, the task of fitting them into a predetermined figure becomes one of combinatorial geometry, offering scope for considerable mathematical ingenuity and sometimes raising questions that are not mathematically trivial. If a set of polygonal pieces is obtained by applying a simple combinatorial rule, it takes on a quality of elegance, and the task of exploring the set's combinatorial properties can be as fascinating as it is time-devouring.

Among recreational mathematics enthusiasts the most popular of such sophisticated jigsaws are the polyominoes. These are pieces formed by joining n unit squares in all possible ways. Many earlier columns have been devoted to them, and Solomon W. Golomb, professor of engineering and mathematics at the University of Southern California, has written a book about them, *Polyominoes.* By joining equilateral triangles along their edges one obtains another well-explored family of shapes known as polyiamonds. The hexiamonds (polyiamonds formed with six equilateral triangles) provided the topic for this department in December, 1964.

Many readers intrigued by polyominoes and polyiamonds have written to propose other ways of obtaining a basic set of polygons that can be used for similar recreations, and this month I shall discuss the two sets that have prompted the most correspondence. Very little has been published about either of them. I am hoping that readers will join in a pioneer investigation of their properties and clear up some of the many unsolved problems connected with them.

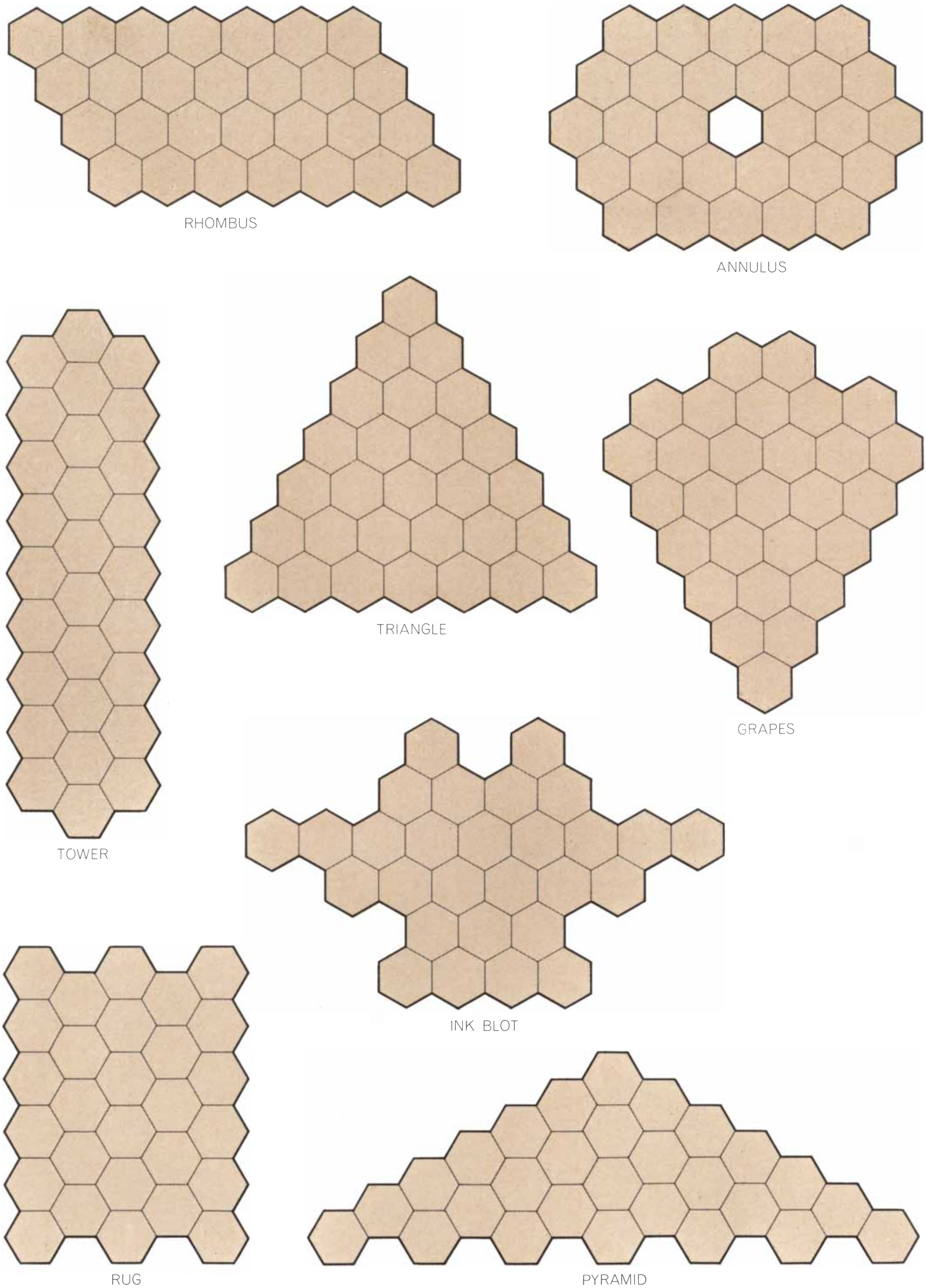


The seven distinct tetrahexes

Since there are only three regular polygons that tile the plane—squares, equilateral triangles and regular hexagons—one thinks at once of forming pieces by joining congruent hexagons. There is only one way to join two hexagons; there are three ways to join three hexagons and seven ways to join four of them. Because these shapes resemble the structural diagrams of benzene-ring compounds two readers, Eleanor Schwartz and Gerald J. Cloutier, have suggested calling them "benzenes." Other names have been proposed, but it seems to me that the best is "polyhexes," the name adopted by David Klarner, who was one of the first to investigate them. The seven tetrahexes, with names culled from the letters of many different readers, are shown in the illustration on this page. The next largest set, the pentahex, has 22 distinct shapes—a bit too unwieldy for recreational uses. There are 83 hexahexes. (Because pieces may be turned over, mirror-image forms are not considered distinct.) The number of heptahexes (order 7) is not yet known. As with polyominoes and polyiamonds, no formula is known by which the number of polyhexes of a given order can be determined.

The reader is urged to cut a set of tetrahexes from cardboard. (If you have a hexagonally tiled floor, you could make the pieces correspond in cell size to the tiles so that the floor can be used as a background for working on tetrahex problems.) Of the eight symmetrical patterns in the illustration on the opposite page, all but one can be formed from a full set of the seven tetrahexes. Many readers proposed the "rhombus," the "triangle" and the "tower." The "ink blot" and the "grapes" are from Richard A. Horvitz, the "ring" from Cloutier, the "pyramid" from Klarner and the "rug" from both T. Marlow and Klarner. Can you identify the impossible figure? No simple proof of its impossibility has yet been found. (The tower is not the impossible one, although it is difficult and may have a unique solution except for a trivial reversal of two pieces that together form a mirror-symmetrical shape.) Next month I shall identify the impossible figure and give the tower pattern I first received from Klarner. I hope readers will preserve any solution they find for the tower and send it to me if it differs from the one to be shown next month, and will let me know at once if they discover more than one basic pattern. Solutions obtainable by reflection of the entire figure are not, of course, counted as different.

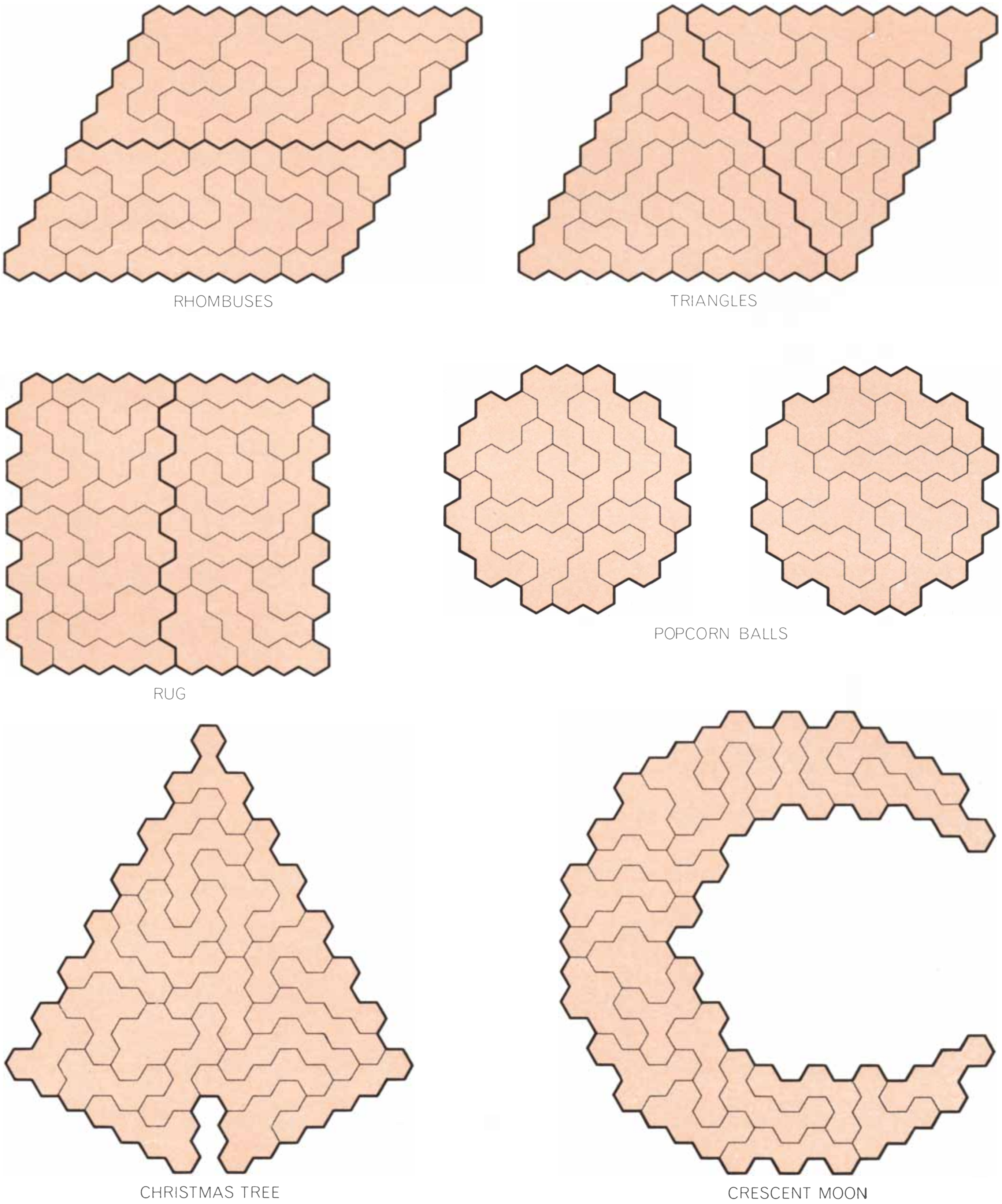
Many striking symmetrical shapes can



Patterns to be formed with tetrahexes, all but one of them possible

be formed with the 22 pentahexes [*see illustration below*]. The "rug" (which can be bisected, the two parts being placed end to end to form a longer, narrower rug) was discovered by Robert G. Klarner (father of David Klarner). The other patterns are from Christoph M. Hoffmann of Hamburg, Germany. Note that the two rhombuses can be put together differently to make a 5-by-22 rhombus. (This bisected rhombus and the rhombus cut into two triangles were solved in different ways by Marlow.) Neither the tetrahexes nor the pentahexes have the required area to form a hexagon, but both Marlow and Miss Schwartz discovered that a hexagon of side 4 could be made by combining the seven tetrahexes with the three trihexes.

Turning to polygonal units that are not regular, we find that the simplest are the isosceles right triangles. They can be joined either at their sides or along their hypotenuses. We shall speak of the sides



Some patterns to be formed with pentahexes

Luis Jiminez is starting 4th grade a little late. Thanks to the Smiths.

In the Colombian village of Soacha, school is a luxury that fathers of even the brightest, most ambitious children can't afford. So it didn't surprise anyone when Luis Jiminez dropped out of school in the third grade. The big surprise—Soacha calls it a little miracle—is that Luis went back to school this year.

Betty and John Chabot Smith made it happen. Through *Save the Children Federation* they're giving $15 a month to give Luis a chance he never thought possible.

Who are these "miracle workers," the Smiths? If you met them, they might tell you of their daughter's baby. Or their son, who's working his way through law school. John might talk about his work as a teacher of creative writing. Or you might be interested in their charming colonial farmhouse in southern Connecticut. It's almost paid for. The Smiths are a long way from being wealthy. Although you'd have a hard time telling that to the people of Soacha.

Until the Smiths came along, few in Soacha had any knowledge of the outside world. They knew a lot about desperate poverty, hunger and hopelessness, though. Take Luis' father, for example. His take-home pay is $10 a month. He has five children to feed. School for Luis wasn't in his budget.

But this was before the Smiths. Betty Smith first became interested in *Save the Children Federation* when she worked for them last year. Time after time she saw them do wonders for people with the money received from sponsors. Now the Smiths are sponsors. And their $15 a month is doing wonders for Luis, his family and even the village.

Luis is back in school. Luis' father has a small patch of land he had never cultivated because he could not afford seed and fertilizer. This year he is growing corn. With all this, there is still money left over. This money, together with funds from other sponsors, was borrowed without interest by the village to build a new school.

More money and more people like the Smiths are needed to give other children the boost they need to permanently end their need for help. That's what *Save the Children Federation* is all about.

Although contributions are tax deductible, *Save the Children* is not a relief agency. The aim is not merely to buy one child a few hot meals and a warm coat. Instead, your contribution is used to give the child, the family and the village, the "seed money" they need to start helping themselves.

As a sponsor you can select a child in Latin America. Or a child in Korea, Vietnam, Africa or Greece. You will receive a photo of the child, regular reports on his progress, and, if you wish, a chance to correspond with the child and his family.

The Smiths know they can't save the world for $15 a month. Only a small corner of it. But maybe that is the way to save the world. If there are enough people like Betty and John Smith. How about you?

Save the Children Federation is registered with the U.S. State Department Advisory Committee on Voluntary Foreign Aid, and is a member of the International Union for Child Welfare. Financial statements and annual reports are available on request.

Save The Children Federation—
Founded in 1932
National Sponsors (partial list): Faith Baldwin, Mrs. James Bryant Conant, Joan Crawford, Hon. James A. Farley, Jerry Lewis, Frank Sinatra, Mrs. Earl Warren

Save The Children Federation
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"It's not German. How good could it be?"

No one who has ever been on a French railroad, flown in a Caravelle jet or sailed on a French ocean liner would talk like that.

Yet there are people around who think France is practically a nation of chefs and painters.

Even if that were true, consider: What makes a great chef great? Or a painter, for that matter?

The answer, obviously, is a frightening, almost inhuman finickiness.

Now is it reasonable to assume these same people who worship meticulousness in all other things, would suddenly not care how they put a car together?

Renault is the world's seventh largest car-maker.

We sell more Renaults in Sweden than Sweden sells Volvos in France. (About 7,700 to 1,000 in '66)

We sell more Renaults in Germany than Germany sells Volkswagens in France. (About 55,000 to 10,000 in '66)

The Renault 10 is very far from being a piece of French pastry.

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Without these little concessions to creature comforts, a car, to us, simply isn't civilized. It is the way we do things in France.

Understand. Some very fine cars have and still do come out of Germany.

We just hate to think anyone wouldn't at least test drive the Renault 10 just because it's French.

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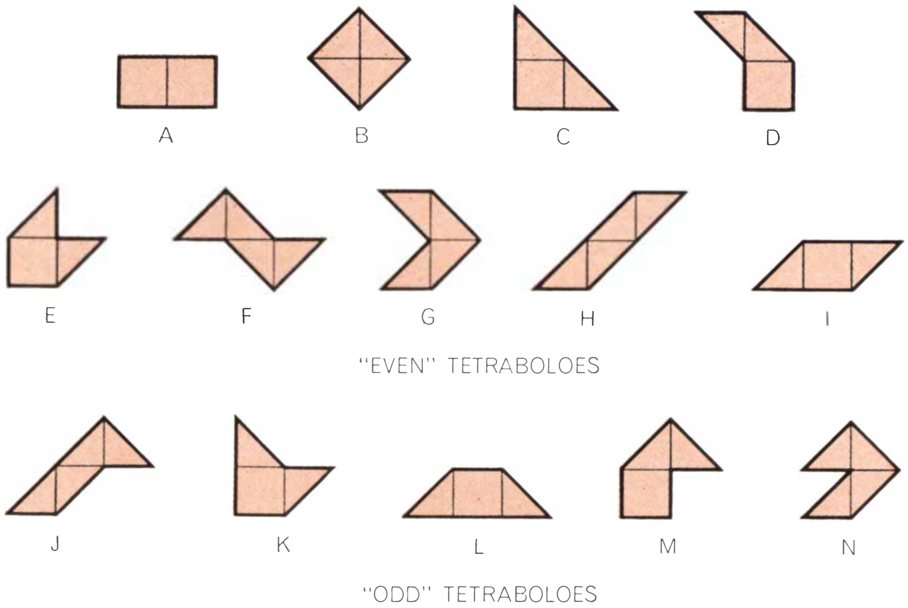


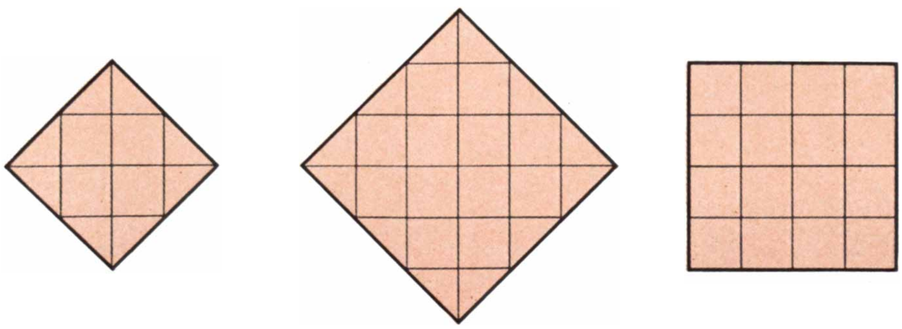
The 14 distinct tetraboloes

as *s* edges and the hypotenuses as *h* edges. This family of pieces was first discussed in print by Thomas H. O'Beirne in *New Scientist*, December 21, 1961, in a column on recreational mathematics that he then contributed regularly to the magazine. The pieces had been suggested to him by S. J. Collins of Bristol, England, who gave the name "tetraboloes" to the order-4 set because the Diabolo, a juggling toy, has two isosceles right triangles in its cross section. This implies the generic name "polyaboloes." There are three diaboloes, four triaboloes and 14 tetraboloes. So little work has been done on the polyaboloes that I cannot report with assurance on the number of pentaboloes. A letter from Hermann Rahn and Mary L. Taggart in 1965 expressed the belief that there are 108. I shall assume that this is correct unless someone is able to prove otherwise.

The set of 14 tetraboloes, illustrated above, has a total area of 28 *s*-unit squares or 14 *h*-unit squares. Since neither 14 nor 28 is a square number there is no possibility of forming a square with the complete set. A 2*s*-by-2*s* square has the right area to be formed with two tetraboloes, but this proves to be impossible. There are three squares that can be formed with subsets of the complete set [*see illustration below*]. If the reader will make a set of cardboard tetraboloes, he will find that it can be a pleasant task to discover patterns for these three squares. The smallest square has only two solutions and the number of solutions for the two larger ones is not known.

The illustration on the next page shows all the rectangles with *s*-edge sides that have the proper area to be formed with the full set or a subset of the 14 pieces; the illustration on page 132 shows all such rectangles with *h*-edge sides. Note that the largest-area rectangle of each type, calling for all 14 pieces, is said to be impossible. I shall give a remarkable proof of this that was discovered by O'Beirne and explained in his column of January 18, 1962.

Most impossibility proofs for polyomino figures depend on a checkerboard coloring of the figure, but in this case



Squares with tetrabolo solutions

such a coloring is no help. O'Beirne's proof focuses on the number of h edges possessed by the full set of pieces. If each piece is placed so that the sides of its unit triangles are vertical and horizontal, as in the top illustration on the preceding page, its h edges will slope either up to the right or up to the left. Piece A has no h edges. It and the next eight pieces (B, C, D, E, F, G, H, I) are called "even" pieces because each of them has an even number of h edges sloping in each direction. (Zero is considered an even number.) The last five pieces (J, K, L, M, N) are "odd" because each has an odd number of h edges sloping in each direction. Because there is an odd number of odd pieces, it follows that no matter how the entire set is arranged in a pattern with its s edges oriented orthogonally, there will always be an odd number of h edges sloping one way and an odd number sloping the other way.

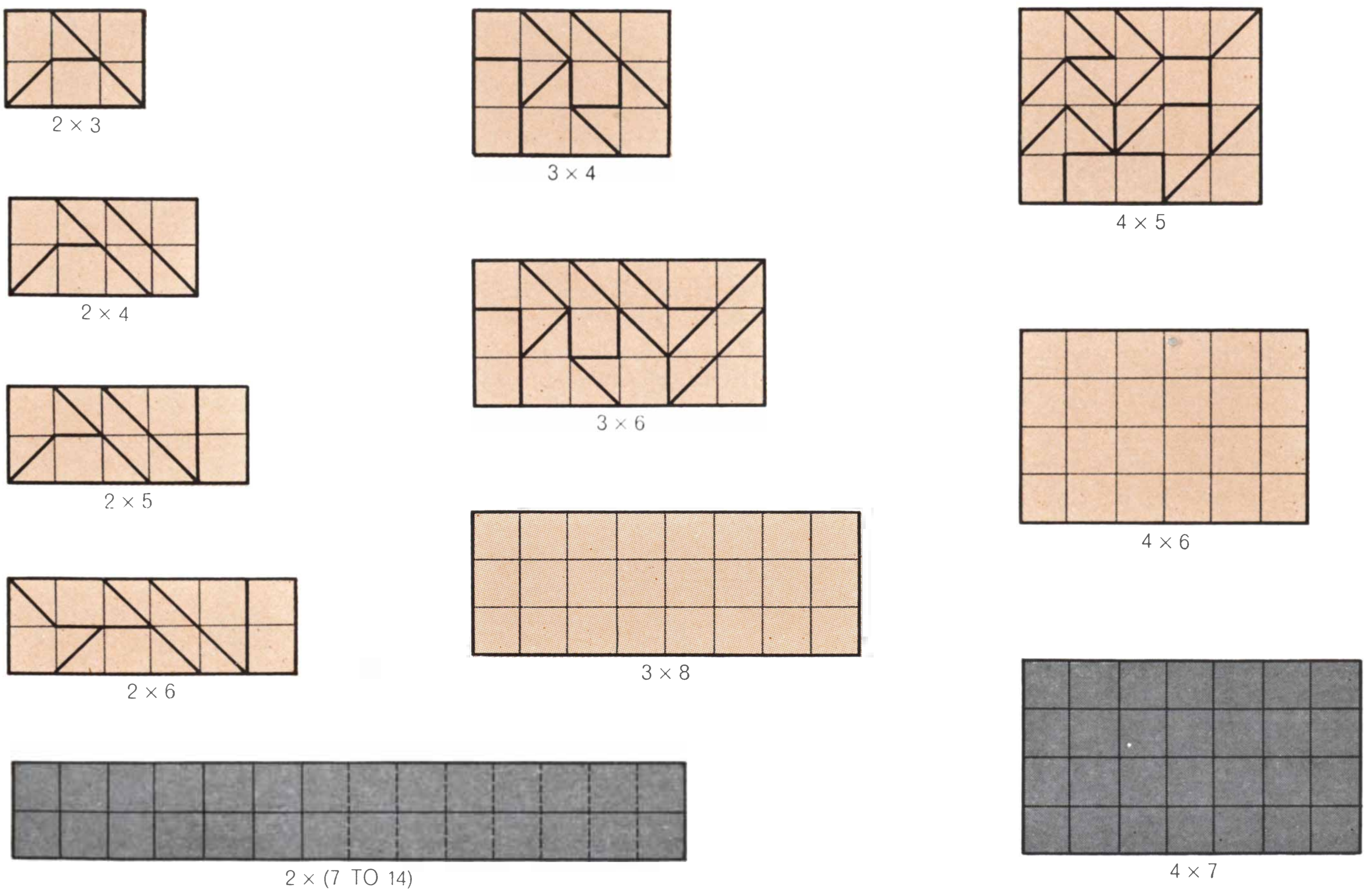
Now consider the two rectangles that require the full set of 14 pieces. Clearly on each rectangle there must be an *even* number of h edges sloping in each direction. Within each rectangle every h edge is paired with another h edge sloping the same way and therefore the number of internal h edges, of either type, must be even. And on the rectangle that has a perimeter of h edges we count an even number of each type along the perimeter. Neither rectangle, therefore, can be made with the 14 pieces. The proof is a powerful one, for it applies not only to the two rectangles but also to any 14-piece figure with bilateral symmetry.

The gray rectangles below that have a height of two s units and a width equal to or greater than seven can be proved impossible by observing that six pieces (B, D, E, G, M, N) cannot be placed within any of them without dividing the field into areas that are not multiples of two s-unit squares. Therefore they cannot appear in the pattern. The remaining eight pieces can contribute a maximum of 17 s edges to the perimeter. But the two-by-seven rectangle has a perimeter of 18 s edges, one more than this subset can provide.

A sample pattern is shown for all s-edge and h-edge rectangles for which solutions are known. Are the four blank rectangles possible? Each calls for 12 pieces, which means that one "odd" piece and one "even" piece must be omitted. The three-by-eight rectangle below may be impossible, because its large perimeter severely limits the number of ways pieces can be placed, but no impossibility proofs for any of the four blank rectangles are known, nor have solutions been found. If the reader finds a pattern for any of them, I should be pleased to receive it. I cannot reply to such letters, but I shall report on them in a later column.

More ambitious readers may wish to tackle a difficult square pattern proposed by O'Beirne. Discard the six symmetrical shapes that are unaltered when they are turned over and consider only the eight asymmetric shapes: D, F, H, I, J, K, M and N. Since their combined area is 16 s-unit squares, they might form an order-4 square, but such a square has 16 s units in its border whereas the eight pieces can contribute no more than 12 s units to the perimeter. Suppose, however, we consider each piece in its two mirror-image forms, making a set of 16 pieces in all. Pieces may not, in this case, be turned over; that is, each "enantiomorphic" pair must be used as a set of two mirror images. The 16 pieces have a total area of 16 h-unit squares. Will they form a square with sides of four h units? O'Beirne found that they would, but such patterns are extremely hard to come by and none has been published. One will be shown next month. The total number is far from being known.

The tetraboloes also provide an answer—perhaps the simplest—to an unusual question asked in 1963 by C.



Tetrabolo rectangles with s-edge borders. Gray rectangles have been proved to have no solutions

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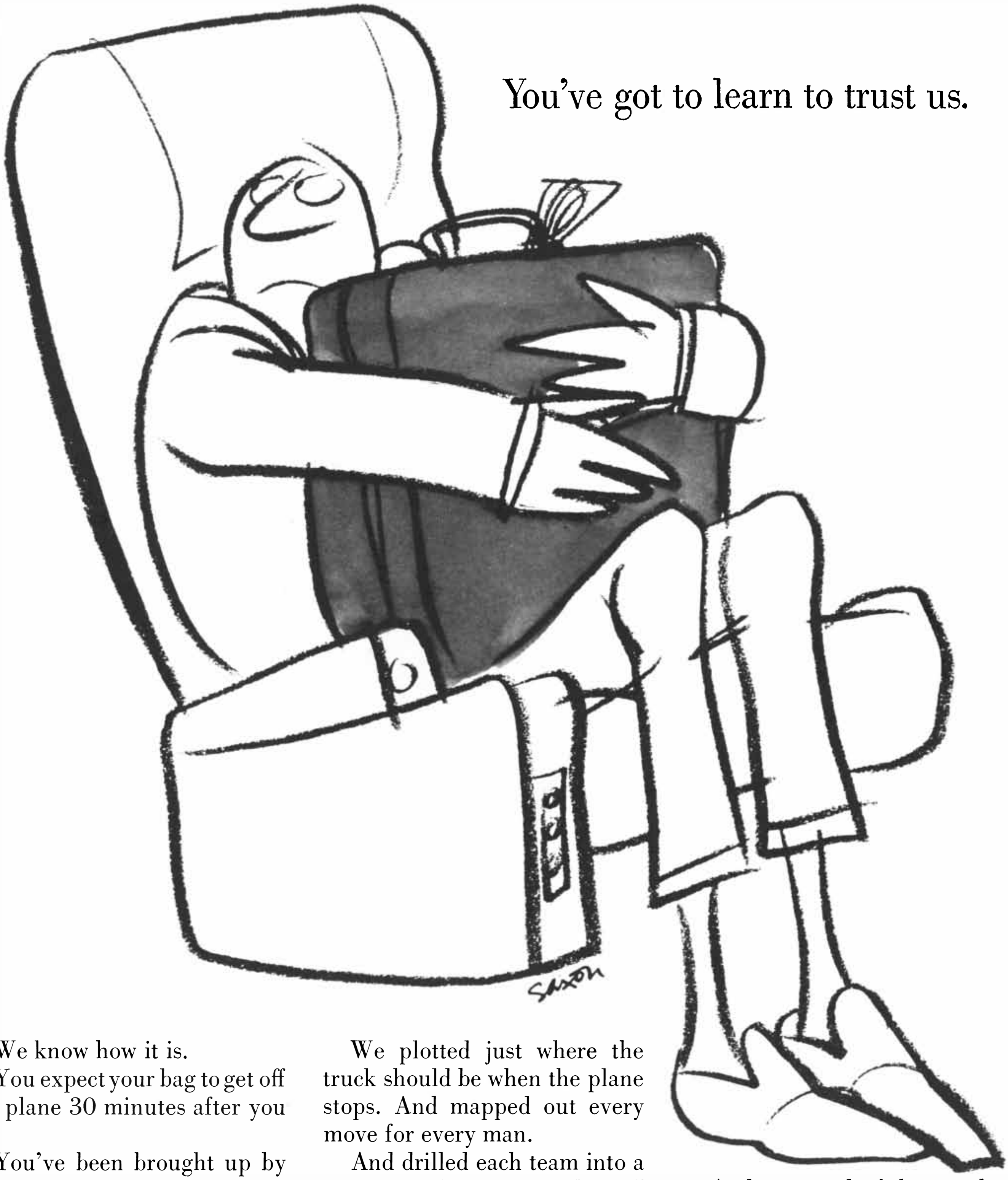

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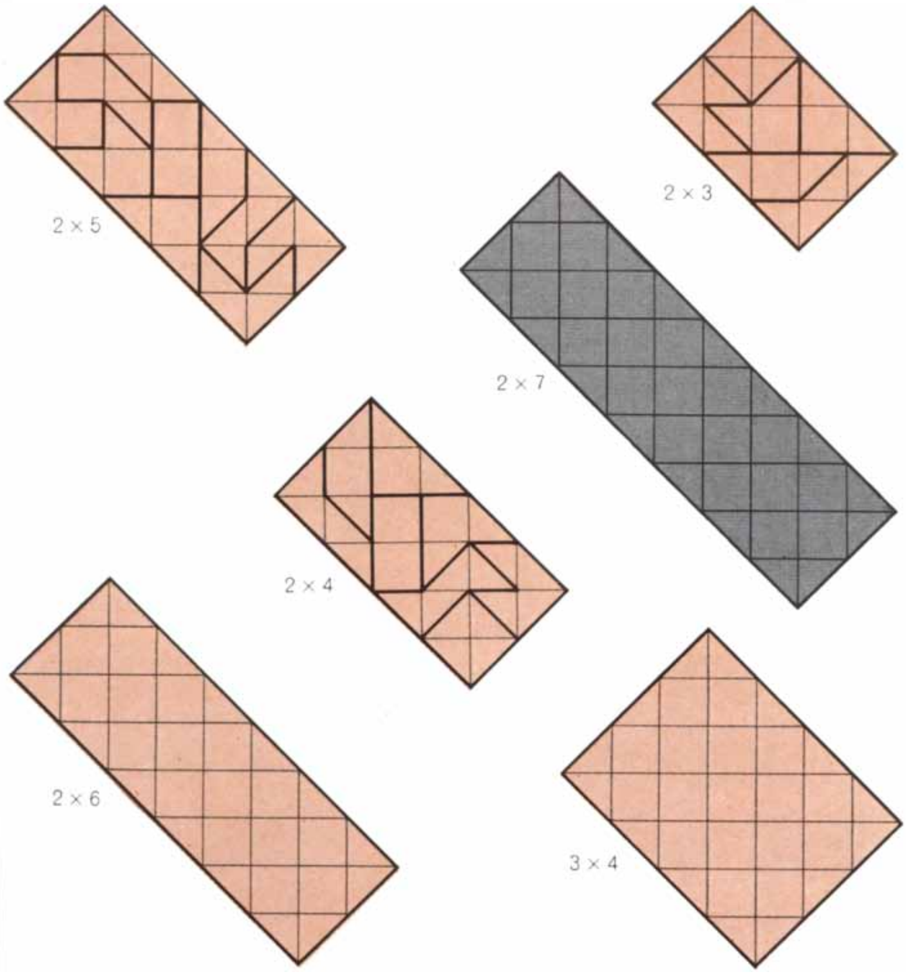


Rectangles with h-edge borders. Gray one is impossible

Dudley Langford of Ayrshire, Scotland, and passed on to me by a British mathematician, H. Martyn Cundy. Langford wanted to know if there are four shapes of equal area, no two of them alike (mirror images not being considered different), that can be put together in four different ways to make four larger replicas of each shape. All four pieces must be used in each replica. I discovered a simple solution with a set of four tetraboloes. Can the reader pick out the four and show how they replicate themselves before the answers are given next month?

The magic numbers used in the lightning multiplication tricks given last month operate on a principle best explained by examples. The number 142,857,143 is obtained by dividing 1,000,000,001 by 7. If 1,000,000,001 is multiplied by any nine-digit number, *abc,def,ghi,* the product obviously will be *abc,def,ghi,abc,def,ghi*. Therefore in order to multiply 142,857,143 by *abc,def,ghi* we have only to divide *abc,def,ghi,abc,def,ghi* by 7.

The second magic number, 2,857,143, is equal to 20,000,001 divided by 7. It is easy to see that in this case a seven-digit multiplier of 2,857,143 must be doubled before the first division by 7 is made. Insisting that each digit of the multiplier be greater than 4 (thus ensuring that there is always 1 to carry as each digit is doubled) makes possible the doubling procedure explained last month. Without this proviso it is still possible to double and divide in the head, but the rules are more complicated.

The smaller magic numbers 143 and 1,667 operate in similar ways. The first is equal to 1,001/7 and the second to 5,001/3. In the second case the multiplier, *abc,* must be multiplied by 5 before the first division by 3 is made. Since multiplying by 5 is the same as multiplying by 10 and dividing by 2, we add a zero to *abc* and divide by 6 as explained last month. The remainder must be halved, to convert it from sixths to thirds, and brought to the front for the second division, which is by 3. The fact that the second division is by a different number prevents the quotient from "stuttering," something that always occurs if 143 is used and the multiplier, *abc,* happens to be a multiple of 7.

THE AMATEUR SCIENTIST

A sensitive electronic thermometer used for making a study in micrometeorology

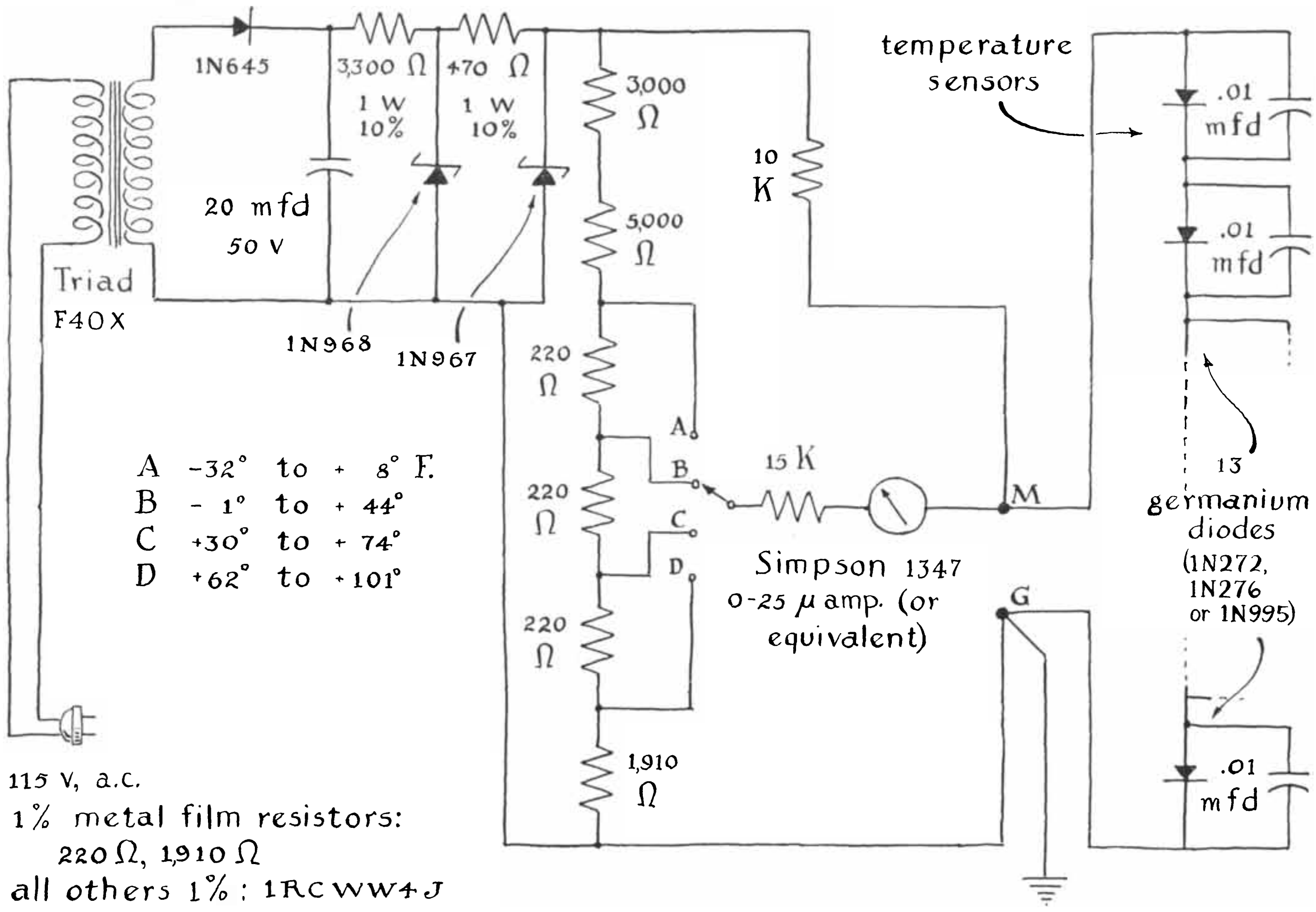
Conducted by C. L. Stong

Most human beings spend the greater part of their lives in the bottom six feet of the earth's atmosphere, and yet until recently little effort was made to describe and understand the distinctive climatic features of that narrow zone. Many clues were virtually unnoticed. For example, when a man walks his dog on a clear day in spring, the animal may pant abnormally and otherwise appear to be suffering from heat, even though the air feels cool and dry to the man. A look at a thermometer might reveal a temperature of about 70 degrees Fahrenheit at the level of the man's eyes.

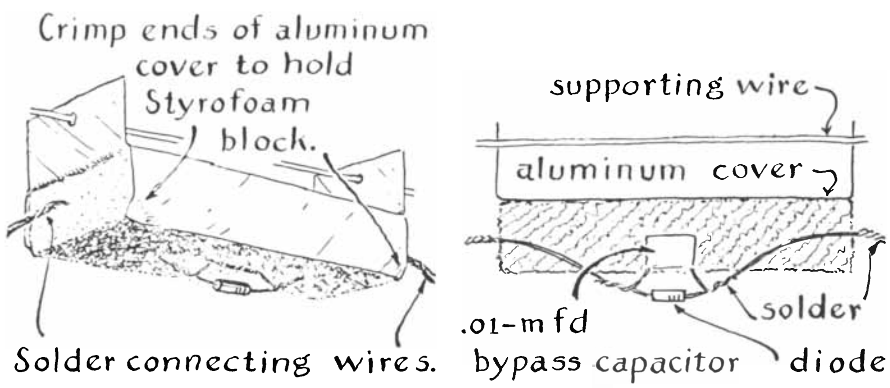
The explanation of the dog's discomfort becomes apparent if one stretches out on the grass. The ground will feel hot and moist, as will the air. The temperature near the surface may be in the 90's and the relative humidity close to 100 percent.

Two areas no more than a few hundred feet apart can exhibit wholly different climatic conditions, depending on the local soil, wind and sunlight and such factors as surface evaporation and transpiration by plants. Factors that influence climate near the surface are of concern to truck farmers, gardeners and viniculturalists, and to those interested in soil conditioning, flood control and erosion control.

Until about 25 years ago no data were available on the small-scale aspects of climate, nor had instruments been developed for measuring the several variables. Since then the new discipline of micrometeorology has evolved rapidly; it now has many specialists, including a number of enthusiastic amateurs. One of the latter is Douglas A. Kohl, an engineer



Circuitry of the electronic thermometer designed by Douglas A. Kohl



Arrangement of the germanium-diode mountings

with Litton Industries in Minneapolis, Minn.

Recently Kohl has been investigating the effect of sunlight on air at low altitude. Everyone feels quick fluctuations in the temperature of the air from time to time, often several a minute. Usually the effect is dismissed as being caused by puffs of hot and cold air, even in the absence of a breeze. Kohl has developed a novel electronic thermometer, capable of rapid response, for investigating the nature of the fluctuations. He writes:

"Weather is powered by sunlight. On the average the earth intercepts the equivalent of about 1,400 watts of solar energy per square meter per minute. That energy is usually expressed as the 'solar constant.' It amounts to 1.95 calories per square centimeter per minute.

"A portion of this vast inpouring of energy heats the earth's surface, which in turn warms the air and so gives rise to the large-scale aspects of weather. Another portion heats the air directly. The extent of the heating in any 'domain,' or particular volume of air, is largely determined by the amount of dust and vapor held in suspension. The density of the suspended substances tends to vary. As a result the air is warmed unevenly in small volumes.

"The presence of these domains can be detected and their size determined by means of a sensitive thermometer. As air in the first few feet of the atmosphere drifts past the sensing element of the instrument the pointer fluctuates constantly in response to 'temperature noise.' At my geographical location the daytime fluctuation ranges from a maximum of about one degree F. in bright winter sunlight to 10 degrees in June. Rates of temperature change amounting to more than two degrees per second have been recorded.

"The sensing element of the instrument consists of a string of germanium diodes connected in series. The electrical resistance of the string varies inversely with temperature. The assembly constitutes one of the four arms of a Wheatstone bridge. A galvanometer connected across the bridge circuit is calibrated to indicate the average temperature of the diodes as the bridge loses balance; the galvanometer thus functions as a conventional thermometer. The voltage that develops across the diodes is also applied to the input terminals of a transistor amplifier. A galvanometer connected to the output terminals of the amplifier measures temperature 'noise' (dT), or transient changes in temperature.

"I selected germanium diodes for sensing temperature. Types 1N272, 1N276 and 1N995 are satisfactory. Germanium diodes are relatively inexpensive; they are also rugged and sealed against weather. Their response time to changes in temperature tends to vary somewhat with type but is measured in seconds. I made up two strings of differing configuration. One consisted of 13 diodes strung five feet apart on a wire 75 feet long for sensing temperature in a straight line. The second unit was assembled as a cluster of 13 diodes in a three-inch square that approximates a 'point' sensor. The potential that develops across the diodes varies in direct proportion to the temperature. From −11 to 100 degrees F. the potential decreases one volt; the change can be measured accurately by an inexpensive meter without amplification [*see illustration on preceding page*].

"Power for the instrument is drawn from a conventional 115-volt, 60-cycle line through a filament transformer. The output of the transformer is converted to direct current by a diode, and the potential of the filtered output is held constant by a pair of voltage-regulating Zener diodes connected in tandem. The output current is then split into two paths: the string of diodes and a series of six fixed resistors that function as a voltage divider. Taps connected between five of the resistors connect sequentially to the galvanometer through a rotary switch. The arrangement enables the operator to observe any one of four temperature ranges between −32 and 101 degrees F.

"Current through the sensing diodes is limited by a fixed resistor of 10,000 ohms [*"10 K" in illustration on preceding page*]; the resistor passes a constant current of 1.7 milliamperes. A current of 25 millionths of an ampere drives the pointer of the galvanometer to full scale. Because current drawn by the meter is small compared with the current of the diodes, the accuracy of the instrument is not impaired by including the meter in this portion of the circuit. The circuit could have been designed so that the full range of temperature from −32 to 101 degrees would have been covered by the three-inch scale of the meter.

"The insertion of the range switch increases the effective length of the scale to 12 inches and, at minor cost in terms of operating convenience, proportionately increases the accuracy with which observations can be made. Fixed resistors of the type guaranteed to be within 1 percent of the rated value were used in the construction not because this accuracy is required but because resistors of this quality have good stability—they are less likely to change with age. Although the circuit is not critical with respect to the value of the components, the range of temperature indications depends directly on the values of the 220-ohm and 15,000-ohm resistors.

"A .01-microfarad capacitor is connected across each of the temperature-sensing diodes to protect the diodes against surges of current that may be induced in the circuit by strokes of lightning. For the same reason a good electrical connection must be made between the G terminal and the ground. The diodes are mounted under a supporting block of Styrofoam that in turn is supported by a shiny cover of light-gauge sheet aluminum. The end tabs of the aluminum are folded up and perforated to pass the suspension wire on which the units are strung. The Styrofoam block hangs below the wire, thus protecting the diodes from direct sunlight and weather.

"The ceramic bypass capacitor is pushed into a knife slit in the foam and held in place by a dab of casein cement. The leads of the capacitor are soldered to the leads of the diode and pushed

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through the Styrofoam block [*see illustration on page 136*]. In the case of the point sensor a single protective capacitor can be connected across all 13 diodes. When solder connections are made, the leads to the diodes should be gripped between the jaws of a pair of pliers that will act as a heat sink and so protect the diode from a damaging rise in temperature.

"A single-stage amplifier is used to couple the changing diode voltage that is developed across the terminals *M* and *G* to the galvanometer or to a pen recorder. Changes in voltage across these terminals are coupled to the 2N338 silicon transistor through the 2,000-microfarad capacitor [*see illustration below*]. The amplifier accordingly responds only to alternating current and therefore only to changes in temperature (dT), not to steady-state values of average temperature.

"After the apparatus has been constructed the base current of the transistor must be adjusted (with the input leads disconnected) by altering the setting of the 10,000-ohm potentiometer until the meter or recorder, which is connected to the output, indicates a deflection of approximately half scale. This position of the pointer or recording stylus represents the zero position of the scale. Changes in temperature are represented by excursions above and below this zero position. The 1N457 silicon diode connected in series with the potentiometer provides temperature compensation for the transistor. The two remaining diodes protect the output meter from damage by excessive voltage. The pointer or pen of the output meter will move away from the zero position when the amplifier is connected initially to the *M* and *G* terminals but will return within about 30 minutes when the circuit operation has stabilized.

"Some current may leak through the 2,000-microfarad capacitor. If so, a small change in bias may be needed to restore the zero position of the output meter after the circuit has stabilized. Make the change by adjusting the potentiometer without disconnecting the input leads of the amplifier. An occasional 2,000-microfarad capacitor may conduct an abnormally large current. In this case insert a three-volt battery in series with the input lead that connects to the *M* terminal. After the battery has been inserted adjust the bias to restore the zero setting of the output meter.

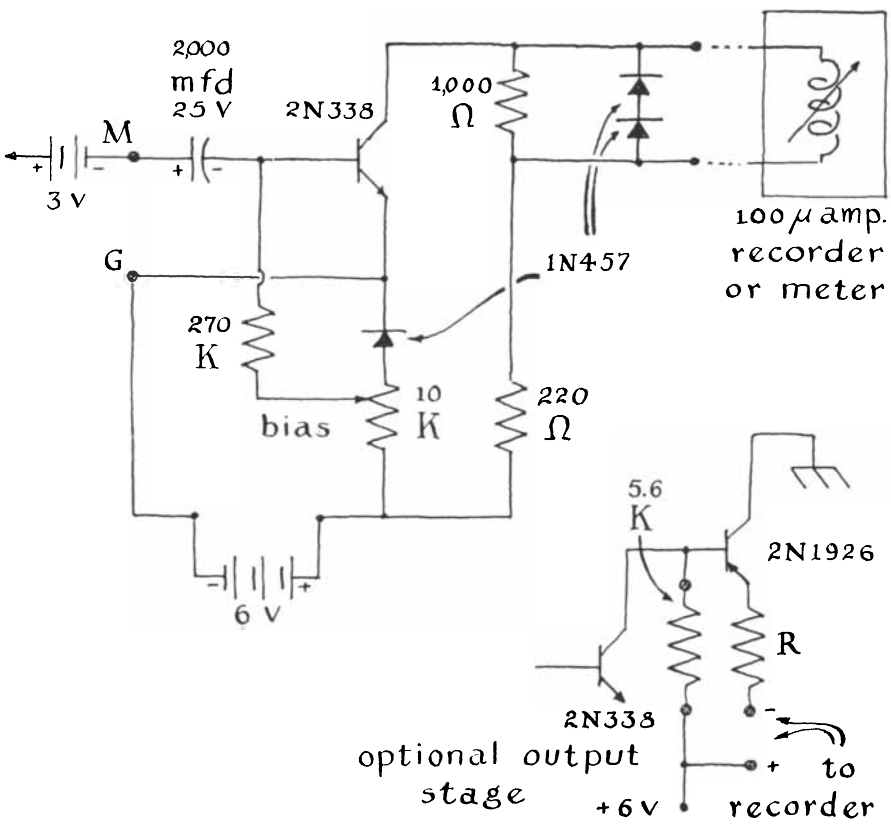
"To calibrate the instrument connect the point sensor, set the range switch to the range between 30 and 74 degrees and measure the room temperature with a conventional mercury thermometer. Observe the meter indication and the temperature. Make a note of the two readings. Then place the point sensor and the thermometer in an environment of a different temperature, such as a kitchen refrigerator, and similarly list the corresponding readings.

"I learned by experiment that the system is linear: the meter indications vary in direct proportion to the temperature. For this reason the measurement of only two temperatures is enough to plot a graph that relates temperature to the meter indications. Repeat the calibration procedure for each of the remaining three ranges. The freezing compartment of the refrigerator can be used to provide the lowest temperature and the kitchen oven the highest.

"With the electronic thermometer calibrated it is easy to calibrate the output meter of the amplifier. Connect a 100,000-ohm rheostat across the *M* and *G* terminals. By turning the knob of the rheostat quickly it is possible to change the voltage across the *M* and *G* terminals sufficiently to cause the pointer of the previously calibrated meter to move a distance equivalent to a temperature change of one degree. The recorder stylus or meter connected to the output of the amplifier will then also move the equivalent of one degree. Record this indication.

"Repeat the procedure, turning the potentiometer enough to cause a deflection of five degrees. Record the result and plot the calibration graph. The value of the 1,000-ohm resistor that is connected across the output terminals of the amplifier (to which the meter connects) may be increased or decreased to a value that causes the stylus or pointer to swing full scale for a desired temperature excursion, such as exactly five degrees or 10 degrees.

"The pen recorder I use swings full scale on a current of 100 microamperes, which occurs when the drop in voltage across the 1,000-ohm resistor is .5 volt. If one removes or changes the 1,000-ohm resistor, the unit will drive any inexpensive recorder, such as the Amprobe instrument with a range of from zero to one milliampere. (This recorder is made by the Amprobe Instrument Corporation, 630 Merrick Road, Lynbrook, N.Y. 11563.) The output current can be increased still more by adding a stage of amplification, such as the one shown at the lower right in the accompanying illustration [*left*]. The value of *R* in the illustration establishes the output current and is determined experimentally to produce the desired deflection of the recording pen. One can make the value of *R* as low as 680 ohms. At this value the



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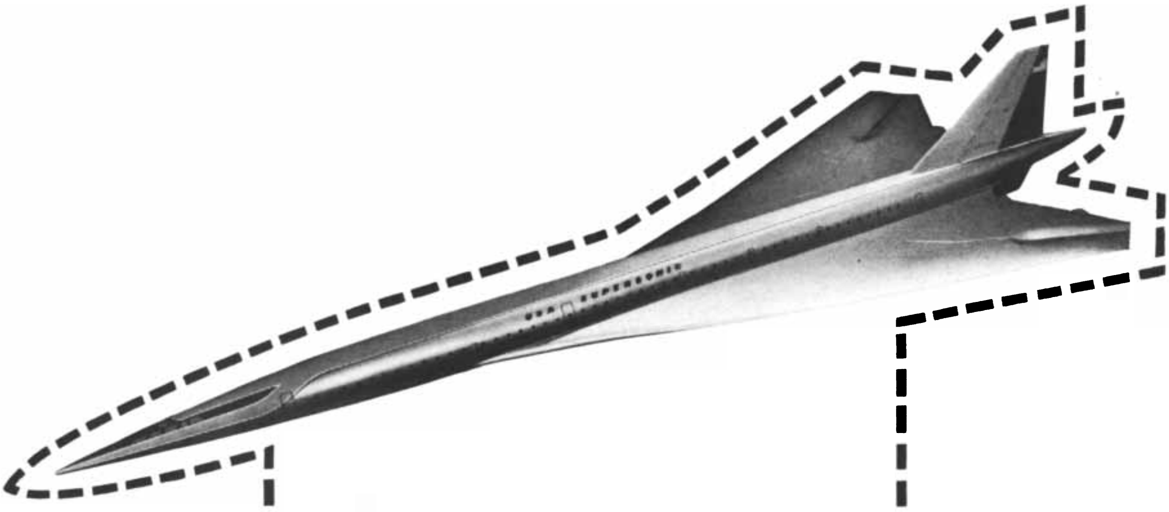

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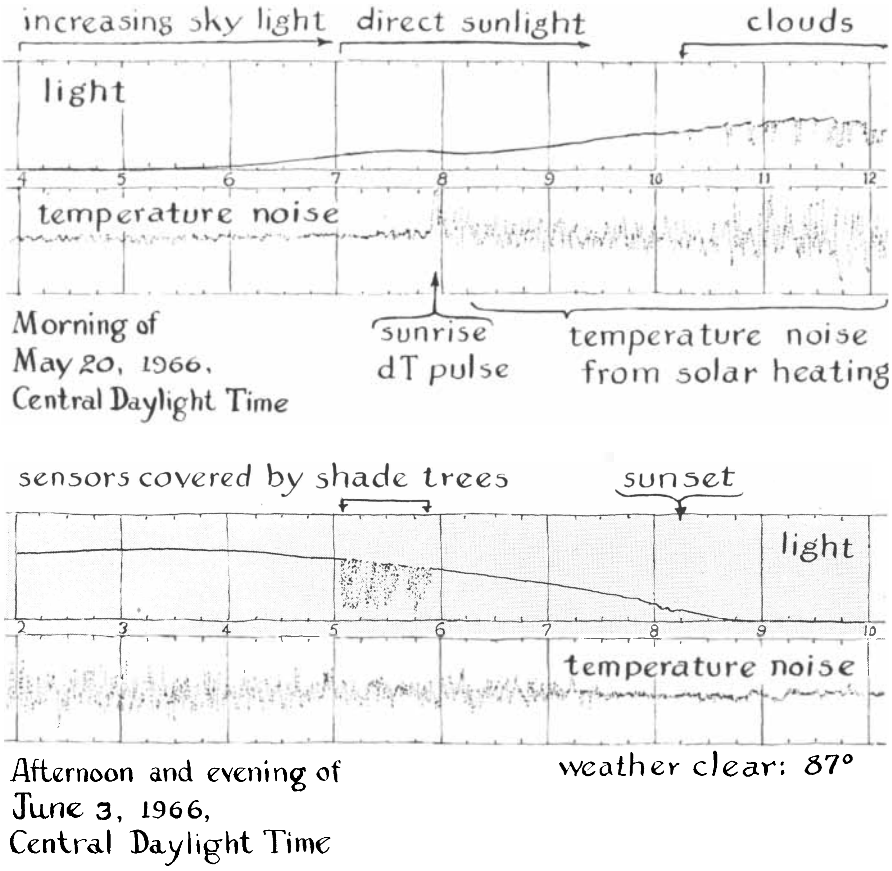


Graphs of light and temperature recorded by the thermometer

output current would be 10 milliamperes.

"The thermometer and the recorder can be used with either the line array or the cluster of diodes without change in calibration if all diodes are bought at the same time from a single supplier. The line sensor provides a more accurate measure of average steady-state temperature than the point cluster does because the sensor averages temperature over a much larger volume of air.

"Simultaneous recordings were made of both temperature and sunlight. Sunlight was picked up by a photocell that actuated a second recording stylus. In the accompanying illustration [*above*] the photocell trace appears at the top and the trace of the temperature noise below. The overall dependence of temperature noise on the intensity of sunlight is evident in each day's recordings. This observation suggests that direct sunlight must reach the lower atmosphere to produce heating. Although the illumination of the sky increases considerably before sunrise, the temperature noise does not appear until the sun rises several degrees above the horizon. Frequently the sunrise effect generates one of the largest temperature excursions of the day.

"Analysis of the continuous recordings made during the four seasons last year led to several generalizations about temperature noise. The amplitude of the temperature noise increases as the sun climbs toward its zenith and usually reaches a maximum about an hour after noon. As I indicated earlier, at Minneapolis the maximums range from one degree in December to about 10 degrees in June.

"The movements of cirrus-cloud layers indicate that temperature noise varies in direct proportion to sunlight. When sunrise is obscured by high overcast, the noise is absent. The fluctuations tend to follow long-term changes in general illumination. Apparently the intensity of direct solar radiation must reach some threshold in the lower atmosphere before domains of heated air appear.

"The suppression of temperature noise becomes most apparent when cumulus-cloud shadows drift in to cover the sensors. Within seconds of the arrival of the shadow the noise level begins to fall. Conversely, it increases to its former level promptly when the shadow passes and the sunlight reappears. This finding suggests that heat is rapidly dissipated by the domains and—a more significant fact—that the domains are heated directly by solar radiation and not by contact with the ground. In order to check this conclusion I placed the sensors in local shadow by erecting cardboard shields five feet above the germanium diodes. The shadows had no effect on the recorded amplitude of the temperature noise.

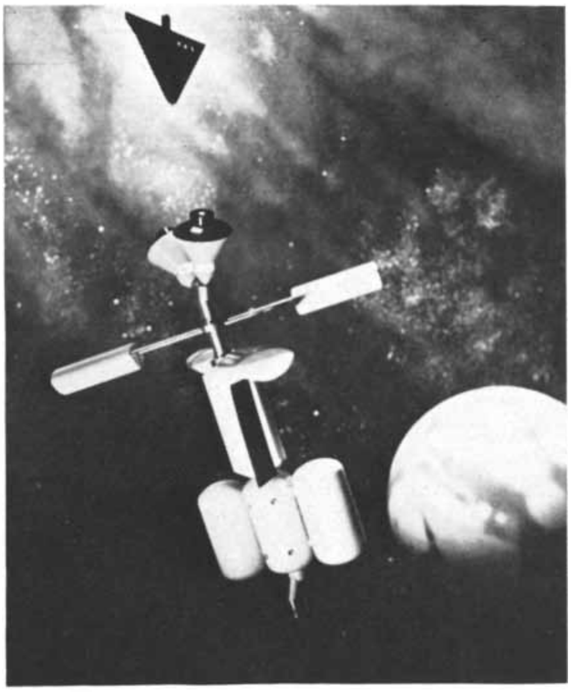
"The largest amplitudes of temperature noise I have recorded came on summer days when vigorous cumulus-cloud activity was observed and when numerous cloud shadows swept across the area. Even on days of fair weather and bright sunshine, however, the differences in the amplitude of temperature noise were as much as threefold. None of the conventional meteorological data—such as average temperature, relative humidity, barometric pressure and so on—changed comparably.

"Some temperature noise is present at all hours, although the amplitude is much greater during daylight. Average temperatures ranged from −26 to 97 degrees F. during the year, but the noise amplitudes were independent of average temperature and dependent on the intensity of sunlight. Temperature noise is also present at all wind velocities. The size of the domains is largest on windy days. The amplitude of temperature excursions during days of near calm approached those observed on windy days, but on calm days the period of the fluctuations increased to more than 10 minutes in contrast to normal periods of about 30 seconds.

"The minimum temperature noise was observed during each of several fogs. Peak-to-peak recordings of less than .05 degree F. for a continuous period of three hours were made during one fog even though the velocity of the wind reached 10 miles per hour. Rain, snow, blizzards and blowing snow under heavy overcasts produce very little temperature noise. Although thunderstorms produce large fluctuations in the average temperature, they generate little temperature noise.

"An important continuing area of study is the correlation of temperature noise and the density of dust in the atmosphere. Nighttime periods of comparatively intense noise occurred when dust clouds of low altitude were visible in a searchlight. This observation suggests that differences in daytime heating may depend on the density of matter suspended in the atmosphere.

"The size of the heated domains was estimated by multiplying the period between temperature minimums by the average wind velocity at the time of observation. They averaged about 300 feet



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GENERAL DYNAMICS

Fort Worth Division

in diameter. The longest measured one mile. The size appears to vary inversely with the noise."

The problem of providing a truly stable mounting for a telescope has long preoccupied amateur astronomers. Among many designs is one recently made by Edwin Snead of Houston, Tex. He claims for his mounting the virtues of rock-solid stability, economy and ease of construction. Snead writes:

"For a long time I have wondered why amateur astronomers invest so much time and effort in precision optics only to have the quality of these optics largely wasted by an unsteady mounting. The best tripod mounts I have seen required completely 'hands off' viewing. Focusing in particular seems to be a trial-and-error process, because the vibration induced by moving the eyepiece makes for a blurry image that persists for some time after the hands are removed.

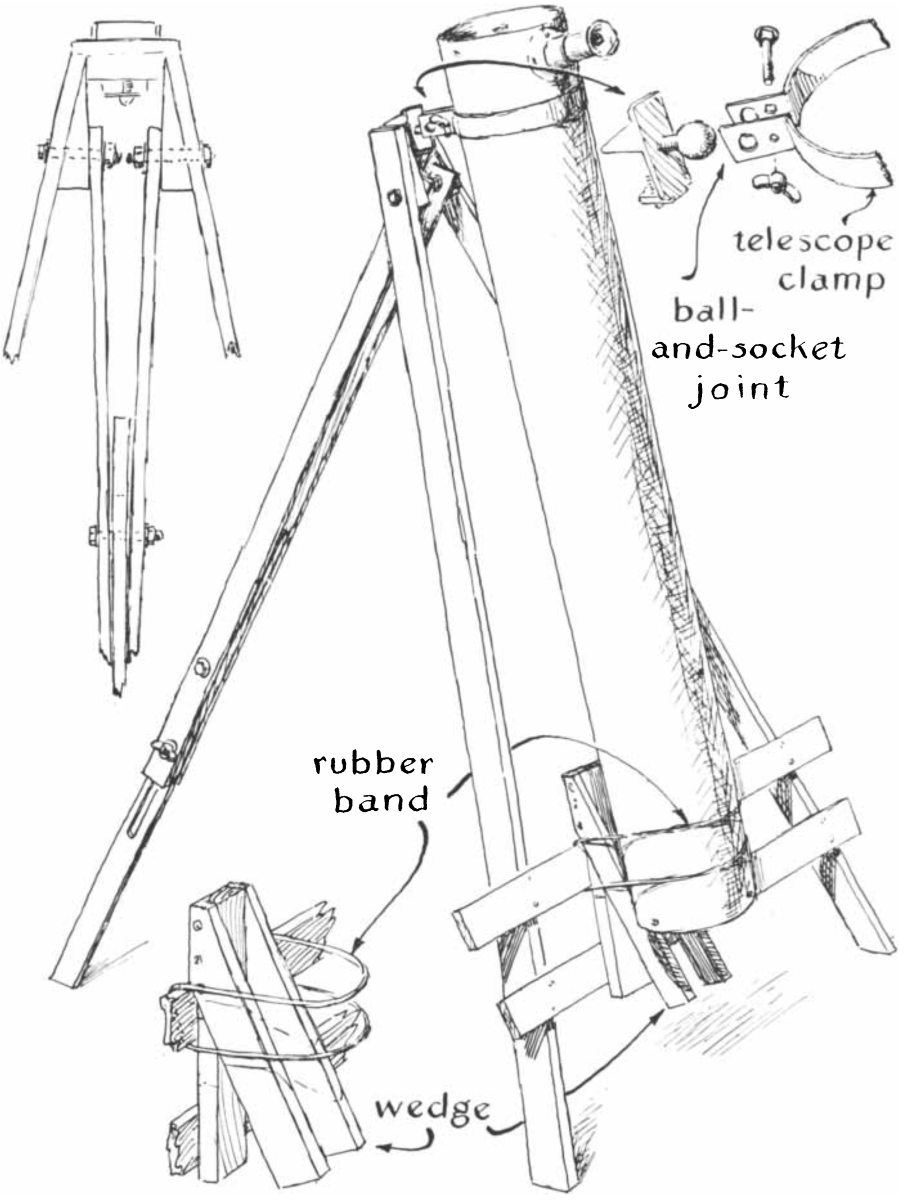
"Generally the observer will be standing or sitting in some rather awkward position, so that it is difficult for him to keep his eye precisely aligned with the eyepiece without actually touching it. When he does touch it, the field erupts into a smear, and he must back off and approach cautiously again. All this 'micromaneuvering' had a tendency to give me a stiff neck and to reduce the pleasure I got from the telescope, so I started looking for a better kind of portable mounting.

"One day I was watching a war story on television and was struck by the fact that a mortar has almost exactly the mounting system I was looking for. I couldn't find any old mortars in the local war surplus stores, but while I was still looking for one I happened to be in Boston and to visit the U.S.S. *Constitution*. I was particularly interested in the guns. Each gun was mounted in a wooden carriage with the stair-step sides I had seen before but never understood. On the *Constitution* their purpose is clear, because each gun position has two crowbars and a wooden wedge handy. To adjust the elevation the gunners placed the crowbars under the breech of the gun and then, using the wooden carriage sides for a fulcrum, they levered the gun into the correct position and slipped the wooden wedge under the breech to hold it. So my search for the ideal portable telescope mount ended with an idea from a 180-year-old piece of naval equipment.

"For $10 I bought a three-inch reflecting telescope made by a well-known toy manufacturer. This telescope came with a ball-joint mounting that was intended to be attached to the back of a chair or to a stepladder. I next collected some 1½-inch-by-⅜-inch wood lath, some ¾-inch-by-1½-inch molding, some ¼-inch bolts and a few wood screws, and went to work in the middle of the living room. All the necessary tools were in a small box I keep around the house for hanging pictures and repairing door latches.

"The two-directional wedge design gave me a good bit of trouble, so I decided to go ahead with the elevation wedge and work out the azimuth wedge later. In order to test the elevation wedge, I built a flat area at the bottom of the tripod for the wedge to rest on while it supported the lower end of the telescope [*see illustration at left*]. Then, to hold the telescope tight against the wedge and to keep the wedge from falling out, I stretched a rubber band over the bottom of the telescope. The elevation wedge worked perfectly. I could adjust the entire tripod enough (by lengthening or shortening the single front leg or by moving it forward or backward) so that the target could be brought into the field by adjustment of the elevation wedge.

"Then, as I moved the elevation wedge right and left, trying to figure out how to build an adjustable slot for it to travel in, I realized that I was having no trouble getting the wedge to remain where I had left it anywhere in an arc of two inches right or left. The rubber band caused sufficient friction to hold the wedge in place but stretched enough to allow plenty of lateral movement for fine adjustment. Before I had even tackled the difficult part of the job the design was complete."



Edwin Snead's telescope mounting

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MARTIN MARIETTA

BOOKS

The life of Niels Bohr, mostly through the eyes of his friends

by O. R. Frisch

NIELS BOHR: HIS LIFE AND WORK AS SEEN BY HIS FRIENDS AND COLLEAGUES. Edited by S. Rozental. North-Holland Publishing Company and John Wiley & Sons, Inc. ($9).

NIELS BOHR: THE MAN, HIS SCIENCE, AND THE WORLD THEY CHANGED, by Ruth Moore. Alfred A. Knopf, Inc. ($6.95).

No physicist of this century, with the possible exception of Einstein, has so strongly influenced our thinking as Niels Bohr. This influence is not limited to physics; Bohr was really a philosopher who had chosen physics as his base but whose interests were much wider. Unlike most philosophers, he never wrote a book (although several collections of papers and essays have been published in book form). His influence made itself felt mainly through personal contact: in the privacy of his study, in seminars at the Institute for Theoretical Physics he had created—making Copenhagen a Mecca for physicists from all over the world—and at the great international conferences. With his heavy build and hairy hands he looked like a peasant; he had a large head with bushy eyebrows, and the eyes held one with all the power of the mind behind them until a sudden smile appeared to turn the argument into a joke. He spoke softly, and the salient point sometimes got lost when for emphasis he dropped his voice to a whisper. As we crowded around after dinner at his house—some sitting on the floor at his feet to hear him better—we felt that here was Socrates returned to life, teasing us with joking paradoxes, helping us to sharpen our arguments, leading us gently to higher understanding.

The plan to write a collective book about Bohr was discussed among his friends in Denmark for several years but was not carried forward until after his death in 1962. The collection appeared in 1964 in Danish, although many of the chapters had originally been written in English. The present English edition, apart from minor details, is identical with the original Danish one. The contributors include not only the Nobel prizewinners P. A. M. Dirac and Werner Heisenberg and a dozen other distinguished physicists and mathematicians but also politicians and painters. Two of Bohr's sons have written chapters of a more intimate character, and there is an introductory chapter on Bohr's ancestry and childhood. The other contributors each write about a different aspect or period of Bohr's life. It all adds up to a fascinating composite picture, enlivened by 60 well-chosen photographs. Although a good deal of physics comes in, there is nothing too difficult for a reader of *Scientific American*.

In contrast Ruth Moore has written a coherent narrative that reads almost like a novel. Much of her book is based on the collective volume, from which she quotes liberally (with due credit). She has done a thorough job of biographical research, but she is not a physicist, and the atmosphere of scientific advance is not well rendered. There is a tendency to overdramatize things, and the explanation of physical matters is mostly vague and often incorrect. Still, Bohr's human qualities are well and lovingly presented; the romantic reader will enjoy knowing about Bohr's struggles with his conscience in wartime, his dramatic flight to America via Sweden and England, and his heroic but, alas, unavailing attempts after the war to stop the atomic arms race.

To the layman Bohr is known mostly for his model of the hydrogen atom, published in 1913. At that time the idea seemed outrageous that electrons, in going around the nucleus, should be confined to specified circular orbits and allowed to jump from one orbit to another only when absorbing or emitting light. The proposal was so out of tune with the long-established laws of classical physics that even some very intelligent physicists said they would rather give up physics than admit such an arbitrary hypothesis. And yet with Bohr's model so many facts fell into place that one had to take it seriously.

Bohr himself was fully aware of the crudeness of his model. It no more resembled the atom than a pencil sketch resembles a living human face, but he had to take the first step in applying Max Planck's quantum law to the structure of atoms. As early as 1899 Planck had been led to assume that electromagnetic radiation could be emitted and absorbed only in certain quanta of energy; he thought that this limitation affected merely the interaction of radiation and matter, and that it would eventually be fitted into the framework of classical physics. Nobody paid much attention until Einstein in 1905 showed that Planck's quanta were much more real: they had momentum as well as energy and indeed behaved like particles (which came to be called photons). Later Einstein showed that by applying Planck's rule to the sound waves in solid bodies one could account for the puzzling change in their specific heat at low temperatures.

The discovery of the atomic nucleus by Ernest Rutherford in 1911 presented the decisive challenge. If the laws of classical physics were right, the electrons in the atom would circle the nucleus, but if they were *exactly* right such a system would be unstable. A few physicists saw that Planck's rule had to be invoked to account for the obvious stability of atoms, and that some elements of classical physics would have to be given up, but where to start? Here Bohr for the first time showed his unique combination of qualities: the courage to give up any assumption, however firmly it might have been held; a clarity of mind that revealed to him the logical consequences of any step he might take; an almost intuitive feeling for the best way to proceed, and relentless tenacity in working it all out.

Bohr was then a modest young man, delighted at having just met such scientific giants as Rutherford and J. J. Thomson. This stage of his life is charmingly depicted in a chapter by Léon Rosenfeld and Erik Rüdinger, with many quotations from Bohr's letters to his fiancée and to his younger brother Harald, already known as a brilliant mathematician. But Bohr had firm views about the presentation of his ideas, and when Rutherford wanted him to shorten his paper, he fought for every word and convinced the great man that the argument was so closely knit that nothing could be left out without destroying its unity and logical coherence. In later years Bohr would rewrite every paper many times, disregarding deadlines, until he was satisfied with its logical completeness and consistency. He was trying to forestall any possible misunderstanding, but the resulting style did not make understanding easy.

Today Bohr's model of the hydrogen atom is a part of the history of science, barely mentioned in the teaching of atomic physics. We still speak of electron "orbits" but in a purely metaphorical way; our present description of an atom uses concepts, such as wave functions, that had not been thought of in 1913. Indeed, it is misleading to speak of a description at all; the term implies that there is something to describe, some reality that our words are trying to define. Bohr liked to stress that "reality" is itself a word. What we try in science—so Bohr insisted—is to evolve a way of speaking unambiguously about our experiences. How far the word "reality" is suitable for that purpose is in itself a question to be decided in the light of experience.

This may sound like an attitude of cold-blooded pragmatism, the kind of attitude an engineer might adopt when he uses terms such as "yield strength," "hardness" and "fatigue" to describe a particular steel. For him the steel is adequately described by those qualities; given their numerical values he can confidently design a structure. He need not know how the atoms in the steel are arranged, or the electrons within them.

That was by no means Bohr's attitude. He was not looking for a minimum of description, sufficient for the job in hand; he was looking for the most detailed description that the nature of a physical system would permit. It had been implicitly assumed that the state of a system could be observed in arbitrarily fine detail, that the position and velocity of any of its parts could be known as accurately as one desired. Of course any observation meant some interaction with the system; for instance, to see a particle one had to shine light on it. But the pressure exerted by a beam of light was usually so weak as not to matter, and moreover the light could in principle be made as weak as one might wish.

In quantum theory this was no longer so. For a particle to be observed at least one photon had to be reflected from it, and that would unavoidably change the particle's velocity by a finite amount. The amount could be reduced by using light of longer wavelength, the quanta of which have less momentum. But such light, as designers of microscopes are well aware, gives less accuracy in observing the position of the particle.

It was this kind of argument that Heisenberg used in developing his famous uncertainty relation. He was led to the relation, however, from quite a different direction. In his chapter in the Bohr volume (called "Quantum Theory and Its Interpretation") he describes in his own quiet way how as a 20-year-old student he met Bohr in Göttingen and was invited to work in Copenhagen for a while, and how there his love for elegant mathematical structures and his skill in creating them were met by Bohr's insistence on physical insight. As he puts it, "I noticed that mathematical clarity had in itself no virtue for Bohr. He feared that the formal mathematical structure would obscure the physical core of the problem, and in any case, he was convinced that a complete physical explanation should ... precede the mathematical formulation." The uncertainty relation was implicit in Heisenberg's mathematics, but it was Bohr's insistence on physical insight that caused Heisenberg to state explicitly that one could not know both the position and the momentum of a particle so well that the product of the two uncertainties was smaller than Planck's constant, and to derive that result from a physical argument. This is one example of how Bohr influenced the development of physics—in an atmosphere of unremitting argument during long country walks in the woods near Copenhagen, during sailing trips on the rough Kattegat and in the attic of the institute till late at night.

By 1929 the theory of quantum mechanics had been given the form we now know, but the struggle for its interpretation went on well into the 1930's. During that time Bohr worked mainly with Rosenfeld, who was perhaps his most perceptive disciple. It was Rosenfeld who most completely absorbed Bohr's philosophy. He was endowed, moreover, with a "photographic" ear, so that the reader can almost hear Bohr's voice whenever Rosenfeld quotes his spoken words in the book. Rosenfeld describes the significant role Einstein played in Bohr's life. Bohr admired Einstein tremendously and was forever distressed that Einstein would not accept his views on quantum theory; his wish to convince Einstein was a particularly important stimulus to him.

The argument was mainly about the meaning of Heisenberg's uncertainty relation. If we have measured the momentum of a particle with great accuracy, its position will then be uncertain by an appreciable amount. Does that mean the position is "fuzzy" in some way, or does the particle have a sharply defined position we merely do not know? Einstein favored the second view; for several years he tried to break down Heisenberg's argument, to find a method by which—in principle—one could accurately measure momentum and position at once. Bohr always found the flaw in Einstein's proposed method, and Einstein always admitted it but remained unconvinced at heart.

One feature of the quantum theory that Einstein particularly disliked was that it was not deterministic: it did not predict the behavior of a given system but only the probability that it would behave in one of several ways. Probability had always been considered the child of ignorance; if we knew exactly how a die had been thrown, we could predict how it would fall, and only our ignorance compelled us to speak of the probability of a particular outcome. But according to quantum mechanics there was no possibility whatever of predicting, for instance, when a given radioactive atom would decay, or which of several wavelengths of light would be emitted by an excited atom.

Einstein thought he could see the reason: with the formalism of quantum mechanics one was trying to make predictions on the basis of incomplete data. He did not believe that the future was indeterminate; "God does not play dice with the world," he said. Bohr, on the other hand, stressed that in the nature of things it was impossible to obtain more complete data. Therefore nothing better than probabilities could be obtained from any conceivable theory.

In 1935 Einstein (with Boris Podolski and Nathan Rosen) published a paper he thought would decide the issue. He showed that one can in principle make an observation in such a way that one can wait until the particle is far away before deciding whether one wants to know its position or its momentum. It is still not possible to obtain both (with an accuracy exceeding Heisenberg's relation), but if one can obtain either momentum or position accurately without interfering with the particle, then surely, Einstein argued, the particle must have well-defined values of both momentum and position. Hence, he concluded, quantum mechanics does not completely describe the particle.

Bohr did not accept Einstein's conclusion. To him a physical attribute such as position or momentum was meaningful only insofar as it could be observed in a given experimental arrangement. You could choose whether you wished to observe accurately the position of a particle or its momentum, but in making that choice you had to choose a particular experimental arrangement, and that unavoidably cut you off from measuring the other quantity. This holds whether you make the decision before the interaction of the particle with the measuring instrument or later, as in the ideal experiment described by Einstein, Podolski and Rosen.

I should mention that in subsequent years attempts were made to introduce "hidden variables" that would go beyond the description offered by quantum mechanics and remove its fuzziness and indeterminacy. This, however, brought fresh difficulties, in particular the need to assume instant interaction between things a long way apart. Such assumptions are even less acceptable than those features of quantum mechanics they were meant to clarify.

To Bohr that relation of mutual exclusiveness between two observations (as of position and momentum) was important enough to deserve a special name, and he coined the word "complementarity." There were other pairs of such complementary attributes, for instance time and energy. The disturbing wave-particle duality—that a stream of particles also had the properties of a train of waves—was likewise seen as two complementary aspects of the same thing. The concept of complementarity became a cornerstone in Bohr's thinking, and not only in physics. For example, justice and mercy are in a similar complementary relation: either one becomes irrelevant when we consider a human problem entirely in the light of the other, yet both are needed for a complete view of the problem. One of Bohr's pupils suggested that truth and clarity were complementary attributes of a piece of writing. That may have been mischievous comment on Bohr's style, but anyone who writes about a difficult topic knows how one has to simplify matters and slur over some aspects of truth in order to achieve a modicum of clarity. Bohr himself enjoyed making fun of his ideas. ("These things are so serious you can only joke about them.") Once, while having an unusually fine meal, he commented that the calorie, useful though it was in measuring the nutritive value of food, was irrelevant to the food's culinary value; a new unit, the culinar, ought to be created, complementary to the calorie. Unfortunately this theory was not developed further.

In 1913 Bohr had laid the foundation of our understanding of the atomic electrons; in 1936 he did the same for the atomic nucleus. Whereas the electrons circle the nucleus, paying scant attention to one another, the conditions inside the nucleus are just the opposite. The nucleus is a jostling crowd of protons and neutrons in which any newcomer—a proton or neutron striking the nucleus—is swallowed up in the general commotion, forming what Bohr called a compound nucleus. It was typical of Bohr's courage that he tackled such a complex problem, which appeared far too difficult to treat by the methods of quantum mechanics, and of his deep insight that he should have succeeded; the compound nucleus has become the key to our understanding of nuclear reactions and in particular of nuclear fission. I had the good luck to be there when Bohr conceived the idea and worked it out, to be in on some experiments whose outcome gave clear support to it, and later to be asked to contribute a chapter to this book, describing that exciting period.

The German occupation of Denmark (1941–1945) created many difficult problems for Bohr and his institute. Stefan Rozental (who is also the editor of the book) vividly describes this period when for a long time Bohr succeeded in keeping the work going, even if "events made dramatic claims on time, strength and nerves." But in 1943 Bohr and his family had to flee to the safety of Sweden, crossing the Ore Sound in small boats at night. From there Bohr and his son Aage (now his successor in Copenhagen) were flown to England in Mosquito bombers. Later they went to the U.S., where they took an active part in the final stages of the construction of the atomic bomb. Bohr felt he had to do that, in view of the war situation, but even then he devoted much thought to the problem of how humanity could be prevented from destroying itself with such an appalling weapon in existence.

A tragic part of Bohr's life was his losing battle with the politicians, whom he tried to warn against the dangers of an atomic arms race. For that battle he was not well equipped; his habit of slow and patient argument exasperated the men whose habit of quick and bold decision had placed them where they were. Finally he appealed to the United Nations with an open letter, which is reprinted at the end of the book. I wonder how many people at the UN have had the patience and the concentration to read this closely reasoned argument for an open world.

There were many other aspects of Bohr. In his young days he was known as an excellent football player (although not quite as good as his brother Harald, who won a silver medal with the Danish team in the 1908 Olympic games). He was a vigorous swimmer, a yachtsman and a skier almost to the end of his life; he could fell trees and fix bicycles. He took an intense and sensitive interest in poetry and painting; two friends who were painters testify to his deep understanding. Above all he was a faithful friend, whose transparent goodness and imaginative kindness made many people feel what Lise Meitner once said: "It is good to live in a world where there are men like Niels Bohr."

Short Reviews

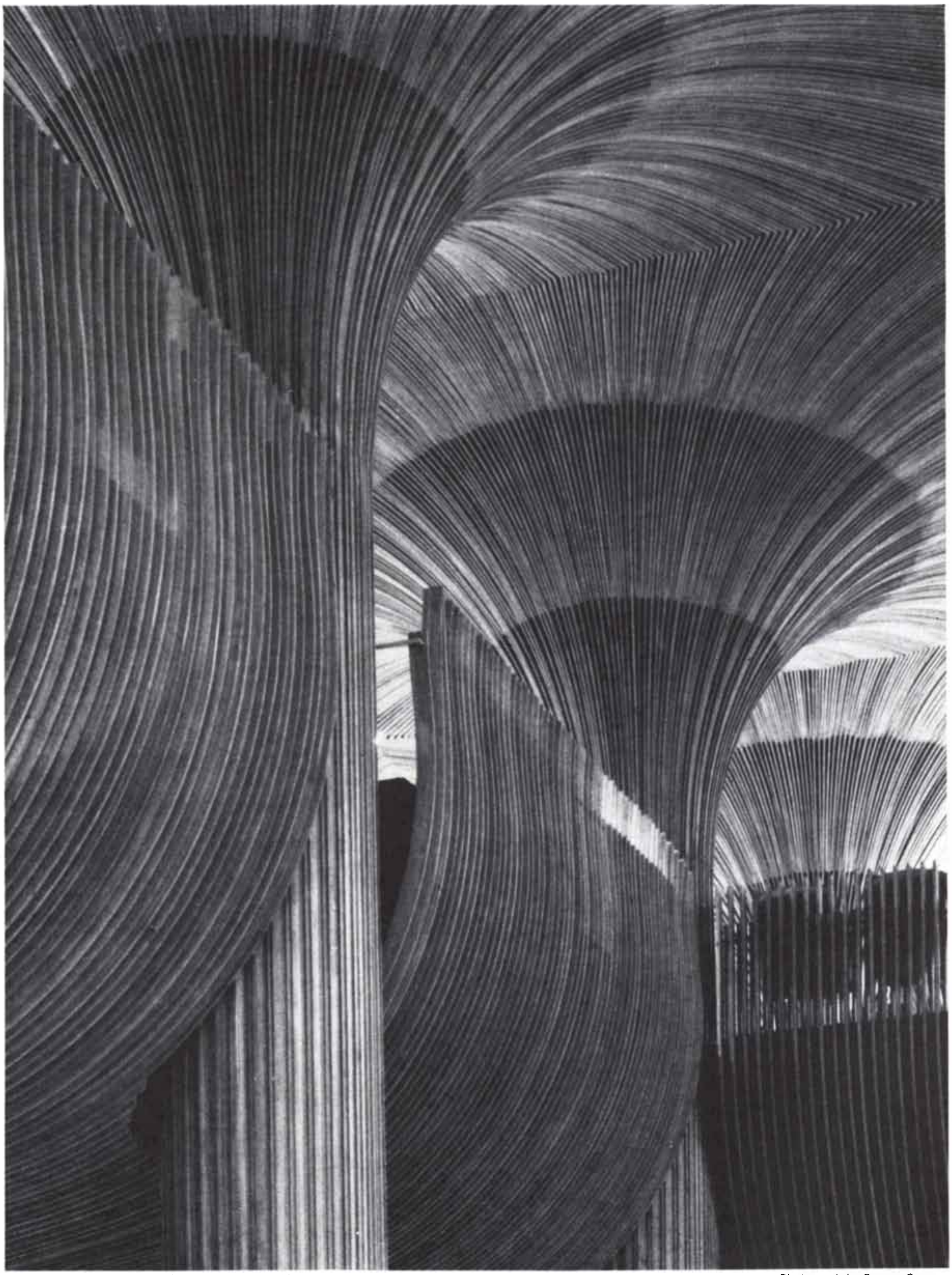
Urban Atlas: 20 American Cities, by Joseph H. Passonneau and Richard Saul Wurman. The M.I.T. Press ($100). Twelve pounds of loose-leaf maps on fine heavy stock, this study collects selected data for 20 cities on the excellent base maps of the U.S. Geological Survey. The maps are presented in a clear, condensed format in black and white at a scale of one to 48,000. For each city there are four plates with complex colored symbols overlaid on a lightly printed repeat of the base map, displaying population density, personal-income density and a rough classification of land use. The built-up area of the cities is covered only insofar as it fits the rather Procrustean grid, and one misses the more volatile suburbs. The data for New York, for example, exclude most of Brooklyn, half of Queens and all of Staten Island.

The authors, who are architects and city planners at Washington University in St. Louis, give coauthorship credit by name to 55 students and four colleagues, and they name seven sponsors. Their detailed and technical introduction is a model of candor and completeness, outlining even the false starts and the misleading sources they encountered. The index maps, like the base maps, are clear and attractive, but the large symbol-bearing maps in color that form the bulk of the work (and bulk it is) seem uncommunicative, however useful the data they present. The array of symbols employed is so coarse that the eye cannot integrate the information. Here the computer-compositor has been clumsy. This is sharply demonstrated by the summary maps in black and white that close the work. These are quarter-scale reproductions of the principal maps; the plates show all the cities at one viewing. Now the eye grasps firmly: Los Angeles, Chicago and Detroit display their great industrial ribbons; Manhattan is revealed in its unmatched density; Seattle, so green and sea-set, reveals its absence of public shorelands; St. Louis, the only one of the cities to receive any attention over a period of time, displays a fascinating set of diffusions and recrystallizations. Whatever the expert may do, the general reader will consult this huge atlas for its 20 base maps and for the splendid summary on the last few plates alone. A pioneering work, with the faults of the frontier.

The Bombs of Palomares, by Tad Szulc. The Viking Press, Inc. ($6.50). In January, 1966, the piece of sky the Strategic Air Command has code-named Saddle Rock Refueling Area was the scene of a midair collision: a flying tanker—rather like a Boeing 707 with jet fuel for passengers—was struck by a B-52 nuzzling too close to the nutrient nipple at an altitude of six miles. Down the shattered planes fell, some engines falling free in flames. Seven dead came to earth near a cemetery below, the victims of an error that occurs once in 400,000 tries. Three parachuted survivors were rescued by fishing boats and a passing helicopter within half an hour. Half a dozen other parachutes ought to have floated down from the crash, four of them with thermonuclear bombs and two bearing classified devices from the Strangelove world.

On more earthly maps Saddle Rock was the village of Palomares, on the arid coast of Almería, a province in southeastern Spain. There, since the ancient Phoenician lead and iron mines closed down in 1945, a couple of hundred families live by the tomatoes they pick in two annual crops from the rainless land irrigated by cooperatively drilled wells. There was no telephone in Palomares, but there were eight television sets, and since 1958 there had been power in the houses around the square.

Three unarmed fission-fusion-fission bombs landed in or near the village. Two cracked open; 10 or 20 kilograms of their TNT exploded and spewed the plutonium trigger charge into the air. The third bomb was reclaimed intact. The fourth, borne by parachute, fell in 3,000 feet of ocean water, watched by a fishing



Wood laminated ceiling. V. A. Lundy, Architect, FAIA. Photograph by George Cserna captain from his shrimp boat five miles off the beach.

To Palomares came Air Force generals from Omaha and Washington, Madrid newsmen, parties of decontaminators and finally a futuristic flotilla of abyssal submarines and their tenders. Radioactivity, wooden secrecy, official falsehood, missing megatons, diplomatic struggle, lawsuit and counterclaim are spread through the clear, pungent, knowing chapters of this book, written by the experienced head of *The New York Times*'s Madrid bureau. The "Broken Arrow" was found deep in the ocean ooze by a 22-foot supersubmarine (which had been flown from Woods Hole) and its fellow ships. The plutonium-laden soil was sent for burial to America; the losses to the farmers at Palomares were paid off, more or less; the Americans energetically ate the local shrimp; Ambassador Duke swam bravely in the cold surf to prove the safety of the region.

That it was not simply a grotesque motion picture is perhaps best demonstrated by two small anecdotes. First, the Air Force began hiring field hands to do the housekeeping at its camp while the fields remained out-of-bounds. One laborer was seen sleeping it off in the road, and an American colonel asked his Spanish colleague why such poor people wasted their pay on drink. "I understand him. He's a man who never before could afford more than a glass of wine a month," replied General Montel. Second, the young B-52 copilot, who was pulled from his life raft in a state of shock, saved by automatic ejection and parachute deployment, has been "routinely assigned to Vietnam."

THE AUTOBIOGRAPHY OF BERTRAND RUSSELL: 1872–1914. Atlantic/Little, Brown ($7.95). This volume, its copyrights strewn from 1951 to 1967, is the first U.S. edition of this witty, emotionally honest and intellectually fragile work. It is not evident just when all its portions were written, but more than a third of it consists of correspondence of the time: self-satisfied love letters from young Russell to his fiancée, a mad letter from Georg Cantor, a great mathematician turned Baconian crank, and letters to and from Joseph Conrad, G. M. Trevelyan, Gilbert Murray, Rabindranath Tagore and Bernard Berenson. This great man remains a luminary of our times. Yet as a child he knew Browning and John Tyndall, as a young man he heard and responded to Giuseppe Peano, he admired as extraordinary the single remark the student T. S. Eliot made in Russell's Harvard seminar, and he secretly paid the Cambridge bills run up by his teacher, friend and collaborator Alfred North Whitehead. There is a touching story of a kind of analogue to the famous vision of Pascal's. In 1901, in one five-minute experience, Russell underwent a sort of mystic illumination that turned him from an imperialist into a pacifist, from exact austerity to a vague feeling for beauty, and to a kind of Buddha-sense. "The habit of analysis has reasserted itself," he ends dryly, but something deep remained, giving rise to his pacifism, his interest in children "and a certain emotional tone in all my human relations."

Young Bertrand began Euclid at 11, with his brother, 18, as tutor. "This was one of the great events of my life, as dazzling as first love. I had not imagined there was anything so delicious in the world.... From that moment until ... I was thirty-eight, mathematics was my chief interest and my chief source of happiness. Like all happiness, however, it was not unalloyed. I had been told that Euclid proved things, and was much disappointed that he started with axioms. At first I refused to accept them unless my brother could offer me some reason for doing so, but he said, 'If you don't accept them we cannot go on,' and as I wished to go on, I reluctantly admitted them *pro tem*. The doubt as to the premises of mathematics...remained with me, and determined the course of my subsequent work."

THE HISTORY OF DISEASES, by Folke Henschen. Longmans, Green and Co. Ltd. (63 shillings). PRIMITIVE AND ARCHAIC MEDICINE: VOLUME I OF A HISTORY OF MEDICINE, by Henry E. Sigerist. Oxford University Press ($3.50). Dr. Henschen, a distinguished Swedish pathologist, has written a highly readable and compact book that reviews the history and distribution in space, time and society of the main human diseases. In its first half it takes up infectious disease; in the second, the diseases of the organs and systems of the body. The illustrations, of which there are more than 100, include maps and photographs, drawings and engravings from all climes and ages. The last illustration is the curve of lung-cancer mortality in Denmark, rising by a factor of 10 in the 20 years between 1930 and 1950. Here is a map of the spread of the Asian influenza over the entire world in 1957–1958 from its probable source in southern China. Its low mortality—about one in 400—contrasts with the influenza pandemic of 1918, which infected half of the people of the world and killed at a rate eight or 10 times higher. The incredible elephantiasis of the sufferer from filarial infection, the nodules of the leper, the lesions of the bony remains of men of the past, the dwarfs and the lamed seen in the art of many ages lend a certain melancholy to the book, and yet this historical and social context is surely the most acceptable in which the nonmedical reader can come to face such facts of life, suffering and death.

There is a remarkable story of the inaugural address by the great Linnaeus when he became professor of medicine at Uppsala in 1741. He put the question: "Why do all men in Orsa die of phthisis before they are 30?" Orsa is a town in Sweden where for half the year the men worked mining and shaping grindstones. The disease was silicosis.

The book is a trove of information, organized and presented with clarity and humanity. It is brief, and much more a first survey of this vast and scholarly area than it is a treatise. There is a substantial and annotated bibliography.

Dr. Sigerist's book, a classic of scholarship, is of course related to the topic of Dr. Henschen's. But where Henschen is statistical, sketchy and synoptic Sigerist is leisurely, meticulous, learned and reflective. The topic is shifted, first to the past and then away from disease itself to the entire social complex of disease and its treatment, and to the growth of theory. This first volume of Sigerist's *History of Medicine* (his death cut off the planned eight volumes at Volume II, concerned with ancient Greece) devotes more than half of its space to Egypt and Mesopotamia, with a fascinating richness of detail. The primitive world is also handled with skill; perhaps the best chapters are those on the medicine man, whose vocation, training, inspiration and methods of work are followed in many sample cultures. He is seen as the "ancestor of most of our professions."

The book was first published in 1951 and reviewed at length in *Scientific American;* this paperback reprint is a splendid buy.

THE ELEMENTS OF PHYSICS: A NEW APPROACH, by F. A. Kaempffer. Ginn and Company ($8.50). Many authors try to live up to the brave subtitle of this book, and this graceful writer, an experienced theoretical physicist at the University of British Columbia, has managed to do it. He avoids ladders, spring guns and falling bricks and instead faces up to the idea of world line and to the unending search among the

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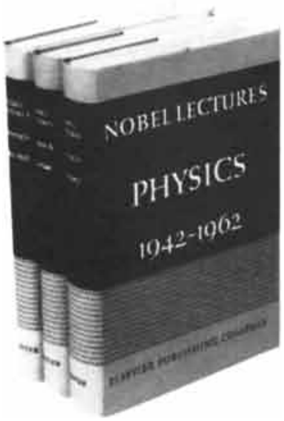

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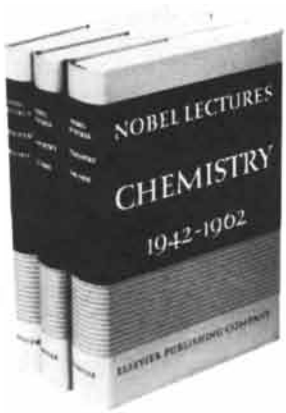

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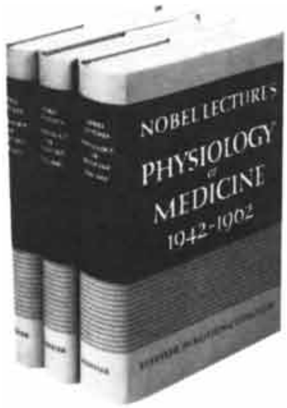

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In 1962, under the auspices of the Nobel Foundation, Elsevier initiated one of the most distinguished publishing projects of this century—the publication in the English language of the complete collected Nobel Prize Lectures. Until that time, only about half of the complete Nobel Prize Lectures existed in the English language.

The project called for a separate three-volume series in each of three subjects: Chemistry, Physics, and Physiology/Medicine. Each series would start with the inception of the awards in 1901 and continue chronologically through 1962. Each lecture would be preceded by the presentation address to the prize winner and followed by his biography.

The collected Nobel Physics Lecture series was concluded late in 1966. The Chemistry series was concluded earlier this year. The final volume (1901–1921) will complete the Physiology/Medicine series in July.

This noteworthy project is now complete. For the first time, everyone interested in the personal accounts of how the Nobel Laureates accomplished their celebrated achievements has access to the official unabridged version in the English language.

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hierarchy of inertial frames for a place to stand. The great dynamical conservation laws are considered with care; the puzzle presented by the pristine reversibility of Newton's laws, against the background of an aging and decaying world, is handled in a few tentative and engaging pages, with plenty of the fascinating intellectual history of the arrow of time. So the thought carries, to charge and its conservation, to variational principles realized in geometrical optics and finally to probability amplitudes, quantum energy levels and the mass spectrum of baryons. In every treatment a careful chapter of description and elucidation precedes a detailed section in which the more taxing mathematics and the logical niceties are set forth in engaging low-key problems, whose answers are always included. An appendix raises the great issues of probability and of rational numbers and their extension.

Kaempffer's principle throughout is to face elementary problems with an approach of great conceptual depth. The book would seem to require a maturity and experience rather beyond the upper-class nonscience students it is in part aimed at (perhaps not in happy Vancouver), but for many a *Scientific American* reader with a somewhat rusty and fretful memory of an earlier college physics and a keen desire to find his way into the modern world it will prove a find.

THE STONE-TIPPED ARROW: LATE STONE-AGE HUNTERS OF THE TROPICAL OLD WORLD, by Bridget Allchin. Barnes & Noble, Inc. ($15). There in the old photograph they sit, a naked family grouped under a huge rock overhang, the ground littered with peel, shells—all the debris of living. These are the Veddas, a hunting people of southern Ceylon, who even at the turn of the 20th century lived, in apparently unbroken continuity, in the same rock shelters their late Stone Age ancestors had used for 10 millenniums. They hunted with bow and arrow—the 10-inch iron arrowheads for which they traded were used against elephants—and had domesticated only the bee and the dog. Great factory sites filled with the quartz tools they elegantly fabricated and traded bear witness to the extended duration of their culture, which is not quite gone yet. The Veddas are a Mesolithic people, deft and brave, making a kind of fading peace with the Iron Age that came at them from the mainland 2,000 years ago. This is a volume of such stories, covering Bushmen, pygmies, Australians and the Indian hunters who must have watched the new cities of the Indus Valley grow out of nothing 6,000 years back. The thread of the book is clear and new: Dr. Allchin traces in place after place (most of the world outside of the Americas is her province) the threads of artifact and practice that connect the archaeological finds of the late Stone Age with living hunting folk. All these people are marked by a technology of skill and aptness, an art of strength and beauty and a steady slow decline. The Neolithic revolution and its aftermath, an iron-bearing and land-hungry peasantry, pressed the hunters back into the wasteland. They are gallant peoples, who bury their dead with red ocher and fashion tiny stone flakes into so many utilitarian jewels, peoples with a pedigree far older than that of Rome, Cairo or Damascus.

Writes Dr. Allchin: "There are enough Stone Age sites ... to keep many generations of archaeologists fully engaged, but ethnographic data is slipping away like quicksilver, and it can never be recaptured." This is a beautiful and a tightly written scholarly work, lying between the specialized treatise on one culture and the broad general text, and making the best of both styles.

AGES OF ROCKS, PLANETS, AND STARS, by Henry Faul. McGraw-Hill Book Company ($2.45). It was the pioneers Pierre Curie and Ernest Rutherford who saw that radioactive clocks could tell the age of the portions of the world. Most of us now know that there are ways of clocking time by the decay of uranium, or of the famous atom that decays on a historical scale, carbon 14. The probe into time is at least as fundamental as our search into space with the big mirrors. Not many people know how the clocks are read; we are in the state of mind of people who understand that there is a pendulum but have never wound, set or consulted a grandfather clock. The author of this bright, plain little book is a skilled and fluent nuclear clock watcher. He lets us see the ingenious and powerful ways in which the rocks of the earth, the meteorites, the sea ooze, the whole stable crust of the earth, the sun and the stars are in fact dated. The metaphor of the clock, of course, is a bit unreal. A better one is an hourglass; indeed, there are two main types of radioactive-dating methods, those that look to see how much sand has fallen through and those, like carbon-14 dating, that see how much remains in the upper cup. Professor Faul, an experienced and felicitous writer, spends most of his pages on the lead- and argon-accumulation clocks, by which the strata of the earth have been assigned their proper dates. He is at his best in telling how one must carefully choose the minerals (some leak gas, some diffuse lead slowly, some feel heat, some leach out chemically) and then aim for a concordant result by many independent methods. These workers seek to enter their Concordia (the name given to one formal representation of the locus of all correct lead-accumulation ages) by repetition and by sharp geological skepticism about the history of every sample.

A rock man himself, the author is sketchy, and perhaps a bit credulous, when it comes to the dating of stars by their evolutionary paths. An astronomer is not as fortunate as a geologist, who can examine his sample at close range, spike it with a known amount of other stuff and check the analyses. An up-to-date list of geological ages is here, and a very brief story of what those who count random events mean by error. By bad luck Faul wrote just too early to give full due to the remarkable method of studying fossil fission tracks by etching them into optical visibility. Today this promises to become the most general of all the dating methods [see "Science and the Citizen," page 51].

MICE ALL OVER, by Peter Crowcroft. Dufour Editions ($5). A reflective Australian mammalogist sets down a lively and winning narrative of his experience in the 1950's with large colonies of the common wild mouse *Mus musculus*. He worked at an old Royal Air Force field in Sussex, watching his mice under red light while they lived in slums and suburbs he constructed on the floor of a special building, once used for bombardier training, where one peers in comfort through a hole in the balcony floor. Sometimes he made small identical rectangular pens, arranged in tastefully chosen orientations each in its little square plot of floor, looking for all the world like a mouse Levittown. Sometimes he built large wire-netting tenements, stuffed with grain and hay for food and cover—an artificial grain stack. He marked and counted, he followed and tracked, he intervened and mixed, he observed. He writes: "I came to recognize elements of the behavior of my fellow men, and...I began to understand both species. It was not a case of creeping anthropomorphism but the awakening of...the capacity to feel compassion. There is something terribly familiar about the awful situation of a mouse in the world."

There is a school of behavior study

that passively watches at great length a few animals in the wild; its errors tend to be diffuseness and self-persuasion. There is another school that studies curious, lively and gregarious animals kept in bare pens ("mouse concentration camps"), producing plenty of numerical data. Its error tends to be categorical oversimplification. Dr. Crowcroft actively marks and counts many animals, but he gives his beasts a rich environment worthy of their small, hardworking brains and their explorer's curiosity. He finds, for instance, that both mice colonies with too little food and mice colonies given a food surplus stop growing in population, some because of few births (the females become sexually inaccessible) and some because of high infant mortality. No one knows, Crowcroft thinks, if such mechanisms work "in the field."

This is a personal book, now lighthearted, now rueful, and it contains many experimental suggestions. It is very good for people who like animals and have a little space. It is also full of lore, doubt and wisdom. Crowcroft ends by forgoing a highbrow peroration and cites instead Lenny's final phrase in *Of Mice and Men:* "It's bad enough as it is."

Catalog of Meteorites, with Special Reference to Those Represented in the Collection of the British Museum (Natural History), by Max H. Hey. Trustees of the British Museum (Natural History) (six pounds). An expert annotated listing of the more than 2,000 meteorites—both finds and falls—known in the world. The British Museum has samples from the majority of them. The facts are enticing beyond their astronomical value. One iron mass of two kilograms fell in the Punjab in 1610 and was forged into sword blades. Another stone was "found in a curio dealer's shop in Beckenham in 1913" but, authentic though it is, the label is incomplete and the fall cannot be traced. One stone is built into the Kaaba in Mecca; no laboratory results are reported for that particular fall.

Principles of Desalination, edited by K. S. Spiegler. Academic Press Inc. ($21). An up-to-date and authoritative collection of technical chapters by experts on the topics from thermodynamics to reverse osmosis to freezing to cost accounting, including all the newest processes, that make up the contemporary art of large-scale desalting of seawater. Power plants are not treated. Excellent bibliographies. A reference work at a high level.

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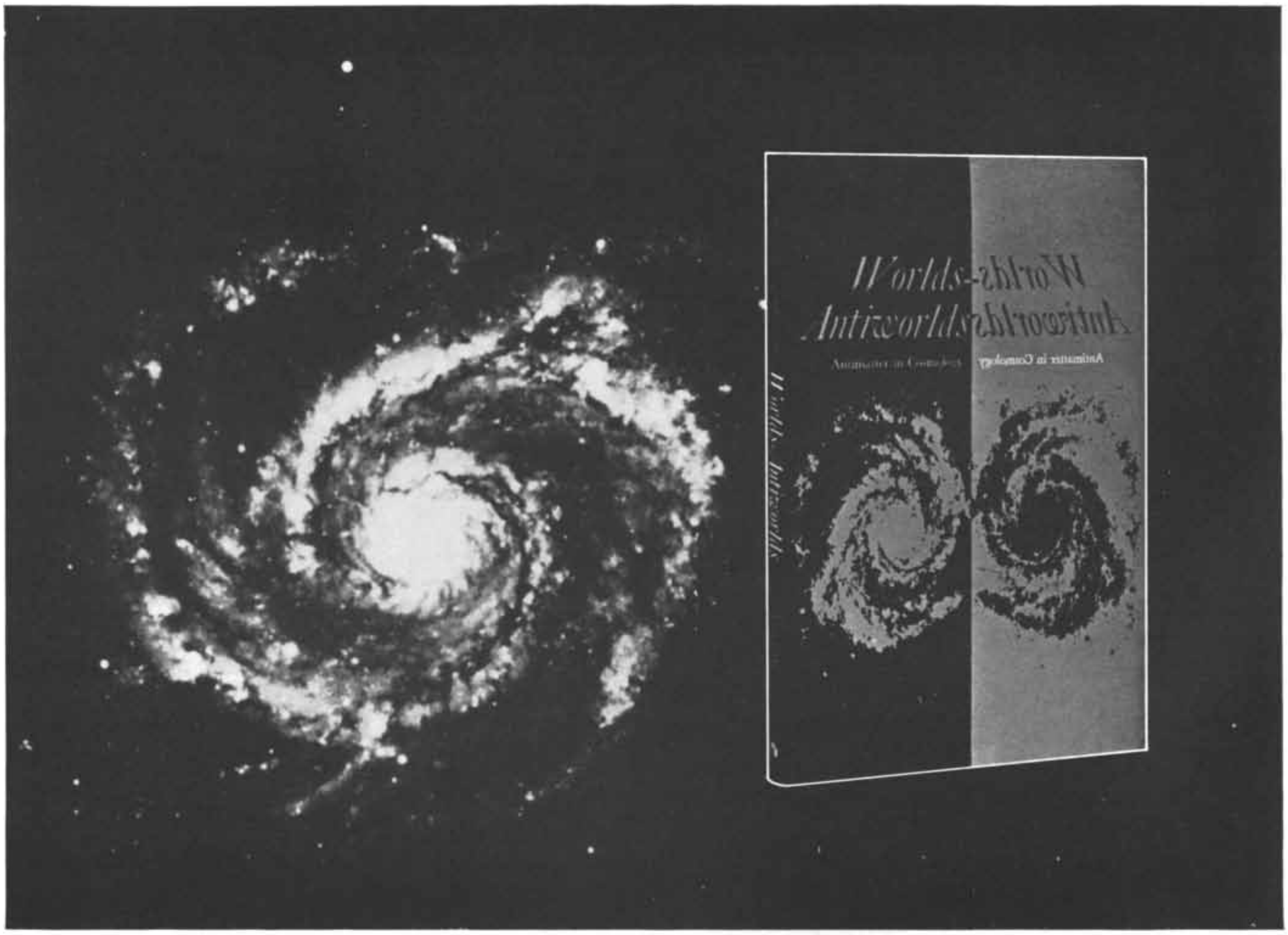

Galaxy with spiral structure. [Photograph from the Mount Wilson and Palomar Observatories.]

Worlds-Antiworlds:
Antimatter in Cosmology

HANNES ALFVEN, The Royal Institute of Technology, Stockholm.
Translated by Rudy Feichtner from the Swedish edition of 1966

"The author has produced a beautifully clear, detailed and yet completely popular, account of his theory and of much orthodox cosmology as well."—*Science Journal,* April 1967

Readers of SCIENTIFIC AMERICAN who enjoyed Hannes Alfvén's article, "Antimatter and Cosmology," in the issue of last April will be particularly interested in this little book. It is the first full-scale exposition of the intriguing new cosmology based on the assumption, supported by experiments in high-energy physics, that matter and antimatter coexist in equal quantities in the universe—perhaps even within our own galaxy. Professor Alfvén explains the new theory fully, compares it to other models, and explores its implications for our understanding of such astronomical spectacles as supernovae, radio stars, and quasars. *1966, 103 pages, 15 illustrations, $3.50*

"Despite the complexities of these difficult cosmological problems, Alfvén has successfully directed this book to the nonscientist. Devoid of equations, adequately illustrated, and interestingly written, with technical details discussed carefully, the book should be intelligible to the nonspecialist. But the specialist may also want to read it, for it is probably the most complete source of information on Alfvén's interesting and original ideas about these cosmological problems."

—R. H. Dicke, Palmer Physical Laboratory,
Princeton University, in *Science,* March 24, 1967

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THE AMATEUR SCIENTIST

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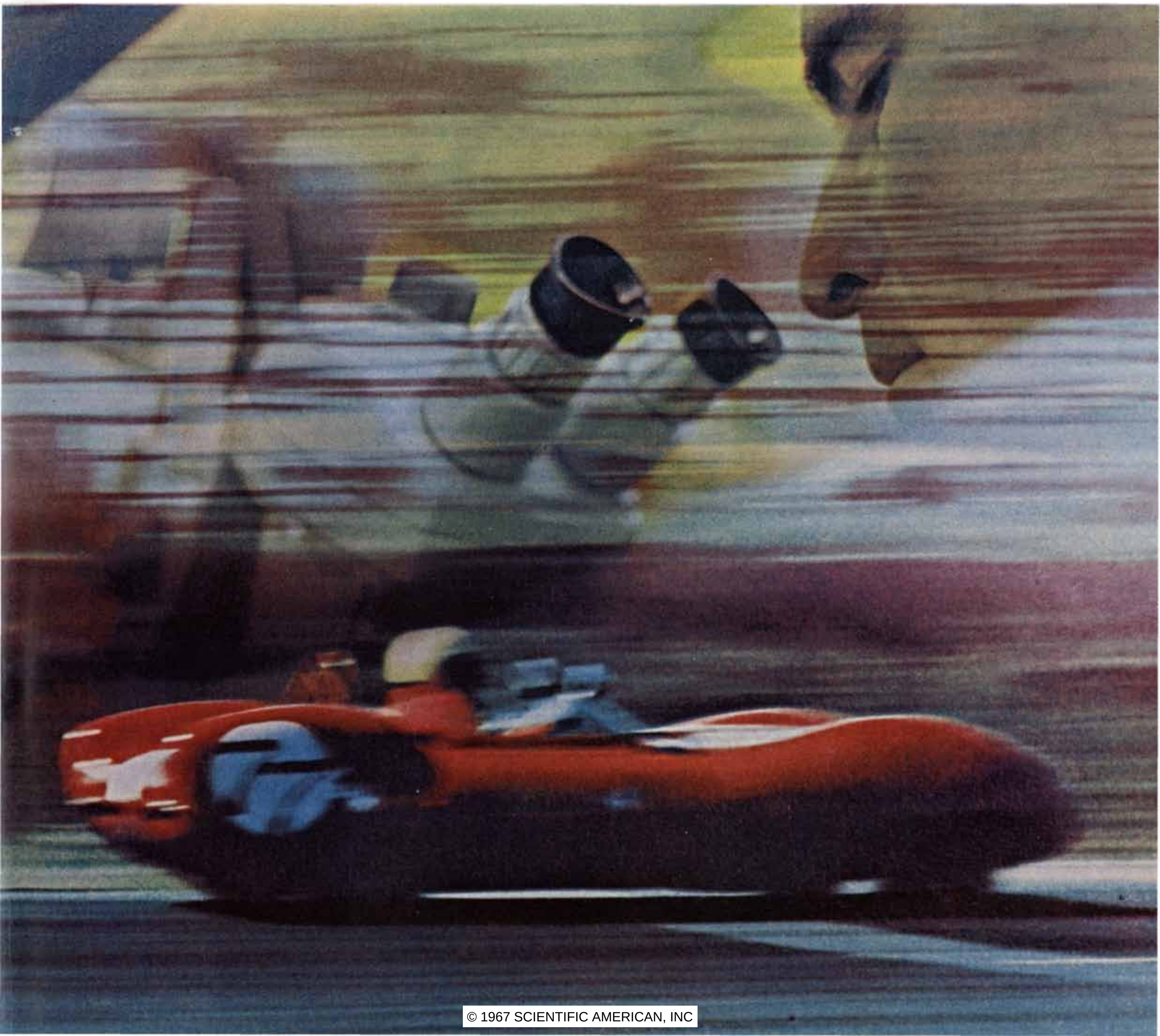

Copper loves company. That's why Anaconda is building another research center.

You'll rarely find copper all by itself. It's usually found in ores as a mineral—interlocked with other elements, other minerals and metals, embedded in rocky waste material.

So to get pure copper you must isolate the copper mineral, then extract the copper from the mineral. That's why most copper ore mined to date has involved only a fraction of the more than 150 known copper minerals—those with the most metal. But as demand soars, we must now find ways to extract copper efficiently from the huge quantity of poorer grade, more complex ores abounding in the earth.

To achieve this, Anaconda is building at Tucson, Arizona, the industry's most advanced extractive metallurgical research center. As we develop better extractive techniques, more and more of today's submarginal deposits will become part of tomorrow's essential copper ore reserves. The Anaconda Company, 25 Broadway, New York, N.Y. 10004.

1. Pyrite (iron sulphide) Chalcopyrite (copper, iron sulphide) and Specularite (an iron oxide). 2. A copper, lead, zinc complex ore containing Chalcopyrite, Galena, Sphalerite, and Pyrite. 3. Chrysocolla (copper silicate) with black copper oxide. 4. Pyrite (iron sulphide) Covellite (copper sulphide) and quartz. 5. Antlerite (a copper sulphate) and Cuprite (copper oxide). 6. Antlerite (a copper sulphate) and Chalcocite (copper sulphide). 7. Covellite and Chalcocite (copper sulphides). 67101