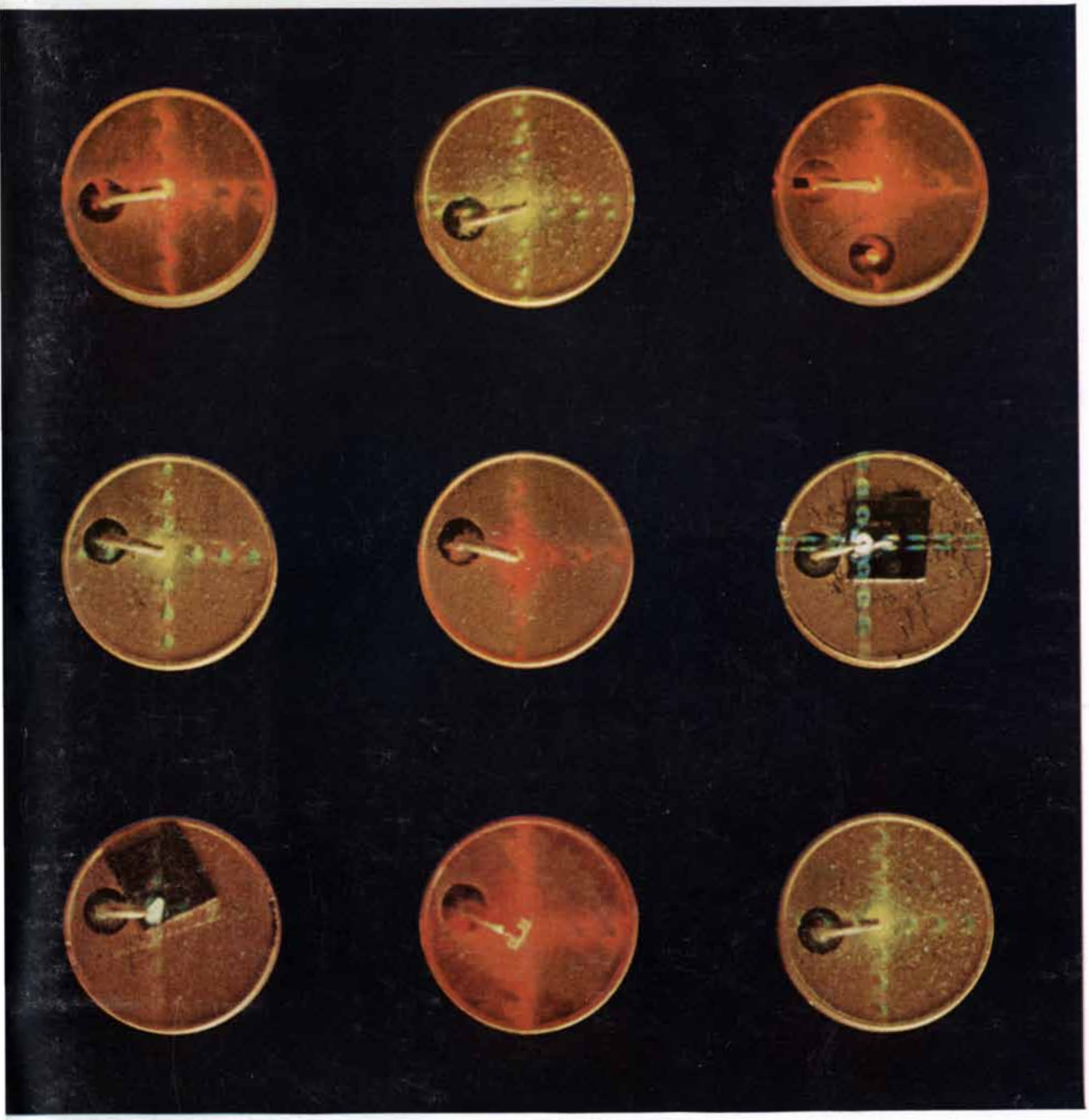
SCIENTIFIC AMERICAN



LIGHT-EMITTING DIODES

SIXTY CENTS

May 1967

How an oil company used First National City Bank to get a line on potential acquisitions, financing for a fertilizer plant, worldwide market data...

...and 10 more services that might give you an idea or two

1. Acquisitions
When the company considered purchase of properties producing oil and gas, Citibank's Petroleum Engineering Staff analyzed their potential loan value, advised company which of several purchase methods would be best. Citibank's Petrochemicals Specialist helped find prospective customers for a company subsidiary, also set up meetings with potential joint venture partners.

2. Long-term financing
When the company entered a joint venture with a major overseas concern to manufacture fertilizer, the bank helped arrange long-term financing. Citibank secured registration with the foreign government to provide repatriation base.

3. Industry analyses
Citibank Petroleum Economists worked with company analyzing worldwide supply and demand for petroleum. Citibank also studied need for solid and liquid fuels by the aerospace industry, supplied information on markets for petroleum products in West Africa.

4. Revolving credit-term loan
Citibank headed a multi-bank revolving credit in nine figures for the company. As agent, Citibank conducted negotiations with the company, prepared credit agreement which provides for funding of money into a long-term loan, handled money flow between banks and company.

5. Specialized studies
When the company planned to establish offices in Brussels, Citibank made a study of costs, including rentals and real estate, local salaries and fringe benefits for employees. Citibank advised on possible acquisitions in oil producing and marketing areas and the requirements of countries offering exploration concessions.

6. Money mobilization
The bank designed the oil company's system for collecting cash from the bulk terminal level on up through its industrial sales.

7. Major foreign expansion
When the company planned a multimillion dollar petrochemical project abroad, Citibank suggested several methods of financing, remitted capital funds, helped transferred employees find housing, set up banking arrangements for company and its employees.

8. Evaluated local banks
As company began operating in new locations, Citibank analyzed facilities of its branches and correspondents, in light of company's needs, and supplied a report.

NOTE: With more than 300 branches in 46 countries, and many more affiliates and correspondents, Citibank's global coverage is complete.

9. Invested Eurodollars
The company sold a multimillion Eurodollar bond issue. Citibank's foreign branches helped company channel the proceeds into short-term investments until permanently invested.

10-13. Other Services
Citibank handled dividend payments, was trustee for employees' Thrift and Pension Plans, consigned over $250,000 in Travelers Checks.

We welcome inquiries about the many ways your company can use First National City Bank.

FIRST NATIONAL CITY BANK
399 PARK AVENUE, NEW YORK, N.Y. 10022 · MEMBER FEDERAL DEPOSIT INSURANCE CORPORATION

Western Electric plots short cuts to probability

The answers to many questions in statistical quality control are based on the cumulative binomial distribution:

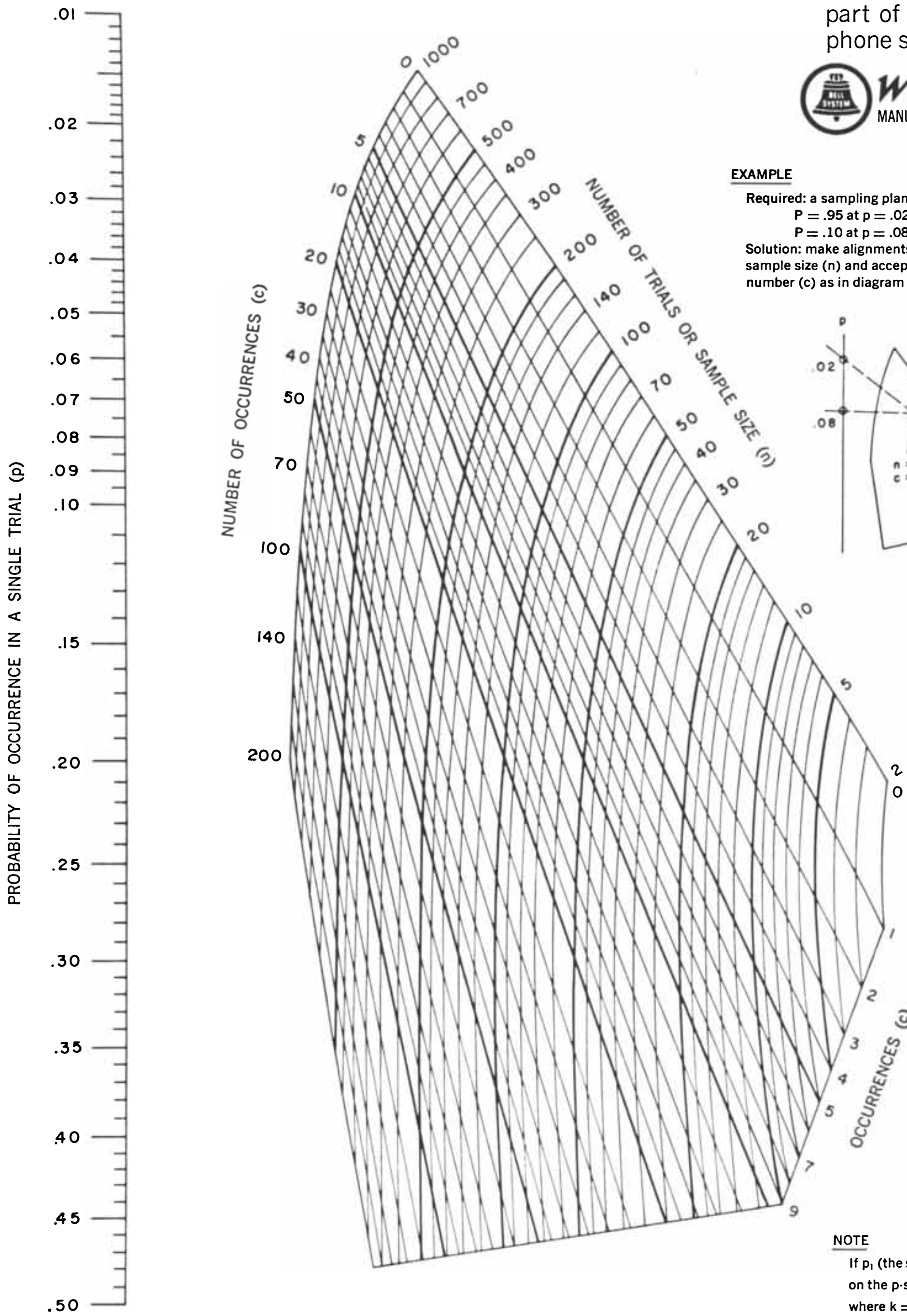
$$P\left\{m \le c\right\} = \sum_{m=0}^{c} \frac{n!}{m!(n-m)!} p^m(1-p)^{n-m}$$

In practice, binomial problems are usually solved by resorting to analytical approximations and cumbersome tabular methods to reduce the computational burden.

Because quality control is of such paramount importance to Western Electric, and because the communications equipment we make for the Bell System is subject to increasingly higher quality requirements, the approximations are of decreasing value. Accordingly, our engineers have developed a nomograph which virtually eliminates computation, facilitates evaluation of alternative solutions, and permits direct solution of some problems not otherwise directly solvable, except by approximation. We have found it extremely useful and timesaving, and we felt that if you are engaged in work requiring statistical analyses, *you* might, too.

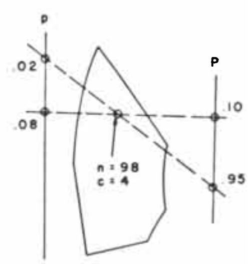
If you *are* so engaged, the usefulness of the nomograph is evident. If you are not, we ask you to consider it only as another example of the ingenuity Western Electric brings to its manufacturing job in the Bell System, which in turn is part of the reason America's telephone service is the world's best.

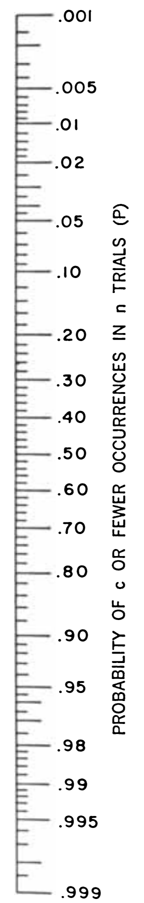
Western Electric
MANUFACTURING & SUPPLY UNIT OF THE BELL SYSTEM



EXAMPLE

Required: a sampling plan having
P = .95 at p = .02
P = .10 at p = .08
Solution: make alignments and read sample size (n) and acceptance number (c) as in diagram below:





NOTE

If p_1 (the smallest p in a problem) is less than .01, set kxp on the p-scale and multiply the values on the n-scale by k, where $k = 0.01/p_1$ (taking k to the next higher integer).

Established 1845 SCIENTIFIC AMERICAN May 1967 Volume 216 Number 5

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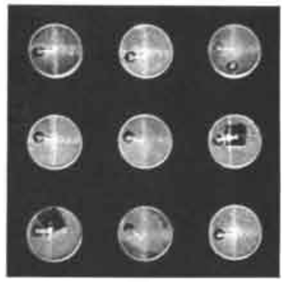

THE COVER

The photograph on the cover shows an array of solid-state diodes that emit intense, distinctly colored light when an external voltage is applied across them (see "Light-emitting Semiconductors," page 108). Each diode consists of a tiny crystal of a semiconducting compound mounted at the center of a gold-plated disk, which serves as a positive electrode. The disks are about eight millimeters in diameter, and the crystals are about a third of a millimeter across. The thin gold-plated wires that serve as negative electrodes pass through insulating plugs in the disks (*dark spots*) and contact the crystals from above. A mesh screen placed between the diodes and the camera has spread out the image of each source into four broken prongs of light. The number of bright spots in each prong depends in part on the intensity of the source. The crystals themselves appear yellow in the photograph because the light from them has overexposed the film.

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THE PLANAR PROCESS

LETTERS

Sirs:

The review by S. A. Barnett of Konrad Lorenz' *On Aggression* in your February issue calls for some comment.

Lorenz' widely acclaimed book has aroused very different responses amongst its reviewers, from enthusiasm to bitter—even abusive—antagonism. Unfortunately the antagonism is not infrequently couched in terms that lead one to suspect that the reviewer is, to say the least, prejudiced....

Barnett's review begins with the implication that other reviewers such as Joseph Alsop and Arthur Koestler—who I had understood to be conscientious men—had not read the book through. He then states that *On Aggression* does not in fact represent the methods or opinions current in ethology. This, I'm afraid, is partly wishful thinking. Further assessments begin: "This unsupported statement...." "This bare statement certainly needs qualification." "Nothing of the kind appears in any of the detailed accounts of the species...."

Referring to one of Lorenz' passages on rat behavior, Barnett writes: "They are said to transmit by tradition knowledge of the danger of poisons. The last statement is reminiscent of the simple tales, often written by clergymen in earlier times, about animal cooperation and its moral implications. (A popular story was about the old blind rat that was guided by a younger rat by means of a twig.)" Now let us see what Lorenz wrote, citing the work of Steiniger: "Within the pack there is a quick news system functioning by mood transmission and, what is more important, there is a conservation and a traditional passing on of acquired experience. If the rats find a hitherto unknown food, according to Steiniger the first rat to find it usually decides whether or not the family should eat it. 'If a few animals of the pack pass the food without eating any, no other pack member will eat any either. If the first rats do not eat poisoned bait, they sprinkle it with their urine or feces. Even when, owing to local conditions, it is extremely uncomfortable to deposit feces on top of the poison, nevertheless it is often done.' But the most astonishing fact is that knowledge of the danger of a certain bait is transmitted from generation to generation and the knowledge long outlives those individuals which first made the experience." This is not a "scientific" statement, nor is it meant to be; it was not written for a scientific journal. Nor can we assume that it is based on insufficient evidence, although this is a criticism of Lorenz often stated or implied; in this case, as in many others, a number of scientific reports with supporting evidence come to mind—admittedly from a broad field, but Lorenz is taking a broad view. And would the "old blind rat" comment be justified in *any* circumstances? Such deficiencies in Barnett's critique mean that a sufficiently knowledgeable reader is unlikely to accept his suggestion that "Lorenz lives in a private world, insulated from the real one...."

Abuse such as this leaves one with a very unpleasant taste. It is to be hoped that people interested in behavior will not be discouraged from reading *On Aggression* by this particular warning display.

PETER M. DRIVER

Mental Health Research Institute
University of Michigan
Ann Arbor, Mich.

Sirs:

Throughout S. A. Barnett's review of Konrad Lorenz' *On Aggression* runs the concern that the innocent layman will come away from the book with all sorts

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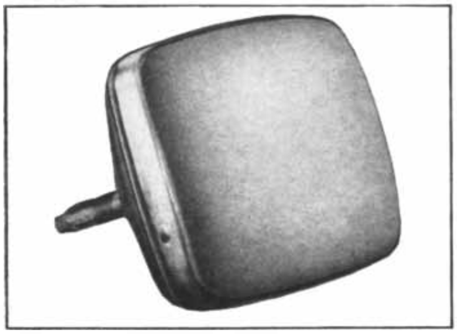
We crucible-tested over 50,000 phosphors last year. Any one of them might solve a problem for you.

Phosphors are an essential ingredient in solid-state electroluminescent displays.



Sylvania developed rare earth europium phosphors to add brightness to color television.

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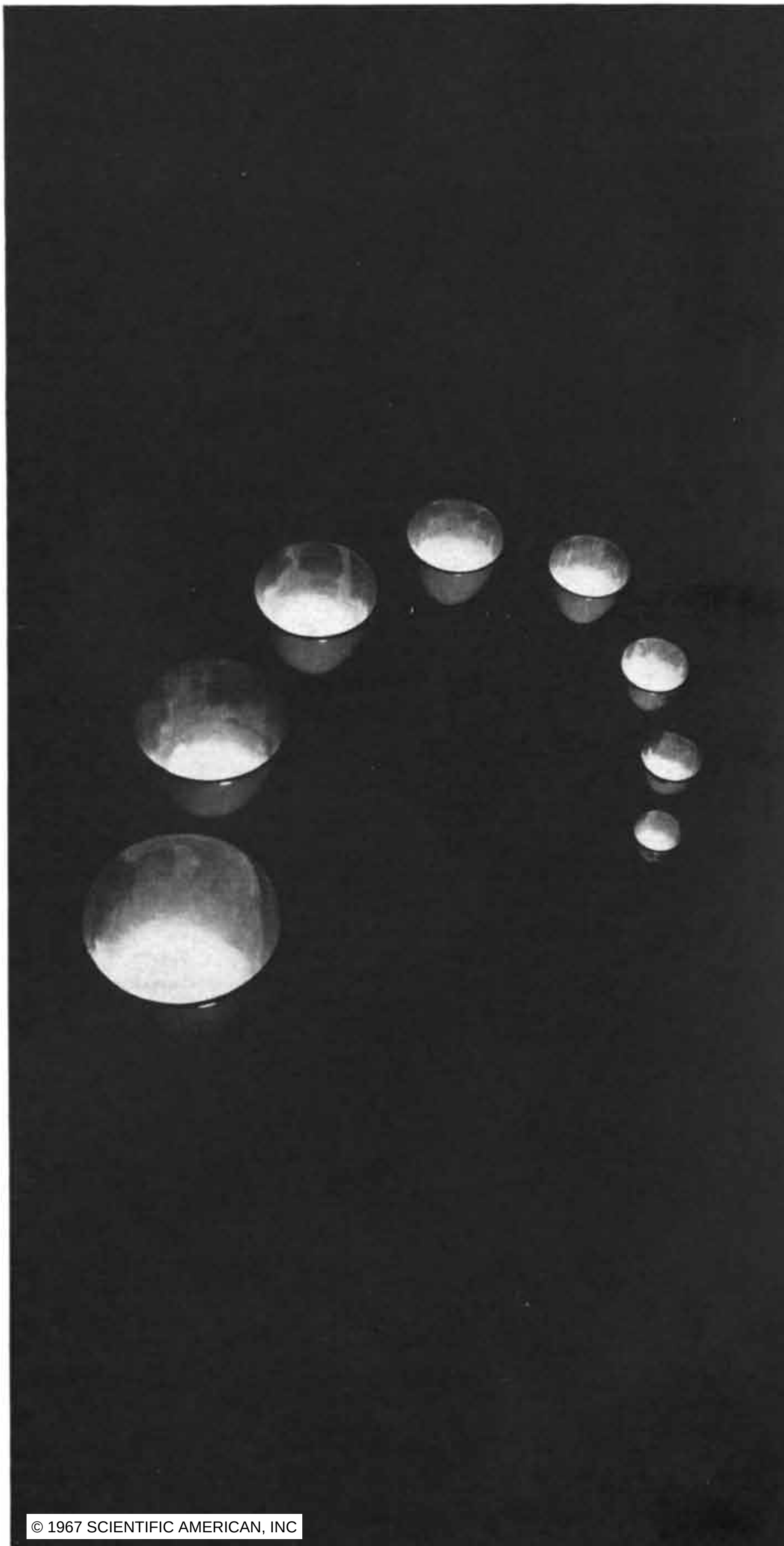


of ideas that Dr. Barnett quite properly considers to be unscientific.

But it is possible that the layman is better able to take care of himself than Dr. Barnett supposes. The layman reading *On Aggression* might argue that the great strength of Lorenz is his willingness to render his data not empirically but rather in terms of imaginative constructs that make possible an imaginative extrapolation from the animal behavioral world to the human. The layman might feel that the "pure" scientist, the sort Dr. Barnett would approve of, may accumulate unlimited data, but unless he is willing at some point to make the imaginative jump Lorenz makes on every page, it will remain forever mere data.

It is possible to achieve a very different perspective on Lorenz' work. All one has to do is admit the bare possibility that men (including scientists) perceive imaginatively, conceptualize imaginatively and act out of this imaginative framework, aggressively or otherwise, and the vistas open up.

One guesses that Dr. Barnett would class such imaginative constructs among Newton's "occult qualities." He sees signs of progress in the fact that we have rejected the imaginative construct called "innate heat," but what would he say about such serviceable concepts as causality, reverse time and curved space? Would he be prepared to assert that all three are not in some substantive sense "occult"? Picture for a moment the molecular biologist studying an oscilloscope-screen image of a protein molecule rendered by computer from electron densities. In the most philosophical sense is not this image entirely "occult"?

Such considerations lead one to suggest that Dr. Barnett's labeling of *On Aggression* as "antirational" is just one way of saying it; "proimaginative" or "metaempirical" seems to fit the case just as well, and perhaps does more justice to Lorenz' methodology.

In any case, Dr. Barnett should stop worrying about the layman. One of the great advantages of being one is that one can, with good conscience, carry about vast quantities of fascinating, often enormously useful misinformation.

ROBERT ZOELLNER

Department of English
Colorado State University
Fort Collins, Colo.

Sirs:

My statement that *On Aggression* does not represent current ethology is supported in my review by a number of examples concerning both facts and concepts. I shall be happy to refer Dr. Driver or anyone else to the published papers on which my criticisms are based. On rats and tradition, I know of no valid evidence, in the work of Steiniger or elsewhere, for the statements made by Dr. Lorenz. I think these statements absurd, and I tried to convey this. Dr. Driver implies that factual accuracy is unimportant when one is writing about science for laymen. I disagree. Similarly, I do not share Dr. Zoellner's liking for misinformation. The passage that Dr. Driver calls abuse is a value judgment and so an opinion. It states that it is wrong for a writer to misinform his readers, especially on such serious topics as war and other socially destructive behavior.

I quite agree with Dr. Zoellner on the importance of bright ideas that at first transcend the evidence. But they need rigorous scrutiny in the light of both facts and logic. (See P. B. Medawar's essay "Hypothesis and Imagination" in *The Art of the Soluble*.) It is no use making an imaginative leap if it lands you in the soup.

S. A. BARNETT

Department of Zoology
The University
Glasgow

Sirs:

All praise to S. A. Barnett for his incisive criticism of Konrad Lorenz' book *On Aggression*. Exposure of the irrational extrapolations from animal to man, the inaccurate descriptions of animal behavior and the entirely unscientific insistence on phylogenetically determined behavior patterns in man is a signal service to clear thinking. We must face the fact that each man's behavior patterns are formed by his own life experience. This places the responsibility for the development of aggression on our cultural environment, which society can modify. Why are literate Americans such as Joseph Alsop so ready to seize on specious ideas of man's built-in instinctual mechanisms? Are we so anxious to absolve ourselves of responsibility for the violence and aggression that our culture generates?

ARMAND M. OPPENHEIMER

Columbia University
New York, N.Y.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MAY, 1917: "The Russians appear to have begun an offensive against the Germans in the Kovel district, heavy artillery fire having destroyed munition depots at points east of Kovel. Some slight actions are reported also on the Rumanian front. It must be confessed that the quiet along all these fronts has, however, an ominous significance. If Russia is in any position soon to strike hard along part of or all her lines on the eastern front, the effect upon this year's campaign will be great because the strong Allied advance on the Western front has drawn many German divisions from the east to help a desperate condition in France. But the present situation on the Russian front resembles the description given of it—an unofficial armistice. To what this has been due cannot at present be exactly determined. It may be a question of food supply; it will be remembered that a scarcity of food was one of the immediate causes of the revolution in Petrograd. At any rate, there is evidently something wrong, something that an outsider cannot fathom."

"Chalmers Mitchell's new book, *Darwinism and War,* is a reply to the argument in favor of war, so often put forth in the last three years by a certain German school, that a state of constant struggle or warfare is a dominant factor in evolution. Mr. Mitchell, a distinguished zoologist and a member of the Royal Society of London, examines at length various examples of the struggle for existence among animals, and his conclusion is that the causes which determine the success of one species in relation to another are variable and often difficult to determine. Such success may be due to a better developed brain, to a greater resistance to microbes or to a superior capability of adaptation to environment. He finds no evidence that violence exerted by individuals of the more favored species upon individuals of the less favored species is an important factor. He also finds nothing in common between the grouping of individuals which forms a modern nation and that which constitutes a race or species of animals. In short, he believes it is entirely inadmissible to attempt to justify human conduct by laws supposed to be dominant in the animal kingdom."

"Time and again in these columns attention has been directed to the tremendous cost of the war in aircraft, but at no time since last September has the monthly total of machines destroyed approached that of April. A compilation from British, French and German official communiqués shows that 717 aeroplanes were shot down on the Western front during the month just brought to a close. The Germans are said to have lost 369, the French and Belgians 201 and the British 147. Last September, while the Somme battle was at its height, the total was 322."

SCIENTIFIC AMERICAN

MAY, 1867: "It is said that Mr. Bessemer now enjoys from his patents for the conversion of iron into steel the princely income of $500,000 a year."

"The Illinois eight-hour law encounters great difficulty in getting into practical operation, from the want of a general concert of manufacturing states in the movement. It is of course impossible for employers to pay the excess of wages over their competitors in other states, and they will be obliged, and are preparing, to close their factories and shops, unless the hands consent to have the 20 per cent taken off equally from the work and the wages. Of these alternatives, neither working on four-fifths time nor being turned out of employment altogether is the entertainment to which the operatives were invited. It would seem to be their only policy, at this stage of their movement, to content themselves with the initiation of the eight-hour standard of day's work, adding two hours' overtime for the old wages at present, and leaving the advance of wages until a period when it can be made simultaneous and so practicable in all states."

"Professor Agassiz' immense collections in Brazil have been in good part opened and arranged (except for about 60 packages) in the Museum of Comparative Zoology at Cambridge. They include 50,000 specimens of fishes, representing more than 2,200 species, 2,000 of which are supposed to be new to science. This collection now exceeds those

Report from
BELL LABORATORIES

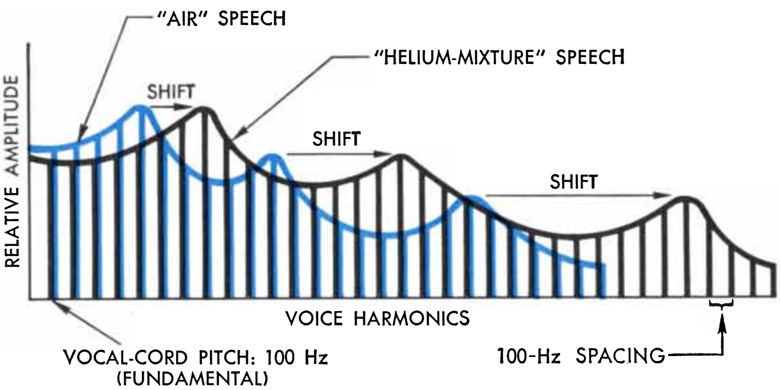
Making voices from the depths sound deeper

Bell Telephone Laboratories has had a long-term interest in speech research—tracing back, indeed, to the work of Alexander Graham Bell. It was for this reason that the U. S. Navy asked us to investigate a problem encountered in Sealab II. To prevent "bends" and nitrogen narcosis, the divers breathe a pressurized mixture of oxygen, nitrogen and helium, but the helium gives their voices an unnatural, squeaky, Donald-Duck-like quality. As a result, voice communications between divers and people on the surface are seriously impaired.

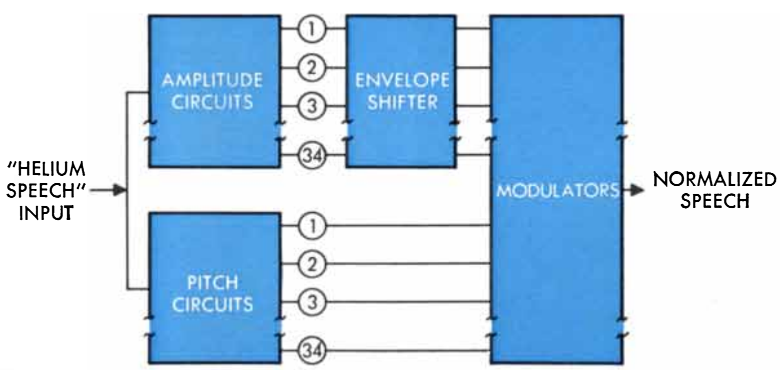
THE MAJOR PROBLEM is that the velocity of sound in the helium mixture is much higher than in air. This does not appreciably affect vocal-cord frequency, but does strongly affect the acoustic resonances of the vocal tract—which give the voice its characteristic sound quality. So, though fundamental voice pitch remains approximately the same (about 100 Hz in men), the amplitudes or loudness values of the various harmonics change markedly. Specifically, the pattern of these resonances (the envelope) shifts toward the higher frequencies (see graph), and voice timbre is grossly distorted.

THE SOLUTION to this problem was found at Bell Laboratories by research scientists M. R. Schroeder, J. L. Flanagan, and R. M. Golden. The distorted "helium speech" is separated into harmonic frequencies and their amplitudes are measured (see diagram). Then the envelope of the harmonic amplitudes is shifted back toward the more normal or low-frequency condition. In other words, the amplitudes of the harmonics are adjusted to match a more normal envelope.

As a test, the technique has been used on recordings of helium speech made in the U. S. Navy's Sealab II. The processed voices are readily understandable and sound enough like the speaker's "air" voice to be identifiable.



Fundamental pitch and harmonics (vertical bars) for normal "air" voice sound (color) and "helium speech" sound (black). Note that the frequencies of the fundamental and harmonics do not change very much, whereas the envelope of the amplitudes shifts toward the right. Note also that the magnitude of the shift increases with increasing frequency.



Block diagram of system for restoring helium speech to normal voice quality. Helium speech is fed to amplitude and pitch circuits. In the pitch circuits, the frequencies of the 34 lowest harmonics are determined. In the amplitude circuits, the power levels within each of 34 150-Hz intervals of the speech spectrum are determined. The amplitudes are shifted and applied to harmonics of lower frequency. In the modulators (right), these power levels control the loudness of the 34 harmonic frequencies . . . thus producing a pattern or envelope closely corresponding to the envelope of normal speech.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

of the British Museum and the Jardin des Plantes united, containing all together more than 9,000 species."

"At a crowded meeting of the members of the Royal Society of Scotland, Professor Sir William Thomson presented a communication based upon the admirable discovery by Helmholtz of the law of vortex motion in a perfect liquid, that is to say, in a fluid destitute of viscosity or friction. Helmholtz has proved mathematically an absolute unchangeability in the motion of any portion of a perfect liquid in which the peculiar motion he calls *wirbel bewegung* (vortex motion) has been created. Professor Thomson therefore boldly throws down the gauntlet by condemning 'the monstrous assumption of infinitely strong and infinitely rigid pieces of matter' and suggests that Helmholtz' rings are the only true atoms. 'A full mathematical investigation,' said Professor Thomson, 'of the mutual action between two vortex rings of any given magnitudes and velocities, passing each other in any two lines so directed that they never come nearer to each other than a large multiple of the diameter of either, is a perfectly solvable mathematical problem, and the novelty of the circumstances presents difficulties of an exciting character. Its solution will become the foundation of a proposed new kinetic theory of gases.' "

"A French engineer named Boutet proposes to bridge the English Channel (20½ miles) with a structure on the suspension plan aided by the buoyant power of water. His foundation would be in effect a submerged wire suspension bridge, a fabric of 60 seven-inch wire cables, crossed and laced together by smaller cables, all carefully galvanized, and the whole thickly coated with gutta-percha and supported at intervals by immense iron buoys. Upon this foundation would rise 65 iron structures of great breadth of base and 600 to 900 feet high as supports at proper intervals for the bridge road, formed of a network of great wire cables, like the foundation. It would be a double suspension bridge on a monstrous scale, with the 65 cable towers acting as trusses between the upper and lower stringers and with the peculiarity of resting the lower portion in the depths of the channel on buoyant supports. The cost is estimated at some $75,000,000."

"The American oil product for the past six years is estimated at about 11,640,670 barrels. In 1859 the product was 325 barrels."

Tougher products for the surfers—thanks to AMOCO IPA

Surf's up. And that board's going to take some pretty hard knocks. Happily, Isophthalic Acid (IPA) from Amoco Chemicals is on the job. IPA polyesters made with AMOCO IPA can make your products tougher, too. They'll resist cracking, crazing, fracture. Provide impact strength, and better tensile and flex strength. Where else is IPA? Try bowling balls, automotive parts, serving trays. IPA polyesters also provide good resistance to chemicals. They're used in chemical resistant tanks and in linings for petroleum storage tanks. Think tough. Ask your resin supplier about AMOCO IPA—or write us. Amoco Chemicals Corporation, Department 8786, 130 East Randolph Drive, Chicago, Illinois 60601.

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Synthetic steel takes 30 mph impact.

ABS plastic body is still intact after John Fitch drove car through wall. Doors and hood were not sprung. (Impact photos follow.)

Uniroyal invented ABS plastic as a substitute for steel. It's the first plastic to combine rigidity without brittleness, toughness without rubberiness.

In the laboratory, tests of ABS plastic indicate it has tremendous impact strength. So much strength, we feel justified in calling it "synthetic steel."

Laboratory tests are one thing. What really counts is how a material performs in actual use.

To demonstrate the superiority of ABS as an engineering material, we asked professional driver John Fitch to drive an ABS plastic car through a brick wall. He proved how really tough it is.

Like steel, ABS is an alloy. ABS is a combination of three basic ingredients: (A) acrylonitrile, (B) butadiene and (S) styrene.

ABS is probably the most versatile plastic ever invented because it combines hardness, rigidity, toughness and chemical resistance in one material.

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Kralastic ABS rivals steel in the range of its applications. And the possibilities have hardly been tapped.

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But a peculiar virtue of Kralastic ABS is that even though it is rigid and holds its shape under stress it can absorb sudden sharp impacts without shattering. And it doesn't need fiber glass or other reinforcements.

Kralastic ABS is so strong it has been chosen for a variety of unexpected uses where plastics were never before considered because they could not meet the requirements.

For example, pipe made of Kralastic ABS can be made tough enough so a truck can drive over it without cracking it.

Because it can be easily molded into intricate shapes, Kralastic ABS gives engineers a design flexibility not possible with metals. Thus in the automotive field it's being used in grilles, door panels, seat backs and even truck cabs.

Kralastic ABS can even be electroplated with a chromium, nickel, copper, silver or even gold finish.

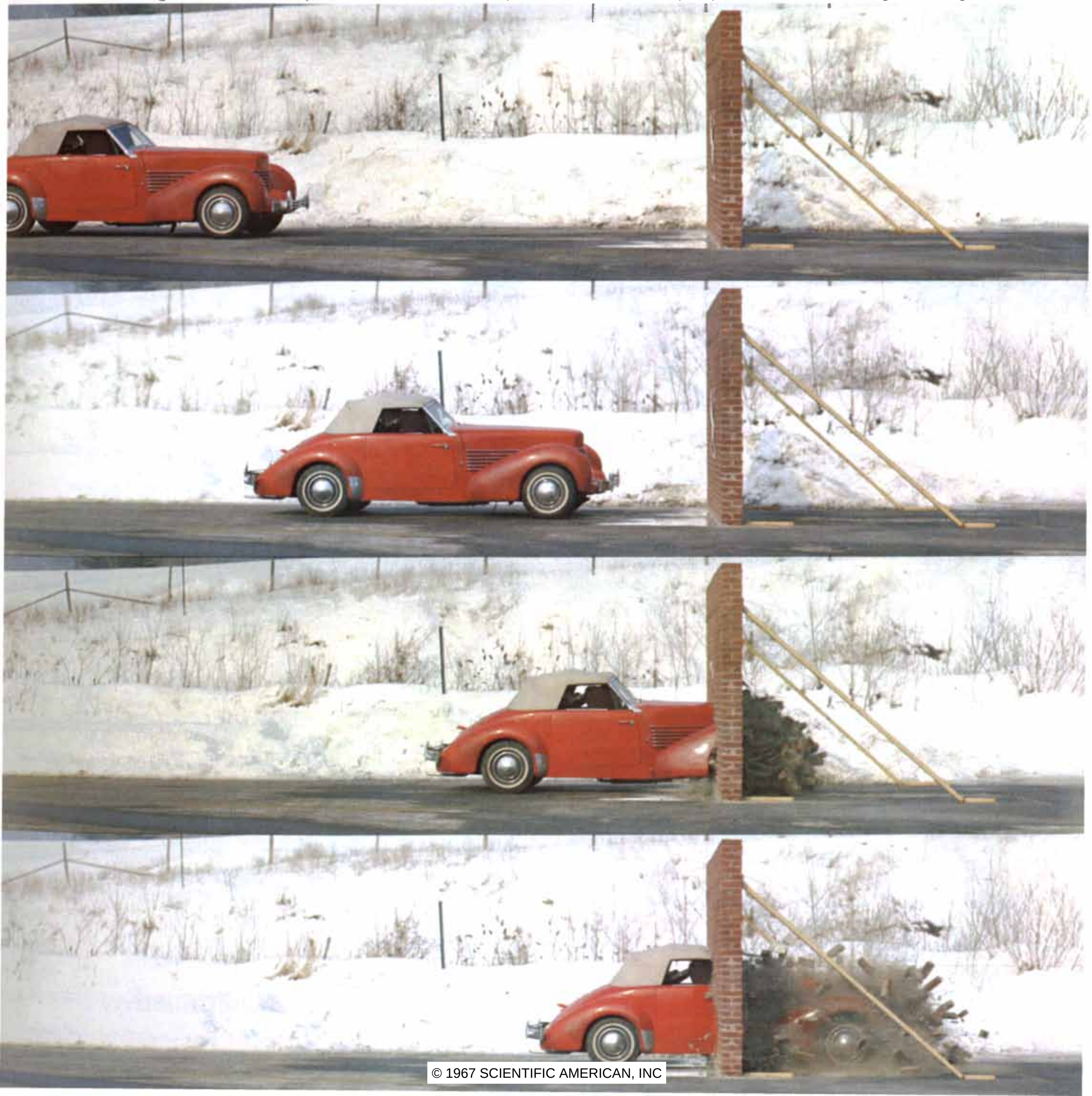
Continued...

The grille of the Chevrolet Camaro is made of ABS. Because it is lightweight and tough, ABS parts are being designed for other external automotive uses.

The cab of the Trend, a new truck from White Motor, is made of impact-resistant expanded ABS. It can't corrode and road noises are drastically reduced.

ABS plastic, like steel, is an alloy whose properties can be varied.

Hitting brick wall at 30 mph demonstrates that ABS plastic can absorb sharp impacts without shattering or tearing.



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THE AUTHORS

T. R. BUMP ("A Third Generation of Breeder Reactors") is a mechanical engineer at the Argonne National Laboratory. He received bachelor's and master's degrees at Iowa State University and a doctorate in mechanical engineering from Purdue University. His educational career was twice interrupted by military service; he was an engineering officer on naval vessels for several months in 1945 and 1946 and for two years during the Korean war. Joining the Argonne Laboratory in 1955 after completion of his studies at Purdue, he worked for several years on the thermal-hydraulic design of the second-generation breeder reactor known as Experimental Breeder Reactor II. He is now engaged in similar work on the prospective third generation of breeder reactors.

SUK KI HONG and HERMANN RAHN ("The Diving Women of Korea and Japan") are professors of physiology, Hong at the Yonsei University College of Medicine in Korea and Rahn at the State University of New York at Buffalo. Each is also chairman of the department of physiology at his institution. Hong was born and educated in Korea. He received the degree of M.D. at Severance Union Medical College (now part of Yonsei University) in 1949 and a Ph.D. from the University of Rochester in 1956. He then joined the faculty of the University of Buffalo School of Medicine (now the State University of New York at Buffalo). Before he left Buffalo in 1959 he and Rahn made plans for a long-term collaborative research program on physiological adaptations to diving. Rahn was graduated from Cornell University in 1933 and received a Ph.D. from the University of Rochester in 1938. He was a member of the department of physiology at Rochester until 1956, when he went to the State University of New York at Buffalo.

DONALD KENNEDY ("Small Systems of Nerve Cells") is professor of biology and head of the department of biological sciences at Stanford University. He was graduated from Harvard College in 1952 and obtained a Ph.D. from Harvard four years later. After teaching at Syracuse University for four years he went to Stanford. He writes that he shares his interest in the subject matter of his article "with a small network of comparative neurophysiologists, most of them located on the West Coast." He adds: "I am especially anxious to acknowledge my gratitude to these friends, most of whom are mentioned in the article. They have provided substantial help in its preparation." Kennedy was the author of "Inhibition in Visual Systems" in the July 1963 issue of SCIENTIFIC AMERICAN.

ERIC OXENSTIERNA ("The Vikings") is a Swedish historian and archaeologist. He was graduated from the University of Uppsala and received a Ph.D. there in 1948. Among the many books he has written are *The Norsemen*, originally published in German and later translated into Swedish, English, French, Spanish and Japanese; *The Golden Horns of Gallehus; The Vikings Lived Like This; Iron Age, Golden Age; We Swedes,* and *Scandinavia: Pictures of Its Landscape and Culture*. In addition to his writings Oxenstierna has lectured widely on the early history of northern Europe.

CHARLES YANOFSKY ("Gene Structure and Protein Structure") is professor of biology at Stanford University. After his graduation from the City College of the City of New York in 1948 he did graduate work in the department of microbiology at Yale University, receiving a Ph.D. there in 1951. He remained at Yale until 1954, when he joined the faculty of the Western Reserve University School of Medicine. Four years later he went to the department of biological sciences at Stanford. Yanofsky has received several awards for his work in molecular biology. He was elected to the American Academy of Arts and Sciences in 1964 and to the National Academy of Sciences last year.

IRVIN ROCK and CHARLES S. HARRIS ("Vision and Touch") are respectively professor of psychology at Yeshiva University and a member of the technical staff at the Bell Telephone Laboratories. Rock, a graduate of the City College of the City of New York, received a Ph.D. from the New School for Social Research in 1952 and remained there as a member of the faculty until going to Yeshiva in 1959. In July he will become professor of psychology at the Institute for Cognitive Studies at Rutgers University at Newark. Rock is the author of a book, *The Nature of Perceptual Adaptation,* which was published last year. Harris was graduated from Swarthmore College, received a master's degree at Yale University and then, he writes, "entered the subterranean depths of Memorial Hall at Harvard University, acquiring there not only a Ph.D. in 1963 but also a wife and collaborator, Judith R. Harris." His portion of the work described in the article was carried out at Harvard, the Lincoln Laboratory of the Massachusetts Institute of Technology and the University of Pennsylvania, where he taught for two years before joining the Bell Laboratories.

FREDERICK F. MOREHEAD, JR. ("Light-emitting Semiconductors"), is with the International Business Machines Corporation as leader of what he describes as "a small group burdened with the title 'electroluminescence technology.' " He was graduated from Swarthmore College in 1950 and received master's and doctor's degrees in physical chemistry at the University of Wisconsin in 1951 and 1953 respectively. He writes: "I taught chemistry for a year at Union College in Schenectady, N.Y. Deciding that my talents lay elsewhere than in teaching, I began a career of industrial research." He was with the General Electric Company before going to IBM in 1959. "My research interests have always been concerned with the interaction of light and solids," he writes. "On the practical side I have been interested recently in the applications of luminescence to computer displays."

GERALD FEINBERG ("Ordinary Matter") is professor of physics at Columbia University. He was graduated from Columbia College in 1953 and remained at the university from 1953 to 1956 as a National Science Foundation fellow. Obtaining a Ph.D. from Columbia in 1957, he spent a year as a member of the School of Mathematics of the Institute for Advanced Study in Princeton and two years as a research associate at the Brookhaven National Laboratory before returning to Columbia as a member of the faculty. Feinberg's article, which is based on a talk he gave in 1964 at a meeting of a scientific society called the $\nabla^2 V$ Club at the University of Cambridge, was originally published in *The Journal of Philosophy*.

ROBERT M. MENGEL, who in this issue reviews *The Original Water-Color Paintings by John James Audubon for the Birds of America,* introduction by Marshall B. Davidson, is lecturer in zoology and ornithological bibliographer at the University of Kansas.

Good Water from Bad: A Report from General Dynamics

When is a water shortage not a water shortage?

Most of the time.

Except for the relatively small areas of the earth covered with desert, water supplies in lakes, rivers, and underground tables would be more than ample for the world's population—if it were all fit to drink.

In many cases it is too brackish; its heavy concentration of dissolved salts makes it either dangerous or just plain bad tasting. "Salts" are not just common table salt (sodium chloride); a dissolved salt, by definition, is a solid substance that is soluble in water.

Hundreds of thousands of families already use double water systems. Available water from the tap is used for general cleaning. For drinking and cooking, they buy bottled water.

Conventional treatment systems can remove most of the solids, such as those that come, say, from the wastes and sewage that pollute so many of the nation's rivers. But to get rid of the dissolved salts—to desalinate—subtler techniques are required. One is reverse osmosis.

Osmosis, forward and reverse:

Since 1962, General Dynamics has used reverse osmosis to desalinate water, mainly under contract to the Office of Saline Water of the Department of the Interior.

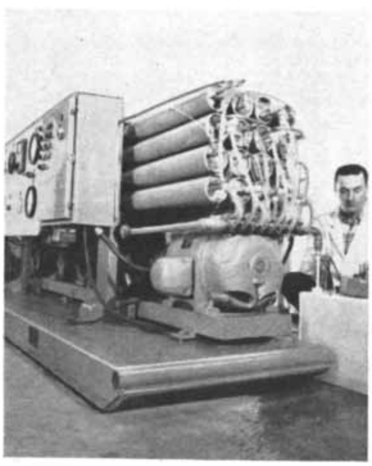
Osmosis is a phenomenon that occurs naturally whenever a dilute liquid (such as fresh water) and a concentrated liquid (such as salt water) are separated only by a semipermeable material—that is, one which selectively permits one kind of molecule to pass through it, but not another kind.

Under ordinary conditions, fresh "pure" water would diffuse through such a membrane material into an adjacent "impure" saline solution.

But apply pressure to the "impure" water and reverse osmosis takes place; the flow through the membrane goes the opposite way.

Water molecules from the salty solution are forced through the membrane into the fresh water. The "selective" permeability of the material acts as an effective barrier to the passage of salt molecules.

Below: water flow from 10,000 gallons-per-day reverse osmosis unit is checked by General Dynamics engineers before unit is shipped.



The mysterious membrane:

The heart of the process is a membrane only five thousandths of an inch thick. This membrane is basically made of cellulose acetate in a transparent film form resembling household plastic wrap.

It had been known for some time that fresh water passed readily through certain of these membranes, but dissolved salts and other impurities did not. Nobody knew quite why. An assumption was that the membrane was a very fine mechanical filter—water molecules were small enough to seep through the holes in the film, but salt molecules were too large.

General Dynamics' scientists found that the cellulose acetate membrane, thin though it is, has two different layers.

A spongy porous material that accounts for 99.8 percent of the membrane's thickness is mainly supportive, and lets both water and dissolved salts through.

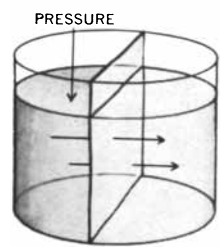
The actual stopper was the second layer, only ten-millionths of an inch thick. This thin second layer is nonporous. Its action is molecular and chemical rather than physical. It *absorbs* water molecules—absorbs them more readily than the salt molecules, allowing the absorbed water molecules to move through the membrane easily and to reappear on the "pure" low pressure side. Less than five percent of the salt molecules get through.

The same process that keeps out dissolved salts also holds back other waste matter, even bacteria, and—some researchers suspect—viruses.

General Dynamics reverse osmosis units are built up of modules which can contain up to 300 square feet of membrane per cubic foot.

Reverse osmosis units are already being built in a variety of sizes. A single small module can satisfy a family's daily drinking water needs. By linking enough modules, larger units process thousands of gallons a day. And still bigger combinations will be able to process hundreds of thousands—or even millions—of gallons of water daily.

Some conventional forms of desalination require large installations and large heat sources to make steam for an essentially distillation process. Reverse osmosis plants can be compact because the water remains in its original liquid state throughout the process.



The Phenomenon of Reverse Osmosis

Normally, water from a dilute solution will flow through a semipermeable membrane towards a concentrated solution. Reverse osmosis takes place when pressure is applied to the concentrated solution and forces water in the opposite direction. **1.** Salt molecules (marked "S") have little chemical affinity with membrane molecules. They tend to be rejected, in spite of the applied pressure, by the membrane barrier. **2.** Water molecules mingle intimately with membrane molecules in the ultra-thin layer of the membrane—the "diffusion region." This union and diffusion is molecular; it is not a physical filtering of water. **3.** When the water molecules pass through the ultra-thin diffusion layer into the porous supportive layer of the membrane, they liquefy and become water again. **4.** Pure water droplets continue to seep through the membrane and emerge on the low pressure side.

Ordinary electric power operates a pressure pump. Simplicity of design permits a system to operate virtually unattended for long periods between maintenance checks.

From rivers and mines:

The General Dynamics units have been test-operated under a variety of local water conditions: on rivers where the water was polluted both with industrial wastes and concentrations of salts from ocean tides, and in industrial applications such as coal mines.

The drainage of acid water from mines presents a major pollution problem. Sulphuric acid in the mine water dissolves minerals containing iron, calcium, and magnesium, creating a whole complex of salts that become a hazard to fish, wildlife, and municipal water supplies. The reverse osmosis experiments held back most of the heavy concentrations of dissolved salts from the mine water and produced high quality fresh water.

In factory use, reverse osmosis units in combination with conventional filters (to eliminate gross physical particles), could clean used factory waste water before it re-enters rivers, with some portion of the freshly processed clean water recirculated for reuse by the factory.

Reverse reverse:

Reverse osmosis has another potentially valuable and almost opposite use: water *extraction*.

For example, water is traditionally boiled out of maple sap to make maple syrup. This is an expensive and time-consuming process. Pilot tests by the Department of Agriculture indicate that a reverse osmosis unit can achieve the same result. In this case, the useful product is what is left after the water is removed.

Theoretically, the extraction principle can be applied to many products, including chemicals and pharmaceuticals, that now require elaborate processing to be concentrated or made water-free. Research is creating a "family" of membranes for a variety of specific jobs.

Certainly fresh water produced by reverse osmosis, or any desalination process, is more expensive than water from local natural sources. Yet in many areas where good water is a scarce and expensive resource, the reverse osmosis process may already be economic.

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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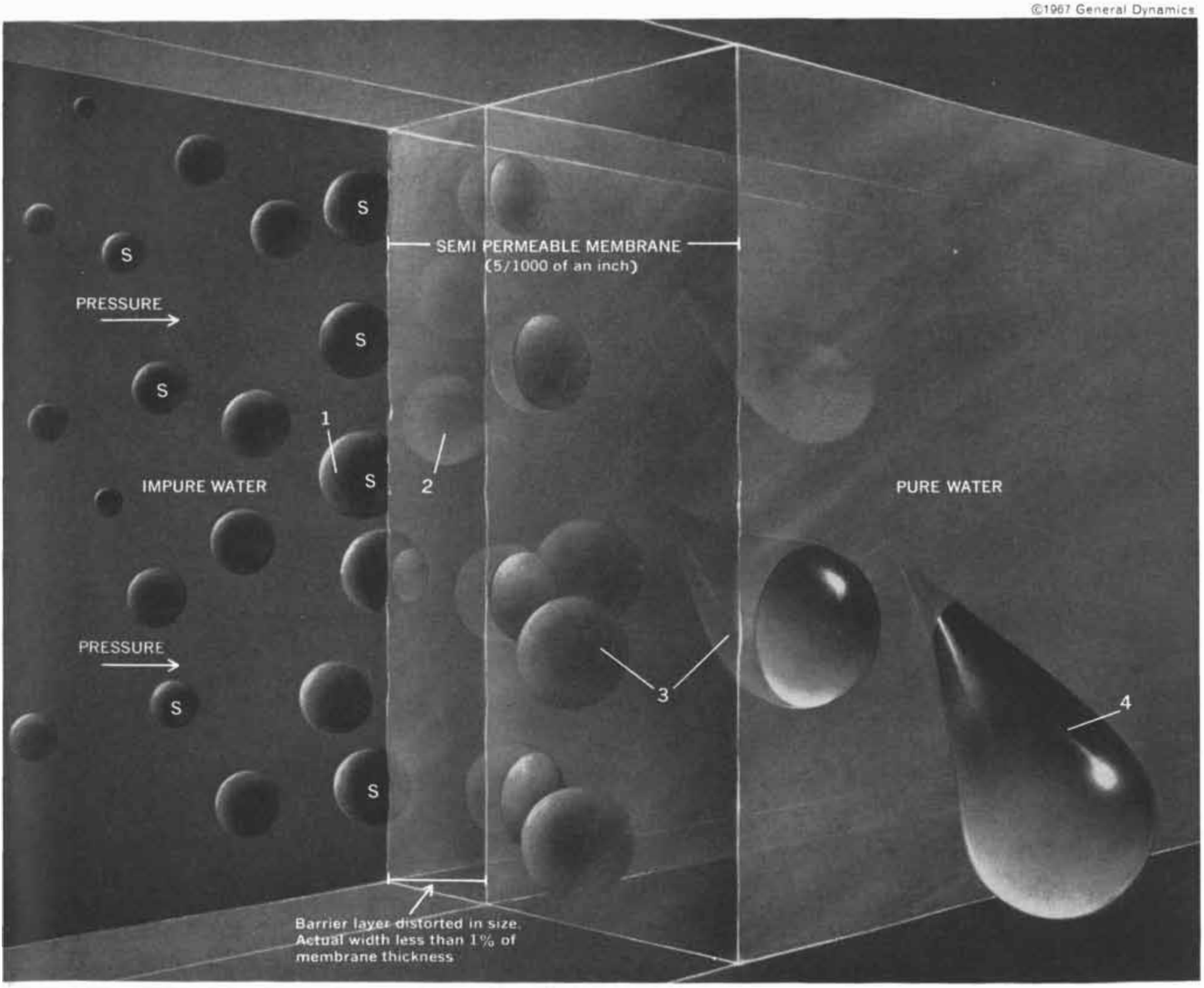

SCIENTIFIC AMERICAN
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A Third Generation of Breeder Reactors

The evolution of fission reactors capable of breeding more fuel than they consume is continuing. The present plan is to develop a plant that will generate a million kilowatts of electric power

by T. R. Bump

Sixteen years have passed since the first experimental nuclear-reactor plant that generated electricity was built at the Atomic Energy Commission's reactor testing station near Arco, Idaho. Today there are commercial nuclear-power plants in almost every section of the U.S. and many in other countries around the world. Nuclear power has become competitive in cost with power from coal or oil, and it is estimated that in the next five years nuclear-plant capacity in the U.S. will increase sixfold.

Oddly enough, with the arrival of fission power's economic success there are already forecasts suggesting that its years may be numbered. Simcha Golan of Atomics International recently projected the U.S. needs for steam-produced electric power over the next half-century; he found that by the year 2030 the requirement will be 10 times the present capacity. Because of the expected decline in fossil-fuel resources, and in the absence of any other large source of energy at reasonable cost, fission power would be counted on to supply about 85 percent of this need. To fill such a demand with fission plants of the present type, however, would call for quantities of uranium ore that would soon deplete reserves [*see illustrations on next page*]. Thus the fission age would be over almost before it began. The cost of mining the dwindling deposits would raise the price of uranium ore to about $30 a ton (compared with $5 today). At that cost for the unrefined fuel, fission power would probably be as expensive as power from difficult-to-mine fossil fuels, and the price of energy might be so high that the U.S. could not afford the projected level of consumption.

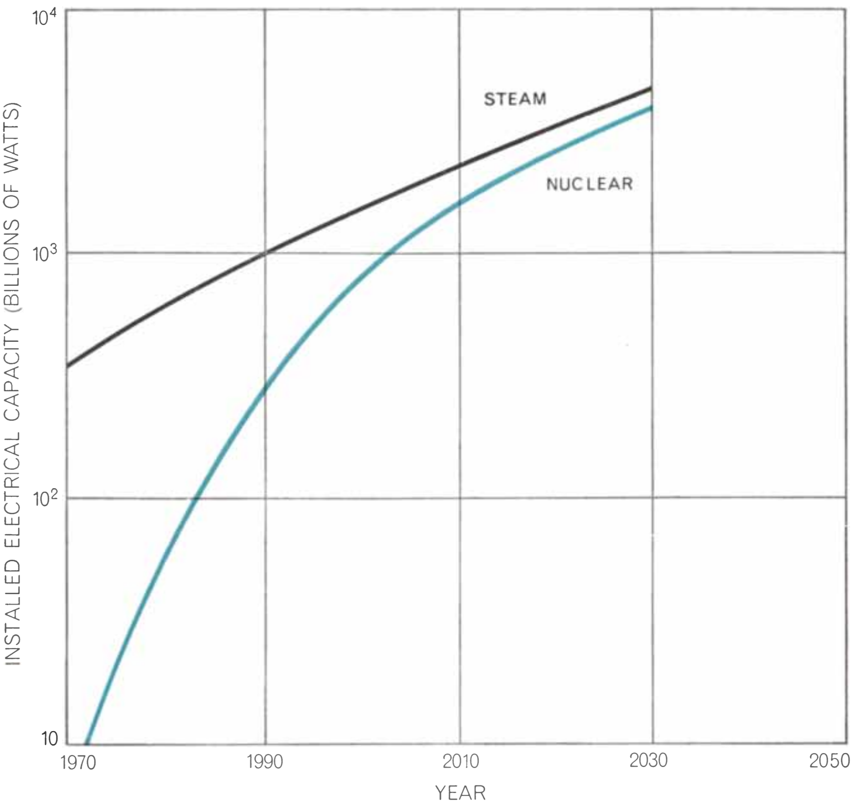
These facts make plain how heavily the "fission age" (perhaps to be followed someday by a "fusion age") can depend on success in developing power plants with breeder reactors that will make the most of the available resources. These plants consume fissionable uranium 235 and plutonium not only to produce energy but also to transmute common uranium 238 into even more plutonium at the same time, thus multiplying by many times the amount of energy obtainable from a given amount of uranium ore. For this reason work on breeder reactors started almost at the beginning of the nuclear age. This explains why the plant that produced electric power at Arco 16 years ago was a breeder.

In spite of that early start, efforts to develop a breeder reactor that can produce power as cheaply as other systems have yet to succeed. On the other hand, nonbreeding reactors have already reached commercial status. Their success is due in part to the benefits they received from the high-priority program to build naval reactors and in part to the fact that nonbreeding reactors present simpler technical problems than breeders. Nonbreeding reactors are usually cooled with water. They use moderated, or slow, neutrons, which are considerably less efficient than fast neutrons both in producing plutonium and in utilizing fuel resources.

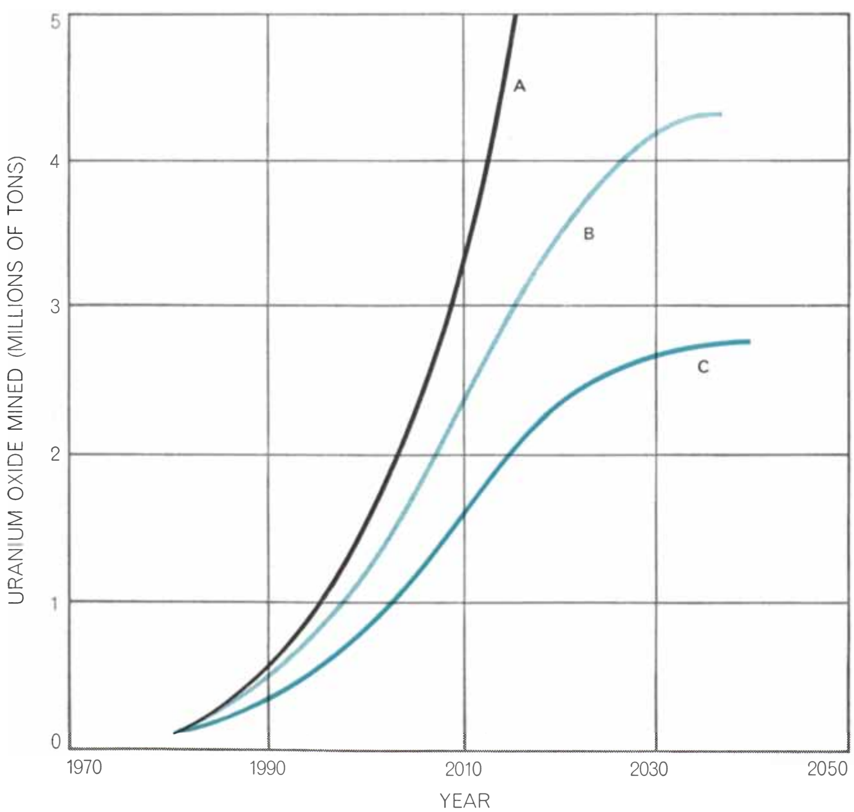
Meanwhile efforts to develop a practicable breeder reactor are being continued with encouraging results. The original experimental breeder reactor at Arco, called EBR-I, is now a museum piece; it was retired in 1964 and placed on exhibition as a historic landmark. EBR-I was followed by several second-generation experimental breeders, which were described in an article in *Scientific American* several years ago [see "Breeder Reactors," by Alvin M. Weinberg; January, 1960].

Now the Argonne National Laboratory of the AEC and a number of other organizations throughout the world are cooperating in the development of a third generation of breeder reactors. The work should make available within 15 years commercial power plants that have breeder reactors and are capable of producing electricity in the million-kilowatt range. These reactors, like EBR-I and several of the second-generation reactors, probably will be cooled by sodium and will operate with solid fuel and fast neutrons.

Another seemingly promising type of breeder that was under investigation at the time of Weinberg's 1960 article—an aqueous system operating with dissolved fuel and slow neutrons—has since been abandoned. As Weinberg pointed out,



ELECTRICAL CAPACITY in the U.S. is projected for power produced in nuclear plants (*color*) and in steam plants (*black*). The projection assumes that fossil fuels will become more expensive and that power costs will be kept down by increasing use of nuclear fuel.



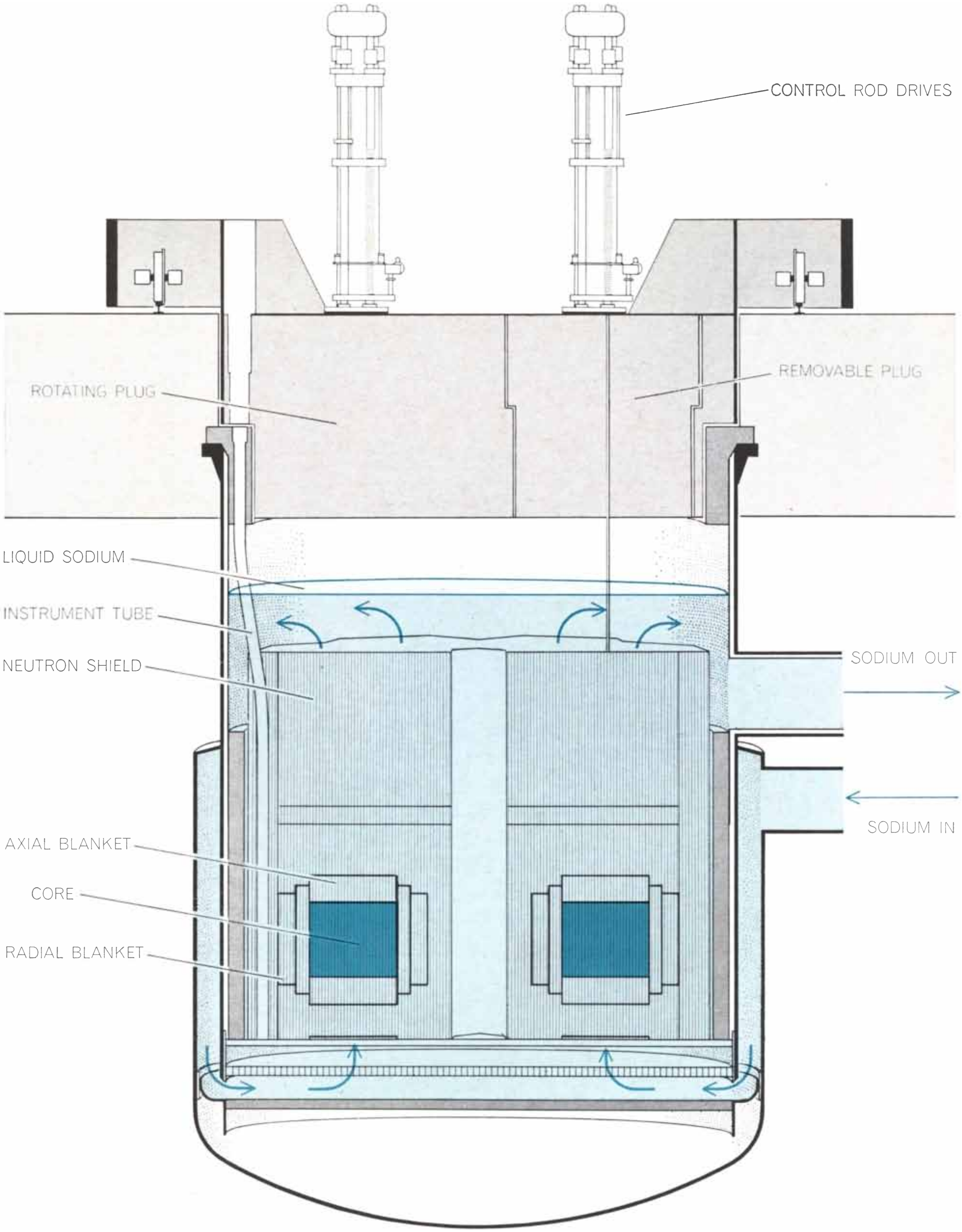
URANIUM CONSUMPTION is projected for an economy that uses only nonbreeder reactors (*A*), one that combines them with breeder reactors (*B*) and one that uses nonbreeders, breeders and heavy-water reactors (*C*), which would further reduce needs for nuclear fuel.

the aqueous system, in which the fuel and the coolant were mixed together as a homogeneous solution, presented serious difficulties, such as local overheating, corrosion of plumbing and a tendency for the fuel and the coolant to separate. The problems proved to be so troublesome that the experiments were dropped, and work is now concentrated on the sodium-cooled fast-neutron breeder.

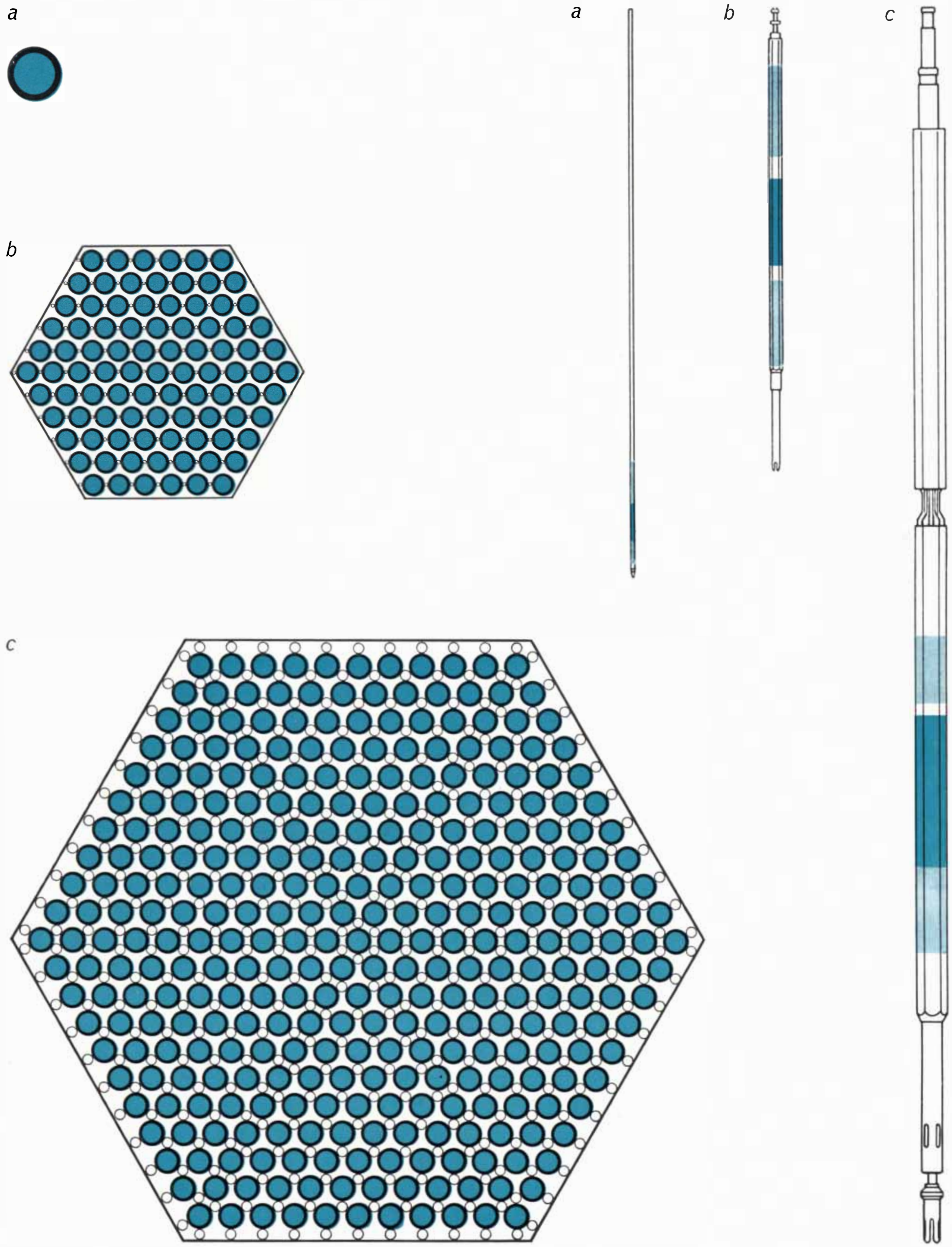
I shall describe the probable commercial breeder plant of the future by comparing it in detail with two of its forerunners, the Argonne Laboratory's experimental breeder reactors I and II. EBR-I was a small installation generating 200 kilowatts of electricity; EBR-II, representative of the second-generation breeders currently in operation, generates 20,000 kilowatts; the commercial plant is expected to generate about a million kilowatts. In nuclear power, as in many other fields, expansion of the size of the plant brings substantial savings in costs. Other reductions in the cost of power from the future plant will flow from such potential improvements as higher temperatures of sodium and steam (which result in increased efficiency of the turbines), a longer lifetime for fuel elements, and cheaper and more reliable components.

First let us consider the fuel itself. The fuel is uranium or plutonium or a combination of both. In EBR-I it was almost pure uranium 235. One of the difficulties with solid-fuel reactors is that the fuel elements (rods of fissionable material jacketed in stainless steel) become swollen with fission products and must be removed for reprocessing by the time a small percentage of the fuel has been burned. In EBR-II, therefore, the uranium fuel is alloyed with other elements that reduce the amount of swelling (by increasing the strength of the fuel so that it is better able to withstand the pressure of the gas that constitutes part of the fission products). For the commercial plant not only metal fuels are being considered but also ceramic ones. Among the apparent advantages of ceramics are their high melting point and the fact that they can be used at high temperatures with a relatively inexpensive jacket of stainless steel.

Another important consideration is the diameter of the fuel elements. In EBR-I the rods were made comparatively thick—.448 inch in outside diameter, including the jacket—for convenience in fabricating and handling. The thicker the fuel rod, however, the hotter



PROSPECTIVE REACTOR for a third-generation nuclear power plant using the breeder principle is shown according to one of several proposals that have been made. Uranium fuel (*dark color*) is in the core; the blankets contain "fertile" uranium in which additional fuel is bred by neutrons leaking from the core. Sodium is used for cooling. The removable plug gives access to the reactor when it is necessary to remove and replace fuel subassemblies for reprocessing. Reactor is designed for a million-kilowatt power plant.



FUEL ELEMENTS of three breeder reactors are compared in sectional views (*left*) and side views (*right*). The first experimental reactor, EBR-I (*a*), had 217 fuel elements that were loaded into the reactor individually. EBR-II (*b*) has about 6,400 fuel elements, mounted in hexagonal subassemblies of 91 fuel elements each; one subassembly is shown here. The reactor in the million-kilowatt plant (*c*) will have about 630 subassemblies, each with about 330 elements. Fuel is shown in dark color, blanket material in light color.

the fuel becomes when it is burned. In a rod half an inch in diameter the central temperature will exceed the melting point even if the burning rate is modest. Since nuclear-power economy depends on operating each reactor at a high specific power (a high power output in kilowatts per kilogram of fuel), the fuel elements must be thin so that they will not overheat internally. In the design of EBR-II the fuel elements were reduced to a diameter of .174 inch. This size, however, has been found to make the fabrication of the elements too costly. For the commercial plant the elements are likely to be at least .21 inch in diameter—a figure that seems to strike a good compromise between cost of fabrication and the specific power level at which the reactor can be operated.

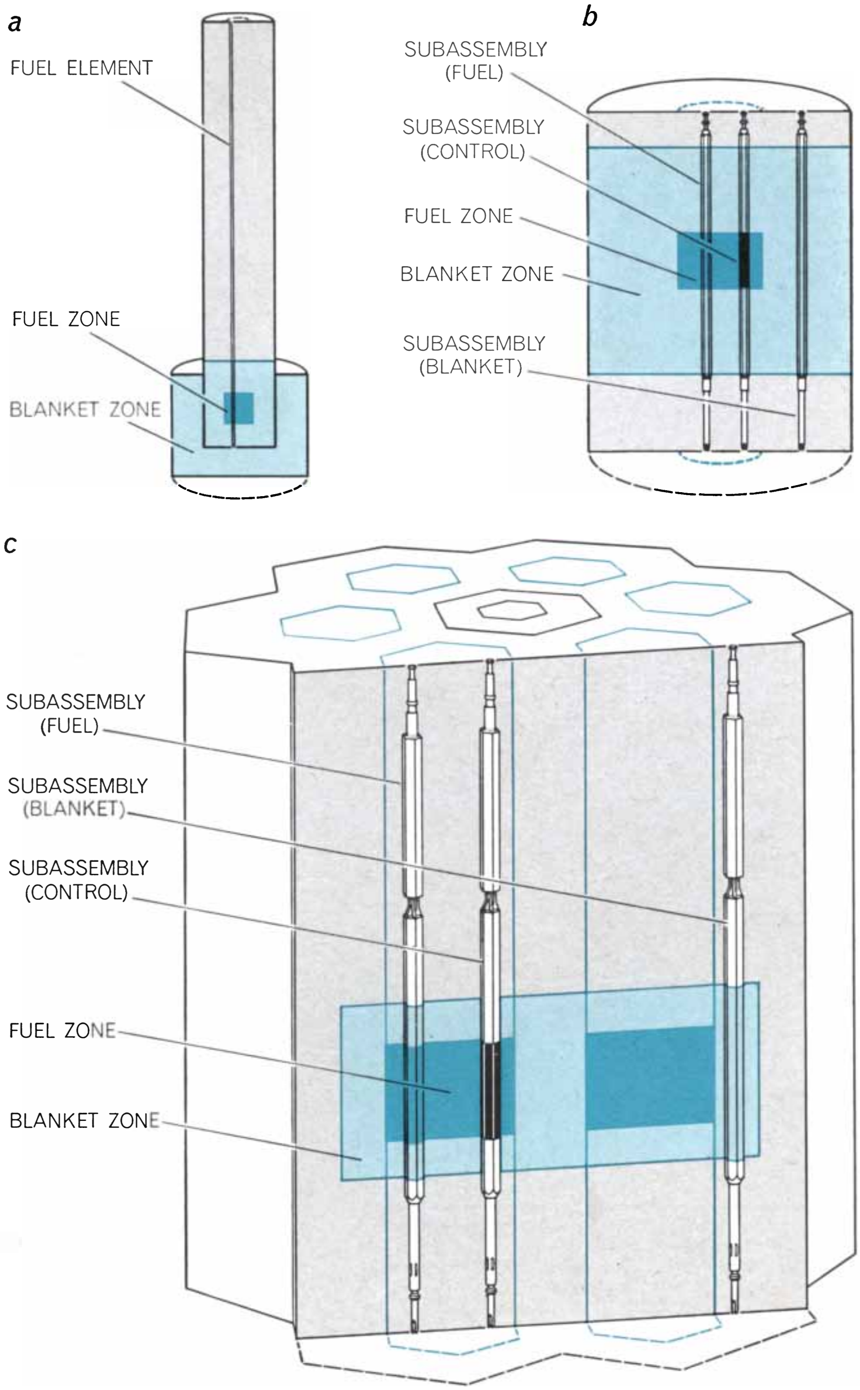
In EBR-I the fuel load consisted of an array of 217 rods, held in a fixed pattern by jacket ridges that ensured uniform distribution of the elements throughout the reactor core. In the larger EBR-II there are about 6,400 fuel rods. To facilitate the handling of this large number of fragile rods they are clustered in hexagonal assemblies of 91 rods each. We anticipate that the million-kilowatt commercial reactor will have a total of as many as 200,000 fuel rods—about 630 clusters with about 330 rods in each [*see illustration on opposite page*]. The arrangement and amount of fissionable fuel required to produce a critical mass will be determined beforehand in a "critical facility": a low-power reactor in which mock-ups of the proposed configurations can be tested.

As in EBR-I and EBR-II, the core of the commercial reactor will be surrounded with a blanket of "fertile" material consisting of rods of uranium 238 in which plutonium will be bred by the capture of neutrons from the fissioning core. Through the reactor will be pumped molten sodium, which will convey the heat generated in the core to a secondary, nonradioactive circulating coolant, which in turn will transfer the heat to a steam generator for the production of electricity.

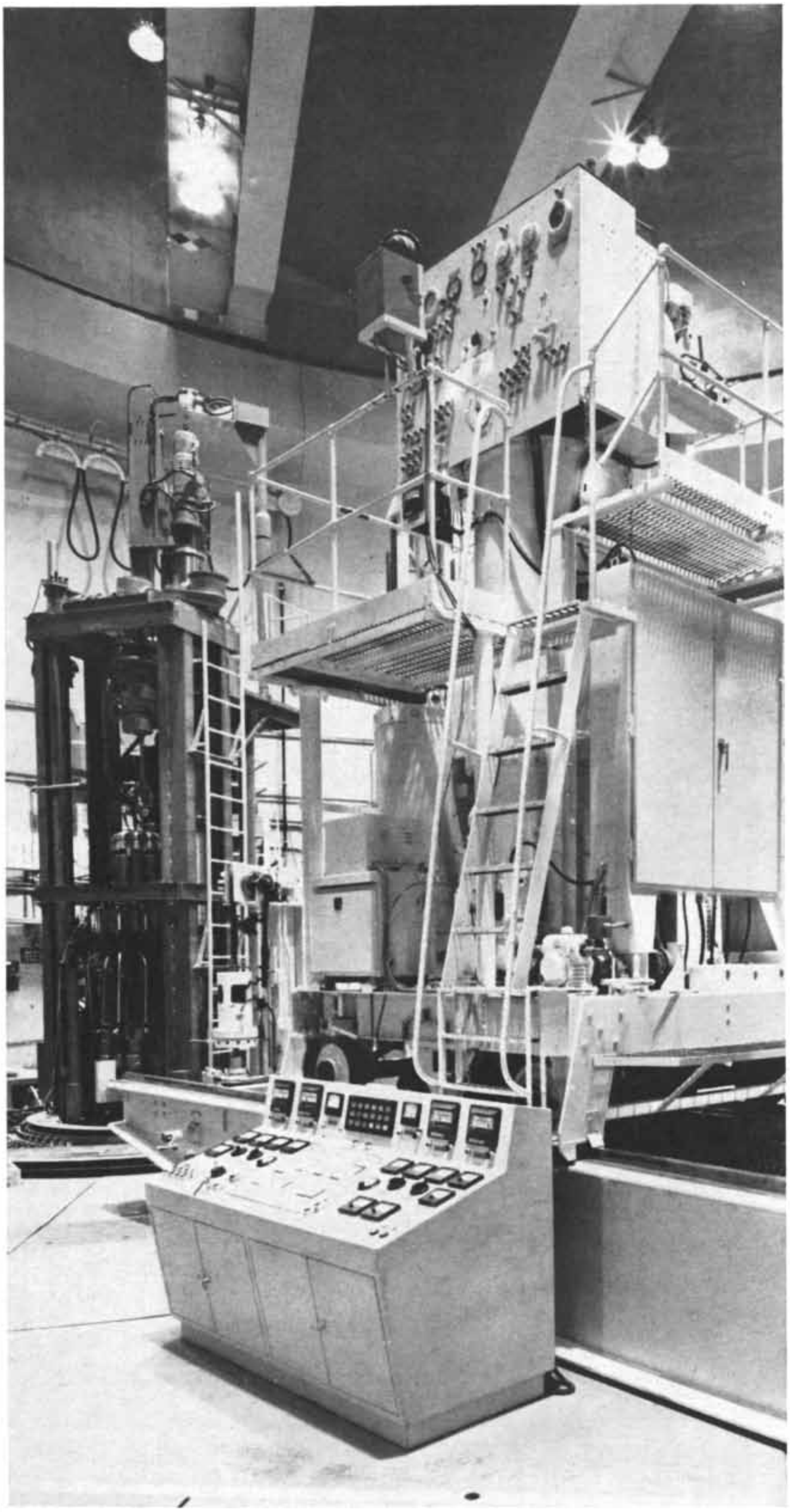
Sodium, the first choice as a coolant for breeder reactors at the outset of the nuclear age, still appears to be superior to other coolants that have been evaluated since. Sodium has a good capacity for absorbing heat and is an excellent heat conductor; it has a low vapor pressure at high temperatures and therefore does not require thick-walled piping, and it does not substantially slow down fast neutrons, which are essential to the

FUEL ELEMENTS	EXPERIMENTAL BREEDER REACTORS I	EXPERIMENTAL BREEDER REACTORS II	1,000-MEGAWATT REACTOR
NUMBER PER SUBASSEMBLY	0	91	630
SUBASSEMBLIES	0	70	331
TOTAL	217	6,370	208,530

NUMBER AND GROUPING of fuel elements are summarized for three stages in the evolution of breeder reactors. Million-kilowatt plant is often called 1,000-megawatt plant.



CORE SECTIONS are compared for EBR-I (*a*), EBR-II (*b*) and a breeder reactor designed for a million-kilowatt power plant (*c*). The three core sections are represented at the same scale to indicate how the size of reactors increases with an increasing output of power.



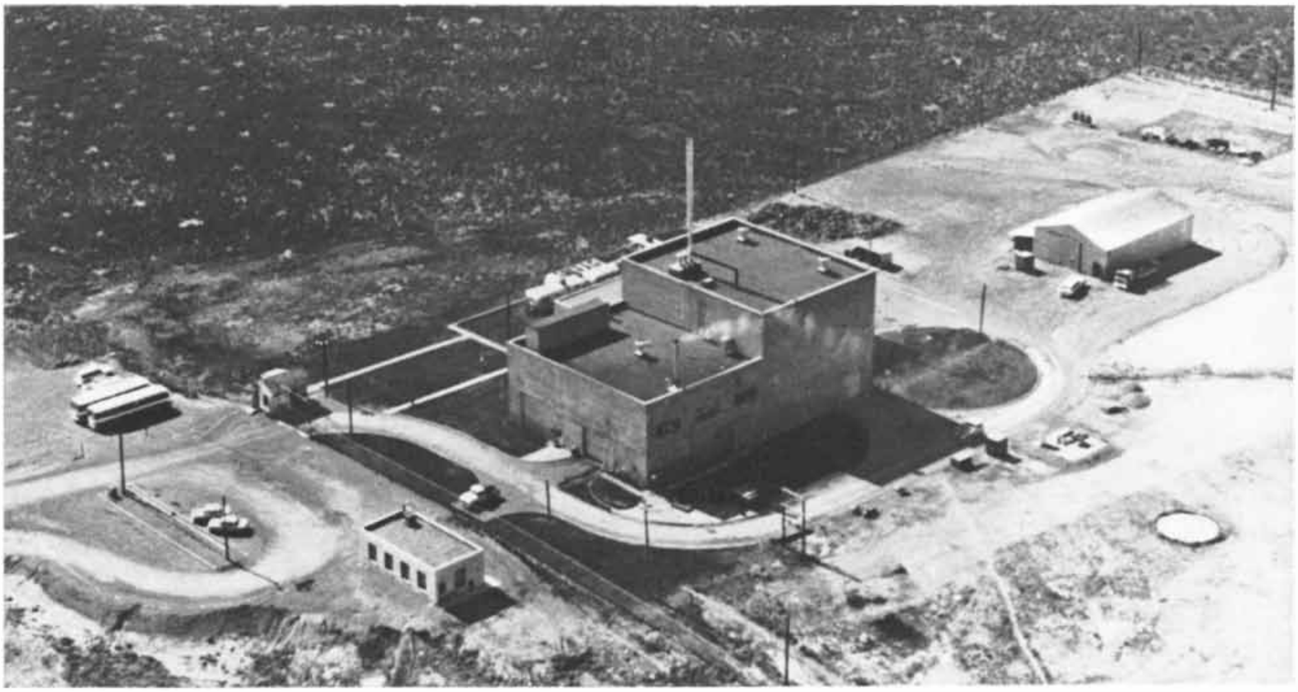
FUEL-HANDLING APPARATUS of the EBR-II includes (*left*) various mechanisms over the reactor. They move spent fuel subassemblies from the reactor vessel and deposit them in a rotatable storage rack immersed in sodium, which cools the highly radioactive subassemblies. After two weeks a subassembly is lifted into an unloading machine (*right*), which moves on rails to the wall of the building and transfers the subassembly to a cask that carries it to a fuel-reprocessing building. Similar plan is likely for the million-kilowatt plant.

efficient performance of a breeder reactor. Sodium has certain shortcomings as a fluid coolant: it has to be heated to a fairly high temperature (above 208 degrees Fahrenheit) to keep it molten; it is active chemically, and it is expensive (compared with water or other conventional coolants). Nevertheless, its advantages considerably outweigh its disadvantages.

The two-stage system of heat transfer that I have mentioned is needed because the sodium within and around the reactor core becomes radioactive. In the first stage the sodium that has been heated in the core transfers its heat to a nonradioactive secondary system in which the coolant is also sodium; in the second stage this intermediate coolant passes its heat on to water boilers and produces steam for driving turboelectric generators. The whole system is rather complex, requires careful engineering and has been a major factor in shaping the evolving design of the breeder reactor.

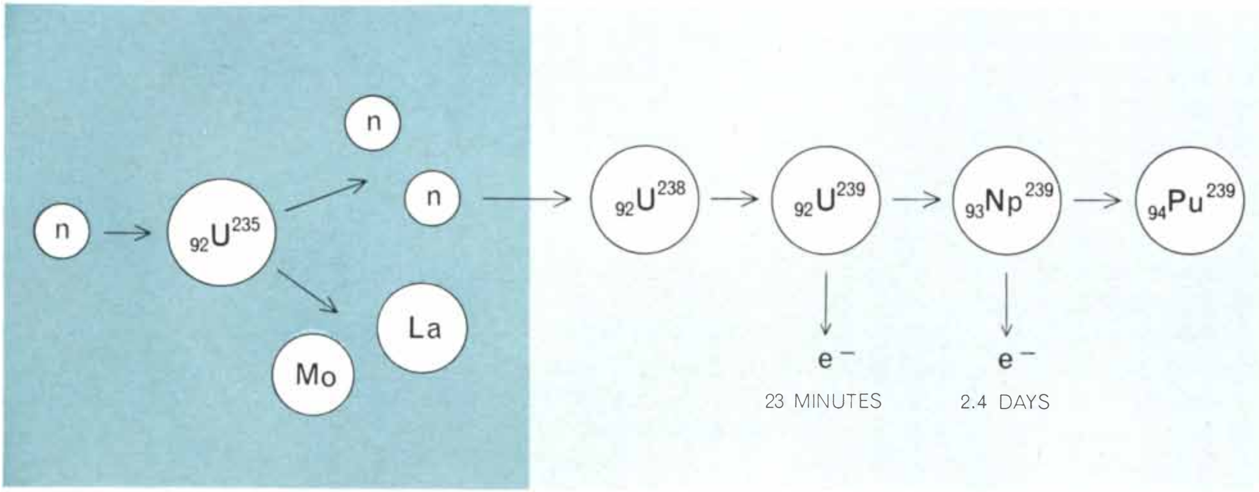
In EBR-I the primary sodium coolant (actually a sodium-potassium alloy) was circulated through the shielded reactor vessel and then to a chamber outside that contained the primary pump and intermediate heat-exchanger; this chamber also had to be shielded. In EBR-II the arrangement is simplified: the entire primary system (including the reactor vessel, primary pumps and intermediate heat-exchanger) is submerged in sodium contained in a tank, so that the radioactive sodium remains within this system and almost all the radioactivity in the plant is confined to one part of it. This arrangement has several advantages. The only sizable structure in the power plant that needs to be enclosed in shielding is the tank. The tank's simple shape makes it comparatively easy to render the tank leakproof. Small leaks are permissible in the primary piping, because the sodium will not escape from the tank itself. There are also benefits that simplify the handling of the fuel and other details of operation. It is likely that the concept of a submerged primary system will be used for the commercial reactor.

The heat-exchangers and pumps required by a sodium-cooled reactor present their own special problems. Heat-exchangers of conventional kinds can be adapted to the needs of a sodium system, but their design must be carefully modified to avoid possible damage from thermal shock. Because of sodium's high thermal conductivity, any abrupt change in the temperature of the sodium (such as might be caused by a sudden



FIRST BREEDER REACTOR is in this building built by the Argonne National Laboratory at the National Reactor Testing Station at Arco, Idaho. The reactor operated from 1951 to 1964 and is now a national landmark. It had a capacity of 200 kilowatts of power.

SECOND-GENERATION BREEDER REACTOR is in the domed structure. In the foreground are cooling towers; at left is a sodium-boiler plant; behind the domed structure is a fuel-reprocessing plant; at right rear is a laboratory and service building, and in the right foreground is the power plant. The EBR-II complex, which is at Arco, has the capacity to produce 20,000 kilowatts of power.



FISSION AND BREEDING are the key nuclear processes in a breeder reactor. In fission (*dark color*) an atom of uranium 235 absorbs a neutron (*n*) and emits at least two neutrons and nuclei of such other elements as lanthanum and molybdenum. In breeding (*light color*) fertile uranium 238 absorbs a neutron and emits a beta particle (e^-) to become neptunium, which then undergoes beta decay to become fissionable plutonium 239. In future breeders the fission process will use atoms of plutonium rather than U-235.

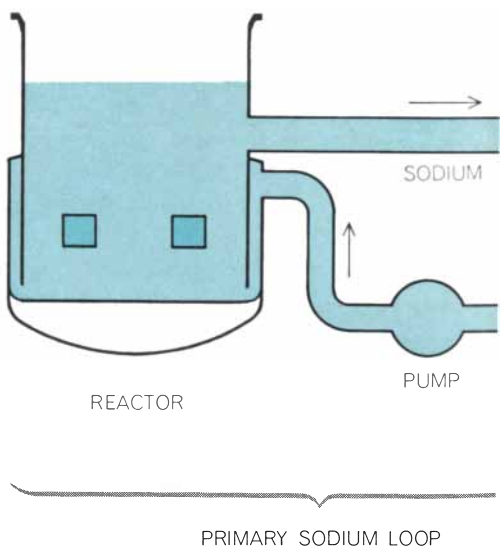
shutdown of the reactor) will be delivered abruptly at the surfaces of the exchanger, and this can cause large thermal stresses. There can also be large stresses arising from normal temperature gradations across the tube walls of the exchanger.

At the interface between the sodium coolant and the water in the steam-generating system a more serious hazard must be dealt with. Sodium, as every chemistry student knows, reacts explosively with water. Extreme care must therefore be taken to prevent any leakage of the sodium into the water at the exchangers where the sodium transfers its heat to make steam. In EBR-I, to ensure that there would be no leaks, the tube walls between the sodium and the water were three-layered—a layer of copper sandwiched between two layers of nickel. This is too expensive a system for large-scale application. In EBR-II the cost is reduced somewhat by the use of double-walled tubes made of low-alloy steel. Stainless steel under stress is corroded by water, and up to now almost all efforts to produce a steam generator with single-walled tubes that is leakproof in a sodium-cooled system have failed. The low-alloy steel used in EBR-II is less susceptible than stainless steel to such corrosion, however, and we have reason to believe that with continued improvements in the design and fabrication of steam generators using this material it will be possible to use single-walled tubes in the commercial plant.

Like the heat-exchange system, the special pumps needed to move the sodium have also undergone a developmental evolution. EBR-I employed an ingenious pump of an electromagnetic type that took advantage of sodium's high electrical conductivity. A direct electric current was passed through the sodium at right angles to an applied magnetic field, and the electromotive force thus produced propelled the sodium in the same way that a rotor is driven in an electric motor. The EBR-I primary pump moved the sodium at the rate of 500 gallons per minute at a pressure of 30 pounds per square inch. For the larger EBR-II, which calls for 10,000 gallons per minute at 60 pounds per square inch, it proved to be difficult to adapt the electromagnetic type of pump. When the pump was scaled up to the larger size, the prevention of leaks and the supplying of the necessary current (200,000 amperes) proved to be major problems. The primary pump used in EBR-II is therefore of the more conventional centrifugal type. It employs liquid sodium under high pressure in a bearing near the impeller to steady and lubricate the rotating shaft of the impeller.

In EBR-II the pump employed to drive the secondary transport system (the nonradioactive sodium carrying heat to the steam generator) is an electromotive device using alternating current. Electric currents induced in the sodium react on an applied magnetic field to develop the driving force. This idea is attractive because it obviates the need for a high-current source and for contacts to feed current into the sodium, and because the pump output can be accurately controlled more easily than in a centrifugal pump. The arrangement is flawed, however, by the fact that the winding for producing the magnetic field must be close to the hot sodium, which makes the problem of cooling its insulation difficult. It now appears that in the commercial plant all the large pumps, both primary and secondary, will be scaled-up versions of the centrifugal pumps used in the EBR-II primary system. In the commercial plant the primary pumps will be required to deliver a total of about 250,000 gallons of sodium per minute at a pressure of as much as 90 pounds per square inch.

Now let us return to the reactor core



KEY ELEMENTS OF A DESIGN for a future breeder reactor power plant with a and examine the arrangements for handling the fuel. The handling involves removing the spent fuel elements for reprocessing and replacing them with fresh elements. Because the spent elements are highly radioactive, provision must be made for cooling and shielding them after they are unloaded from the reactor.

In EBR-I the handling system was rather simple. An aperture in the top lid of the reactor vessel was opened, a grapple was lowered to seize and lift the element that was to be removed, and the grapple deposited the element in a lead-shielded cask, in which the element was transferred to a storage area to await reprocessing. In EBR-II several complications made it necessary to devise a more elaborate system. Because its fuel assemblies are all deeply immersed in sodium, the problem of locating individual assemblies for removal arose. Cooling became more difficult, because more positive cooling measures are required for an assembly of elements than are necessary for a single element. Furthermore, in EBR-II the space above the reactor is crowded with control-rod mechanisms, which complicates the problem of access to the reactor.

The system that was developed for EBR-II works as follows. The reactor is shut down by means of control rods, the cover of the reactor vessel is unlocked and raised, and the cover is turned to place an opening over the fuel assembly that is to be removed. A "hold-down" mechanism is then lowered into the vessel to keep in place the assemblies around the one to be removed, after which a gripper is attached to the assembly and it is lifted out of the reactor. A swinging transfer arm moves the assembly to a storage rack, still inside the primary tank and immersed in sodium. The transfer arm picks up a fresh, unspent fuel assembly that has been stored in the same rack and delivers it to the gripper, which lowers it into the empty position in the reactor.

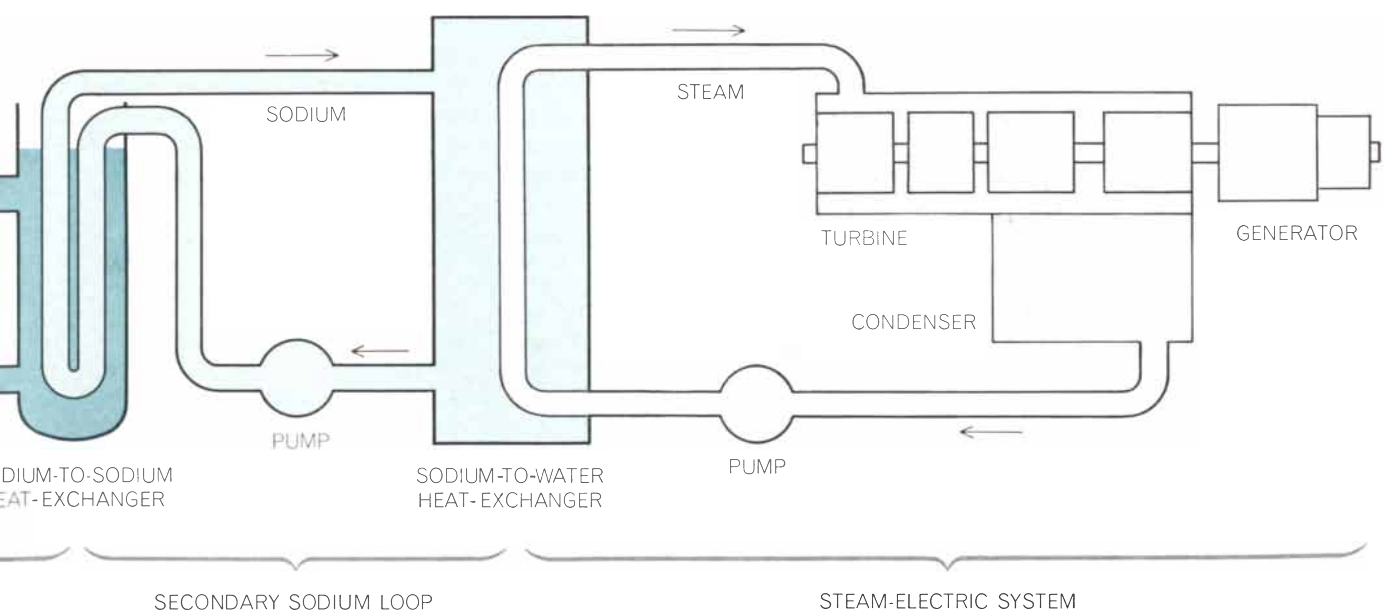
The spent assembly remains in the storage rack for two weeks, until its heating from fission-product radioactivity has decreased substantially. It is then lifted out of the sodium into a shielded cask that runs on rails to an air lock in the side of the reactor building, through which it is discharged into another cask for transportation to the fuel-reprocessing building. There the fuel elements are separated. For the first time they no longer require the cooling provided initially by the sodium in the primary tank and later by forced circulation of argon gas.

The loading of the reactor with fresh or reprocessed fuel follows a reverse procedure. The assembly of fuel elements is preheated by hot argon gas during its trip to the storage rack, so that the assembly will not be damaged by thermal shock when it is lowered into the hot sodium in the tank.

The entire fuel-handling operation is conducted by remote control, of course, and fresh fuel assemblies can be delivered to the storage rack or spent ones removed from it while the reactor is in operation. The fuel-handling system for the commercial reactor probably will be modeled on the one in EBR-II, with perhaps some application of simpler features from EBR-I.

To complete the picture, the reactor control system should be mentioned. In EBR-I the reactor's power level was regulated by movement of both the blanket of uranium 238 surrounding the core and of 12 uranium rods inserted in the blanket. The movements controlled the number of neutrons available to cause fissions in the fuel. In EBR-II the control rods are inserted into the core itself, because such a placement will be necessary in the large reactor of a commercial plant. The 12 control rods of the EBR-II contain fissionable fuel; in the commercial plant the rods might be loaded with nonfissionable neutron-absorbing material to ensure more effective control.

I have suggested many of the principal problems to which research is being directed in the advance toward an economically competitive breeder reactor plant. Much work remains to be done in all these areas, but systematic progress has been made, and we have every reason to believe that by the 1980's the breeder plant will come into its own. In that event there will be no need to be concerned about the reserves of uranium, because the breeder will assure mankind of a sufficient supply of fissionable fuel for many centuries to come.



capacity of a million kilowatts are depicted schematically. The primary sodium loop is involved in cooling the reactor. The secondary sodium loop transfers heat to a water system in which steam is generated to run the turbines that generate electric power.

The Diving Women of Korea and Japan

Some 30,000 of these breath-holding divers, called ama, are employed in daily foraging for food on the bottom of the sea. Their performance is of particular interest to the physiologist

by Suk Ki Hong and Hermann Rahn

Off the shores of Korea and southern Japan the ocean bottom is rich in shellfish and edible seaweeds. For at least 1,500 years these crops have been harvested by divers, mostly women, who support their families by daily foraging on the sea bottom. Using no special equipment other than goggles (or glass face masks), these breath-holding divers have become famous the world over for their performances. They sometimes descend to depths of 80 feet and can hold their breath for up to two minutes. Coming up only for brief rests and a few breaths of air, they dive repeatedly, and in warm weather they work four hours a day, with resting intervals of an hour or so away from the water. The Korean women dive even in winter, when the water temperature is 50 degrees Fahrenheit (but only for short periods under such conditions). For those who choose this occupation diving is a lifelong profession; they begin to work in shallow water at the age of 11 or 12 and sometimes continue to 65. Childbearing does not interrupt their work; a pregnant diving woman may work up to the day of delivery and nurse her baby afterward between diving shifts.

The divers are called ama. At present there are some 30,000 of them living and working along the seacoasts of Korea and Japan. About 11,000 ama dwell on the small, rocky island of Cheju off the southern tip of the Korean peninsula, which is believed to be the area where the diving practice originated. Archaeological remains indicate that the practice began before the fourth century. In times past the main objective of the divers may have been pearls, but today it is solely food. Up to the 17th century the ama of Korea included men as well as women; now they are all women. And in Japan, where many of the ama are male, women nevertheless predominate in the occupation. As we shall see, the female is better suited to this work than the male.

In recent years physiologists have found considerable interest in studying the capacities and physiological reactions of the ama, who are probably the most skillful natural divers in the world. What accounts for their remarkable adaptation to the aquatic environment, training or heredity or a combination of both? How do they compare with their nondiving compatriots? The ama themselves have readily cooperated with us in these studies.

We shall begin by describing the dive itself. Basically two different approaches are used. One is a simple system in which the diver operates alone; she is called *cachido* (unassisted diver). The other is a more sophisticated technique; this diver, called a *funado* (assisted diver), has a helper in a boat, usually her husband.

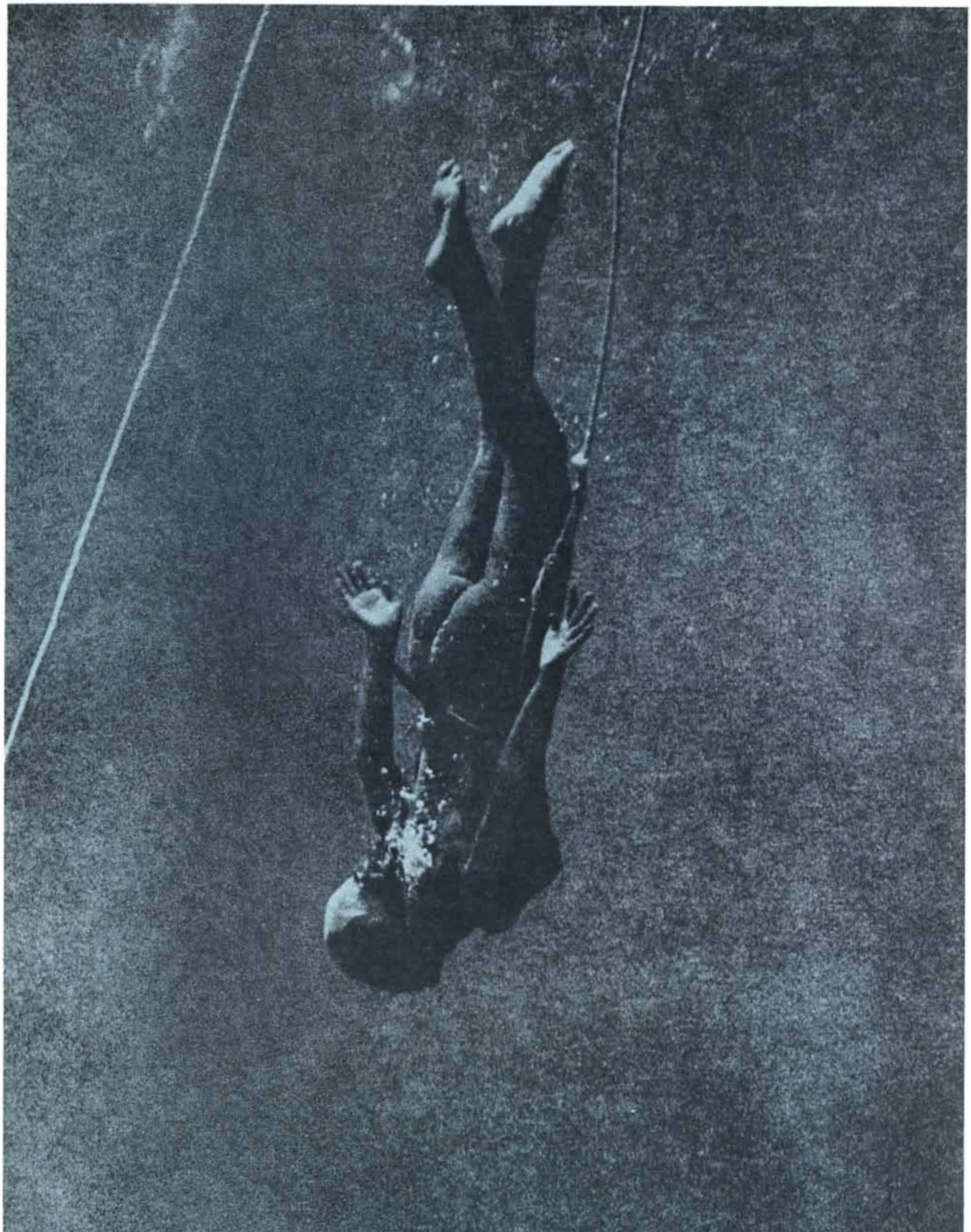
The *cachido* operates from a small float at the surface. She takes several deep breaths, then swims to the bottom, gathers what she can find and swims up to her float again. Because of the oxygen consumption required for her swimming effort she is restricted to comparatively shallow dives and a short time on the bottom. She may on occasion go as deep as 50 or 60 feet, but on the average she limits her foraging to a depth of 15 or 20 feet. Her average dive lasts about 30 seconds, of which 15 seconds is spent working on the bottom. When she surfaces, she hangs on to the float and rests for about 30 seconds, taking deep breaths, and then dives again. Thus the cycle takes about a minute, and the diver averages about 60 dives an hour.

The *funado* dispenses with swimming effort and uses aids that speed her descent and ascent. She carries a counterweight (of about 30 pounds) to pull her to the bottom, and at the end of her dive a helper in a boat above pulls her up with a rope. These aids minimize her oxygen need and hasten her rate of descent and ascent, thereby enabling her to go to greater depths and spend more time on the bottom. The *funado* can work at depths of 60 to 80 feet and average 30 seconds in gathering on the bottom—twice as long as the *cachido*. However, since the total duration of each dive and resting period is twice that of the *cachido*, the *funado* makes only about 30 dives per hour instead of 60. Consequently her bottom time per hour is about the same as the *cachido*'s. Her advantage is that she can harvest deeper bottoms. In economic terms this advantage is partly offset by the fact that the *funado* requires a boat and an assistant.

There are variations, of course, on the two basic diving styles, almost as many variations as there are diving locations. Some divers use assistance to ascend but not to descend; some use only light weights to help in the descent, and so on.

By and large the divers wear minimal clothing, often only a loincloth, during their work in the water. Even in winter the Korean divers wear only cotton bathing suits. In Japan some ama have recently adopted foam-rubber suits, but most of the diving women cannot afford this luxury.

The use of goggles or face masks to improve vision in the water is a comparatively recent development—hardly a century old. It must have revolutionized the diving industry and greatly increased the number of divers and the size of the harvest. The unprotected human eye suffers a basic loss of visual acuity in water because the light passing through water undergoes relatively little refraction when it enters the tissue of the cornea, so that the focal point of the image is considerably behind the retina [*see top*



JAPANESE DIVING WOMAN was photographed by the Italian writer Fosco Maraini near the island of Hekura off the western coast of Japan. The ama's descent is assisted by a string of lead weights tied around her waist. At the time she was diving for abalone at a depth of about 30 feet. At the end of each dive a helper in a boat at the surface pulls the ama up by means of the long rope attached to her waist. The other rope belongs to another diver. The ama in this region wear only loincloths during their dives.

illustration on page 40]. Our sharp vision in air is due to the difference in the refractive index between air and the corneal tissue; this difference bends light sharply as it enters the eye and thereby helps to focus images on the retinal surface. (The lens serves for fine adjustments.) Goggles sharpen vision in the water by providing a layer of air at the interface with the eyeball.

Goggles create a hazard, however, when the diver descends below 10 feet in the water. The hydrostatic pressure on the body then increases the internal body pressures, including that of the blood, to a level substantially higher than the air pressure behind the goggles. As a result the blood vessels in the eyelid lining may burst. This conjunctival bleeding is well known to divers who have ventured too deep in the water with only simple goggles. When the Korean and Japanese divers began to use goggles, they soon learned that they must compensate for the pressure factor. Their solution was to attach air-filled, compressible bags (of rubber or thin animal hide) to the goggles. As the diver descends in the water the increasing water pressure compresses the bags, forcing more air into the goggle space and thus raising the air pressure there in proportion to the increase in hydrostatic pressure on the body. Nowadays, in place of goggles, most divers use a face mask covering the nose, so that air from the lungs instead of from external bags can serve to boost the air pressure in front of the eyes.

The ama evolved another technique that may or may not have biological value. During hyperventilation before their dives they purse their lips and emit a loud whistle with each expiration of breath. These whistles, which can be heard for long distances, have become the trademark of the ama. The basic reason for the whistling is quite mysterious. The ama say it makes them "feel better" and "protects the lungs." Various observers have suggested that it may prevent excessive hyperventilation (which can produce unconsciousness in a long dive) or may help by increasing the residual lung volume, but no evidence has been found to verify these hypotheses. Many of the Japanese divers, male and female, do not whistle before they dive.

Preparing for a dive, the ama hyperventilates for five to 10 seconds, takes a final deep breath and then makes the plunge. The hyperventilation serves to

GEOGRAPHIC DISTRIBUTION of the ama divers along the seacoasts of South Korea and southern Japan is indicated by the colored areas. The diving practice is believed to have originated on the small island of Cheju off the southern tip of the Korean peninsula.

remove a considerable amount of carbon dioxide from the blood. The final breath, however, is not a full one but only about 85 percent of what the lungs can hold. Just why the ama limits this breath is not clear; perhaps she does so to avoid uncomfortable pressure in the lungs or to restrict the body's buoyancy in the water.

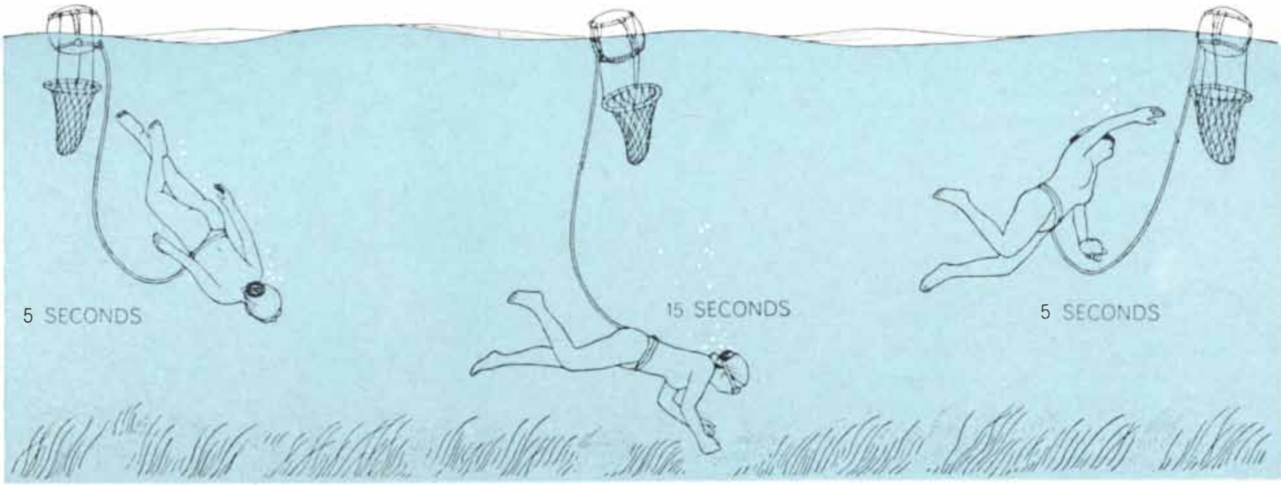
As the diver descends the water pressure compresses her chest and consequently her lung volume. The depth to which she can go is limited, of course, by the amount of lung compression she can tolerate. If she dives deeper than the level of maximum lung compression (her "residual lung volume"), she becomes subject to a painful lung squeeze; moreover, because the hydrostatic pressure in her blood vessels then exceeds the air pressure in her lungs, the pulmonary blood vessels may burst.

The diver, as we have noted, starts her dive with a lungful of air that is comparatively rich in oxygen and comparatively poor in carbon dioxide. What happens to the composition of this air in the lungs, and to the exchange with the blood, during the dive? In order to investigate this question we needed a means of obtaining samples of the diver's lung air under water without risk to the diver. Edward H. Lanphier and Richard A. Morin of our group (from the State University of New York at Buffalo) devised a simple apparatus into which the diver could blow her lung air and then reinhale most of it, leaving a small sample of air in the device. The divers were understandably reluctant at first to try this device, because it meant giving up their precious lung air deep under water with the possibility that they might not recover it, but they were eventually reassured by tests of the apparatus.

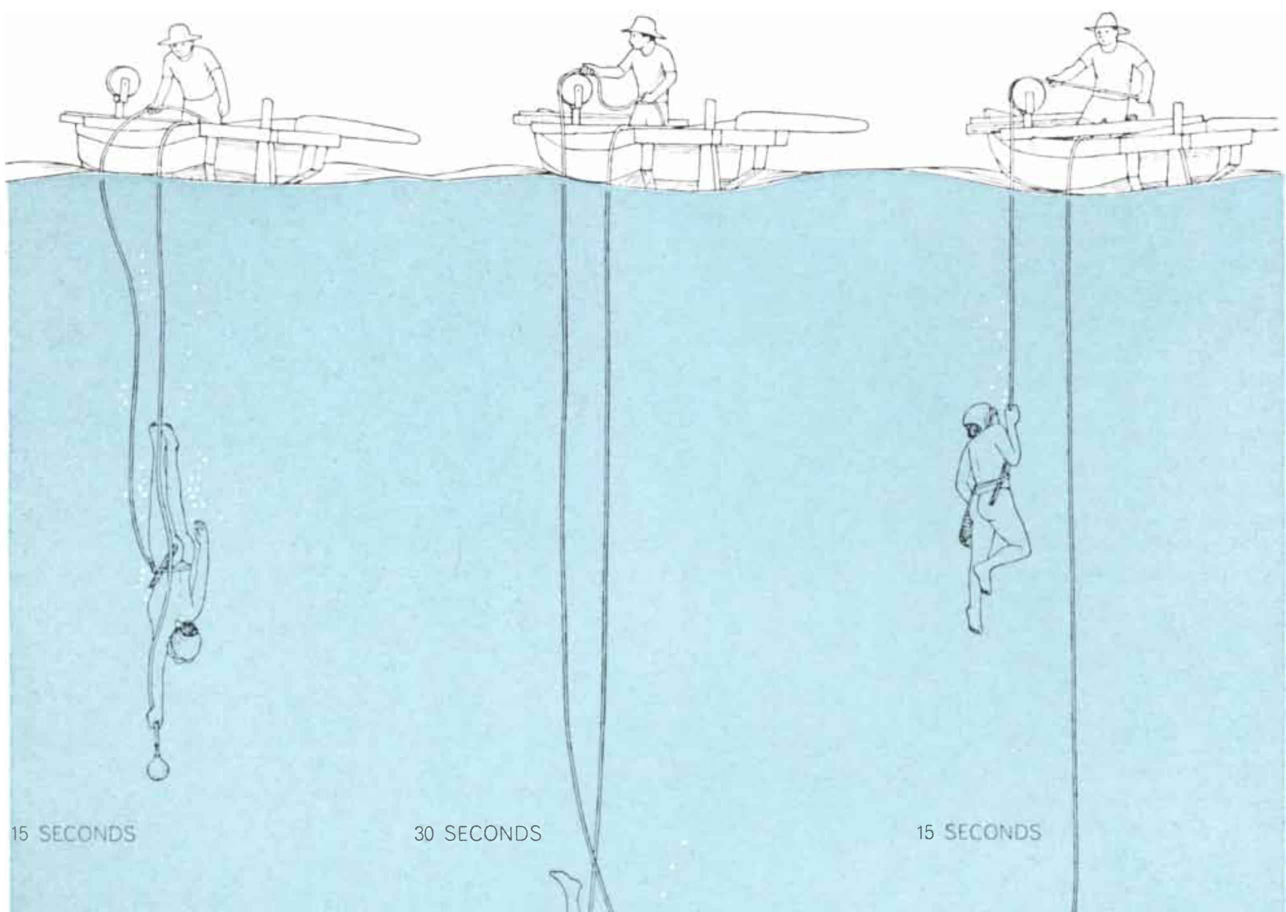
We took four samples of the diver's lung air: one before she entered the water, a second when she had hyperventilated her lungs at the surface and was about to dive, a third when she reached the bottom at a depth of 40 feet and a fourth after she had returned to the surface. In each sample we measured the concentrations and calculated the partial pressures of the principal gases: oxygen, carbon dioxide and nitrogen.

Normally, in a resting person out of the water, the air in the alveoli of the lungs is 14.3 percent oxygen, 5.2 percent carbon dioxide and 80.5 percent nitrogen (disregarding the rare gases and water vapor). We found that after hyperventilation the divers' alveolar air con-

KOREAN DIVING WOMAN from Cheju Island cooperated with the authors in their study of the physiological reactions to breath-hold diving. The large ball slung over her left shoulder is a float that is left at the surface during the dive; attached to the float is a net for collecting the catch. The black belt was provided by the authors to carry a pressure-sensitive bottle and electrocardiograph wires for recording the heart rate. The ama holds an alveolar, or lung, gas sampler in her right hand. The Korean ama wear only light cotton bathing suits even in the winter, when the water temperature can be as low as 50 degrees Fahrenheit.



UNASSISTED DIVER, called a *cachido,* employs one of the two basic techniques of ama diving. The *cachido* operates from a small float at the surface. On an average dive she swims to a depth of about 15 to 20 feet; the dive lasts about 25 to 30 seconds, of which 15 seconds is spent working on the bottom. The entire diving cycle takes about a minute, and the diver averages 60 dives per hour.



ASSISTED DIVER, called a *funado,* uses a counterweight to descend passively to a depth of 60 to 80 feet. She averages 30 seconds in gathering on the bottom but makes only about 30 dives per hour. At the end of each dive a helper in the boat pulls her up.

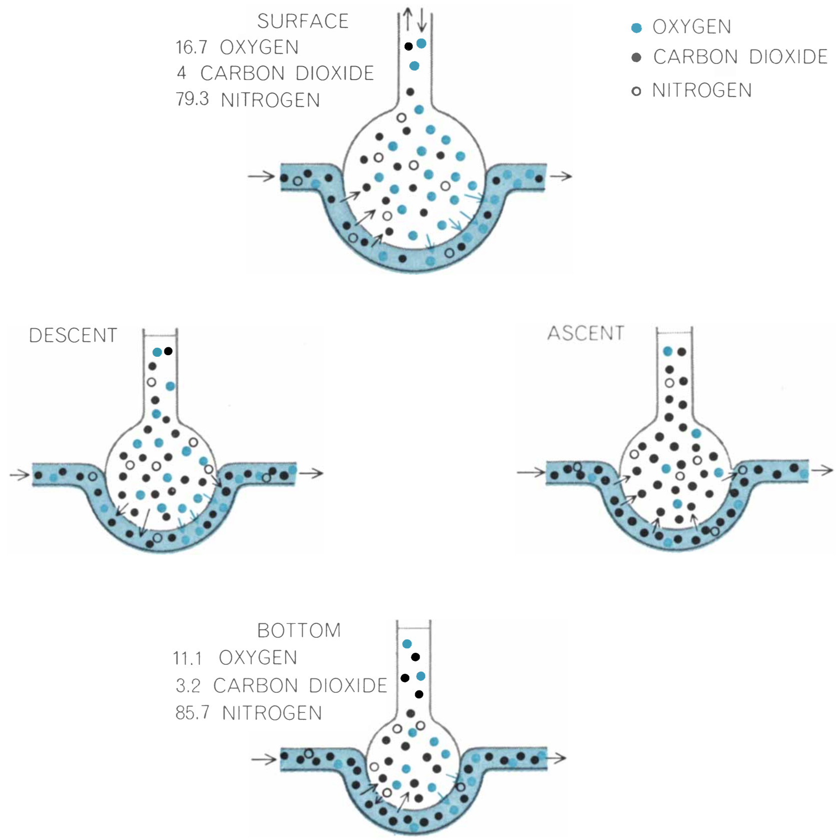
sists of 16.7 percent oxygen, 4 percent carbon dioxide and 79.3 percent nitrogen; translating these figures into partial pressures (in millimeters of mercury), the respective proportions are 120 millimeters for oxygen, 29 for carbon dioxide and 567 for nitrogen.

By the time the *cachido* (unassisted diver) reaches the bottom at a depth of 40 feet the oxygen concentration in her lungs is reduced to 11.1 percent, because of the uptake of oxygen by the blood. However, since at that depth the water pressure has compressed the lungs to somewhat more than half of their pre-dive volume, the oxygen pressure amounts to 149 millimeters of mercury—a greater pressure than before the dive. Consequently oxygen is still being transmitted to the blood at a substantial rate.

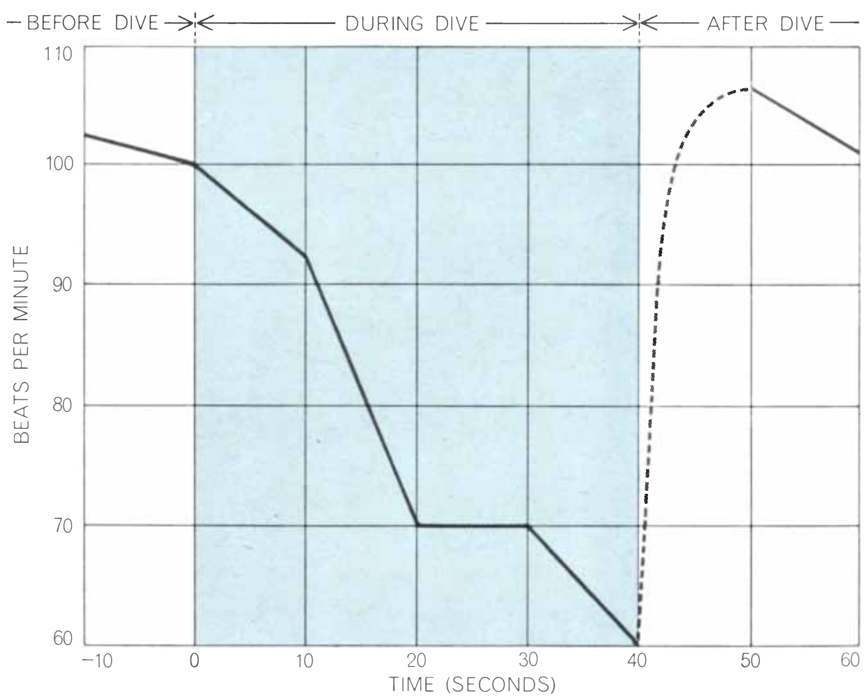
For the same reason the blood also takes up carbon dioxide during the dive. The carbon dioxide concentration in the lungs drops from 4 percent at the beginning of the dive to 3.2 percent at the bottom. This is somewhat paradoxical; when a person out of the water holds his breath, the carbon dioxide in his lungs increases. At a depth of 40 feet, however, the compression of the lung volume raises the carbon dioxide pressure to 42 millimeters of mercury, and this is greater than the carbon dioxide pressure in the venous blood. As a result the blood and tissues retain carbon dioxide and even absorb some from the lungs.

As the diver ascends from the bottom, the expansion of the lungs drastically reverses the situation. With the reduction of pressure in the lungs, carbon dioxide comes out of the blood rapidly. Much more important is the precipitous drop of the oxygen partial pressure in the lungs: within 30 seconds it falls from 149 to 41 millimeters of mercury. This is no greater than the partial pressure of oxygen in the venous blood; hence the blood cannot pick up oxygen, and Lanphier has shown that it may actually lose oxygen to the lungs. In all probability that fact explains many of the deaths that have occurred among sports divers returning to the surface after deep, lengthy dives. The cumulative oxygen deficiency in the tissues is sharply accentuated during the ascent.

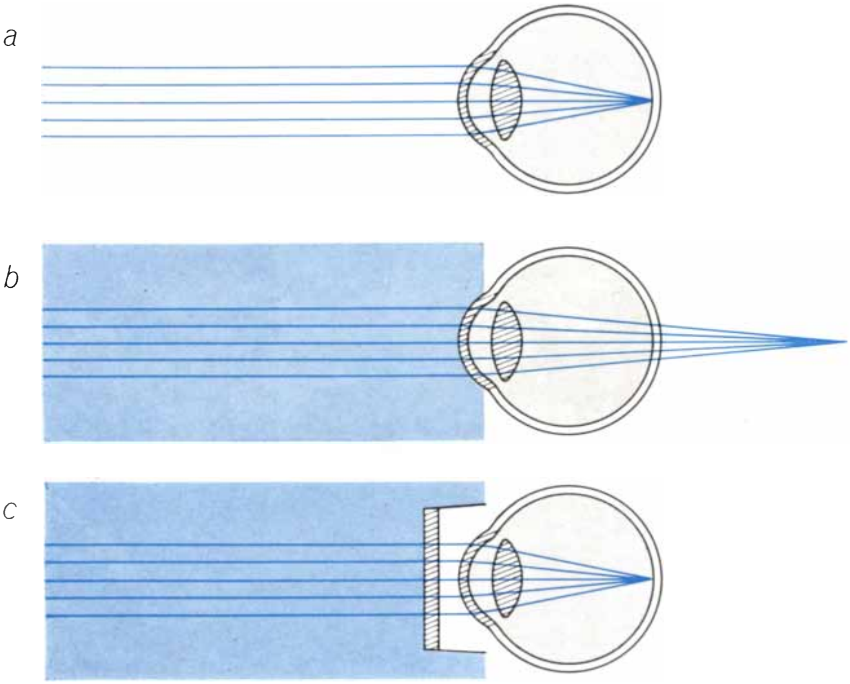
Our research has also yielded a measure of the nitrogen danger in a long dive. We found that at a depth of 40 feet the nitrogen partial pressure in the compressed lungs is doubled (to 1,134 millimeters of mercury), and throughout the dive the nitrogen tension is sufficient to drive the gas into the blood. Lanphier has calculated that repeated dives to



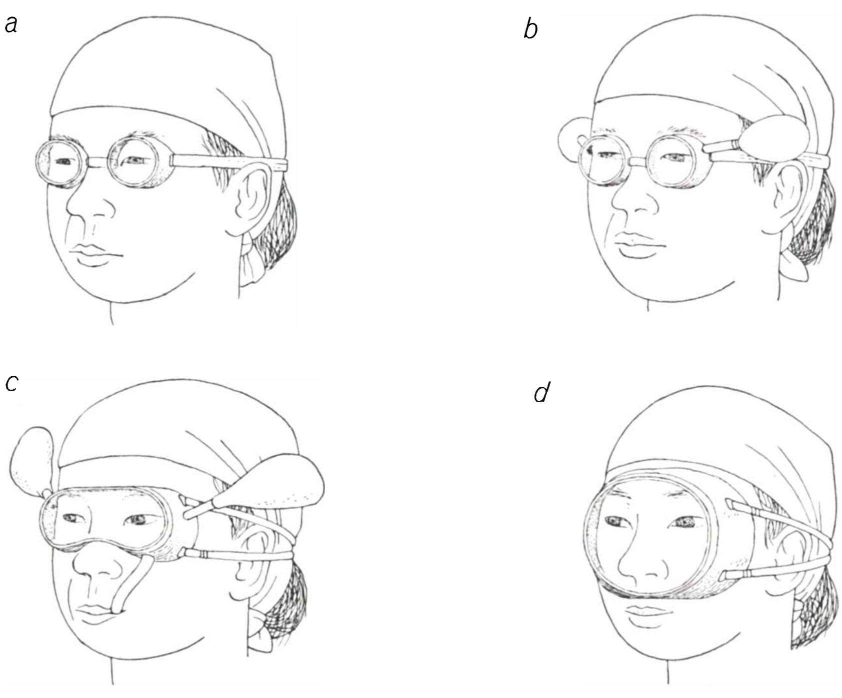
GASES EXCHANGED between a single alveolus, or lung sac, and the bloodstream are shown for four stages of a typical ama dive. The concentrations of three principal gases in the lung at the surface and at the bottom are given in percent. During descent water pressure on the lungs causes all gases to enter the blood. During ascent this situation is reversed.



AVERAGE HEART RATE for a group of Korean ama was measured before, during and after their dives. All the dives were to a depth of about 15 feet. The average pattern shown here was substantially the same in the summer, when the water temperature was about 80 degrees Fahrenheit, as it was in winter, when water temperature was about 50 degrees F.



GOGGLES SHARPEN VISION under water by providing a layer of air at the interface with the eyeball (*c*). Vision is normally sharp in air because the difference in refractive index between air and the tissue of the cornea helps to focus images on the retinal surface (*a*). The small difference in the refractive index between water and corneal tissue causes the focal point to move considerably beyond the retina (*b*), reducing visual acuity under water.



EVOLUTION OF GOGGLES has resulted in several solutions to the problem presented by the increase in hydrostatic pressure on the body during a dive. The earliest goggles (*a*) were uncompensated, and the difference in pressure between the blood vessels in the eyelid and the air behind the goggles could result in conjunctival bleeding. The problem was first solved by attaching air-filled, compressible bags to the goggles (*b*). During a dive the increasing water pressure compresses the bags, raising the air pressure behind the goggles in proportion to the increase in hydrostatic pressure on the body. In some cases (*c*) the lungs were used as an additional compensating gas chamber. With a modern face mask that covers the nose (*d*) the lungs provide the only source of compensating air pressure during a dive.

depths of 120 feet, such as are performed by male pearl divers in the Tuamotu Archipelago of the South Pacific, can result in enough accumulation of nitrogen in the blood to cause the bends on ascent. When these divers come to the surface they are sometimes stricken by fatal attacks, which they call *taravana*.

The ama of the Korean area are not so reckless. Long experience has taught them the limits of safety, and, although they undoubtedly have some slight anoxia at the end of each dive, they quickly recover from it. The diving women content themselves with comparatively short dives that they can perform again and again for extended periods without serious danger. They avoid excessive depletion of oxygen and excessive accumulation of nitrogen in their blood.

As far as we have been able to determine, the diving women possess no particular constitutional aptitudes of a hereditary kind. The daughters of Korean farmers can be trained to become just as capable divers as the daughters of divers. The training, however, is important. The most significant adaptation the trained diving women show is an unusually large "vital capacity," measured as the volume of air that can be drawn into the lungs in a single inspiration after a complete expiration. In this attribute the ama are substantially superior to nondiving Korean women. It appears that the divers acquire this capacity through development of the muscles involved in inspiration, which also serve to resist compression of the chest and lung volume in the water.

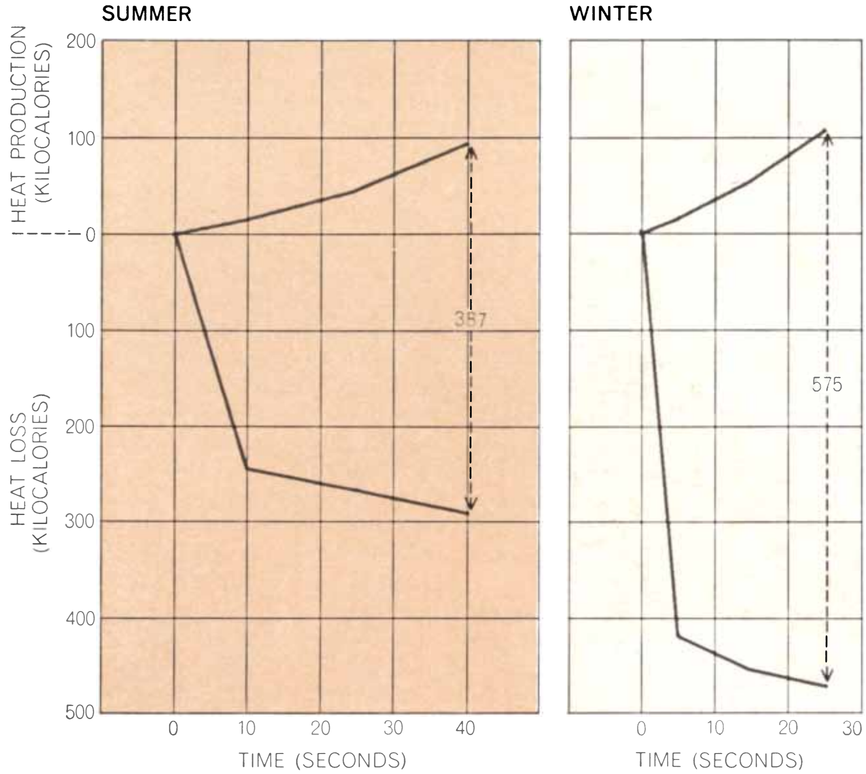
A large lung capacity, or oxygen intake, is one way to fortify the body for diving; another is conservation of the oxygen stored in the blood. It is now well known, thanks to the researches of P. F. Scholander of the Scripps Institution of Oceanography and other investigators, that certain diving mammals and birds have a built-in mechanism that minimizes their need for oxygen while they are under water [see "The Master Switch of Life," by P. F. Scholander; SCIENTIFIC AMERICAN, December, 1963]. This mechanism constricts the blood vessels supplying the kidneys and most of the body muscles so that the blood flow to these organs is drastically reduced; meanwhile a normal flow is maintained to the heart, brain and other organs that require an undiminished supply of oxygen. Thus the heart can slow down, the rate of removal of oxygen from the blood by tissues is reduced, and the animal can prolong its dive.

Several investigators have found recently that human subjects lying under water also slow their heart rate, although not as much as the diving animals do. We made a study of this matter in the ama during their dives. We attached electrodes (sealed from contact with the seawater) to the chests of the divers, and while they dived to the bottom, at the end of a 100-foot cable, an electrocardiograph in our boat recorded their heart rhythms. During their hyperventilation preparatory to diving the divers' heart rate averaged about 100 beats a minute. During the dive the rate fell until, at 20 seconds after submersion, it had dropped to 70 beats; after 30 seconds it dropped further to some 60 beats a minute [*see bottom illustration on page 39*]. When the divers returned to the surface, the heart rate jumped to slightly above normal and then rapidly recovered its usual beat.

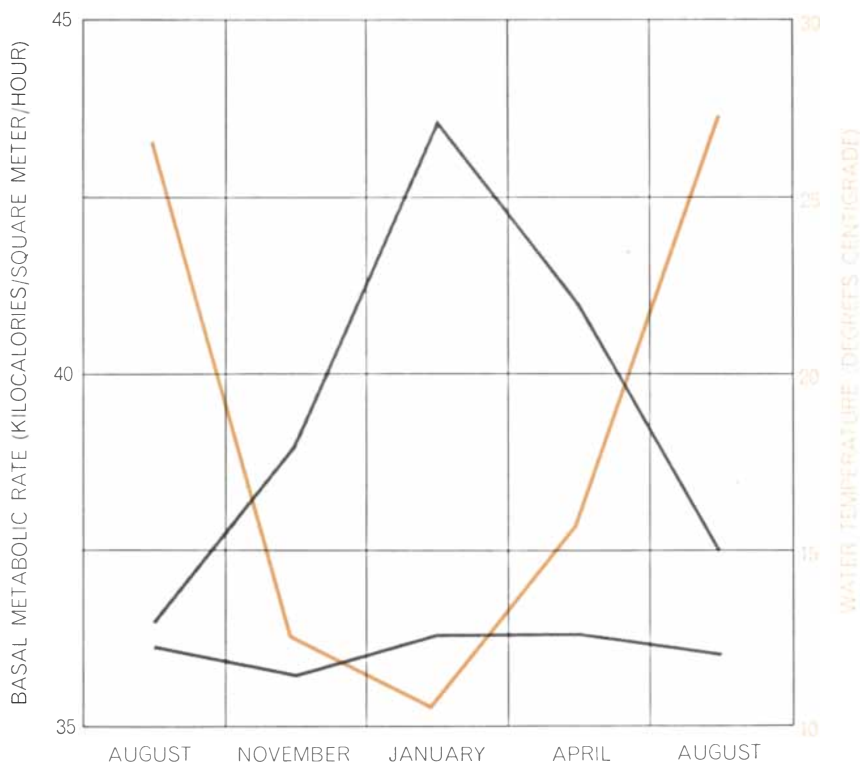
Curiously, human subjects who hold their breath out of the water, even in an air pressure chamber, do not show the same degree of slowing of the heart. It was also noteworthy that in about 50 percent of the dives the ama showed some irregularity of heartbeat. These and other findings raise a number of puzzling questions. Nevertheless, one thing is quite clear: the automatic slowing of the heart is an important factor in the ability of human divers to extend their time under water.

In the last analysis the amount of time one can spend in the water, even without holding one's breath, is limited by the loss of body heat. For the working ama this is a critical factor, affecting the length of their working day both in summer and in winter. (They warm themselves at open fires after each long diving shift.) We investigated the effects of their cold exposure from several points of view, including measurements of the heat losses at various water temperatures and analysis of the defensive mechanisms brought into play.

For measuring the amount of the body's heat loss in the water there are two convenient indexes: (1) the increase of heat production by the body (through the exercise of swimming and shivering) and (2) the drop in the body's internal temperature. The body's heat production can be measured by examining its consumption of oxygen; this can be gauged from the oxygen content of the lungs at the end of a dive and during recovery. Our measurements were made on Korean diving women in Pusan harbor at two seasons of the year: in August,



BODY HEAT lost by ama divers was found to be about 400 kilocalories in a summer shift (*left*) and about 600 kilocalories in a winter shift (*right*). The curves above the abscissa at zero kilocalories represent heat generated by swimming and shivering and were estimated by the rate of oxygen consumption. The curves below abscissa represent heat lost by the body to the water and were estimated by changes in rectal temperature and skin temperature.



BASAL METABOLIC RATE of ama women (*top gray curve*) increases in winter and decreases in summer. In nondiving Korean women (*bottom gray curve*) basal metabolic rate is constant throughout the year. The colored curve shows the mean seawater temperatures in the diving area of Pusan harbor for the same period covered by the other measurements.

when the water temperature was 80.6 degrees F., and in January with the water temperature at 50 degrees.

In both seasons at the end of a single diving shift (40 minutes in the summer, 25 minutes in winter) the deep-body temperature was found to be reduced from the normal 98.6 degrees F. to 95 degrees or less. Combining this information with the measurements of oxygen consumption, we estimated that the ama's body-heat loss was about 400 kilocalories in a summer shift and about 600 kilocalories in a winter shift. On a daily basis, taking into consideration that the ama works in the water for three long shifts each day in summer and only one or two short shifts in winter, the day's total heat loss is estimated to be about the same in all seasons: approximately 1,000 kilocalories per day.

To compensate for this loss the Korean diving woman eats considerably more than her nondiving sisters. The ama's daily food consumption amounts to about 3,000 kilocalories, whereas the average for nondiving Korean women of comparable age is on the order of 2,000 kilocalories per day. Our various items of evidence suggest that the Korean diving woman subjects herself to a daily cold stress greater than that of any other group of human beings yet studied. Her extra food consumption goes entirely into coping with this stress. The Korean diving women are not heavy; on the contrary, they are unusually lean.

It is interesting now to examine whether or not the diving women have developed any special bodily defenses against cold. One such defense would be an elevated rate of basal metabolism, that is, an above-average basic rate of heat production. There was little reason, however, to expect to find the Korean women particularly well endowed in this respect. In the first place, populations of mankind the world over, in cold climates or warm, have been found to differ little in basal metabolism. In the second place, any elevation of the basal rate that might exist in the diving women would be too small to have much effect in offsetting the large heat losses in water.

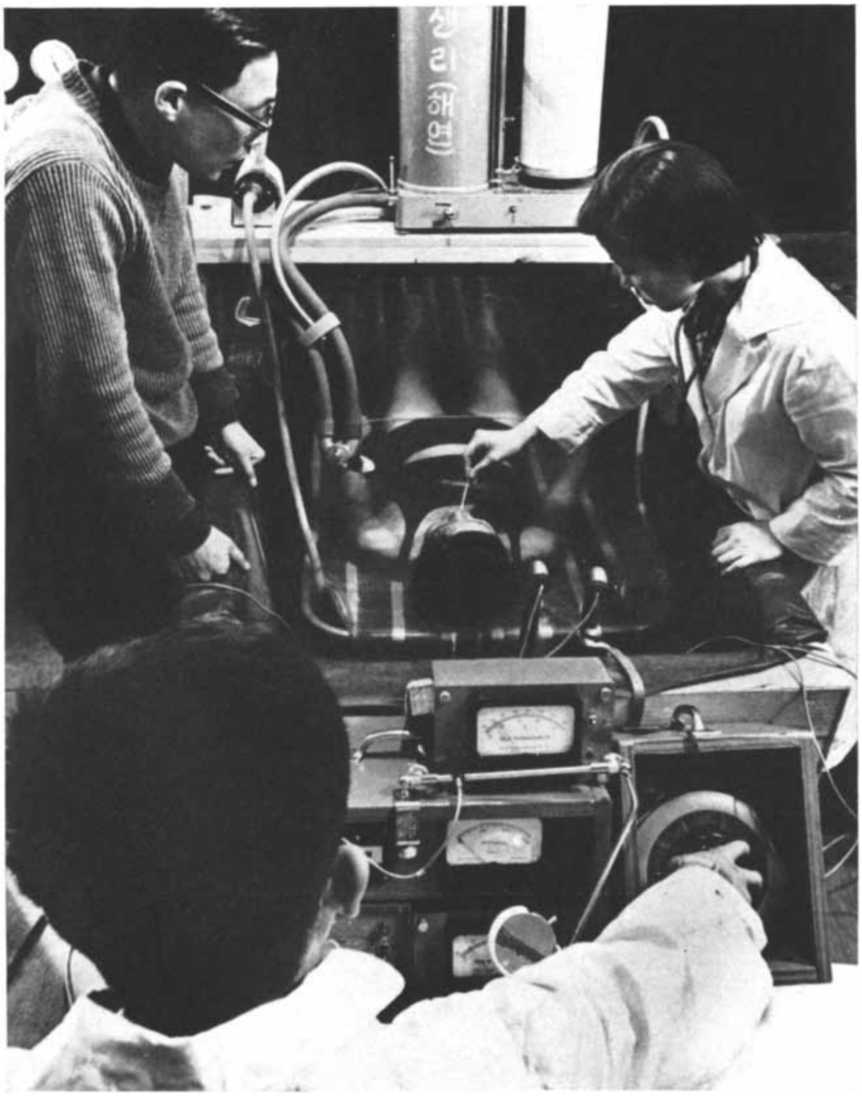
Yet we found to our surprise that the diving women did show a significant elevation of the basal metabolic rate—but only in the winter months! In that season their basal rate is about 25 percent higher than that of nondiving women of the same community and the same economic background (who show no seasonal change in basal metabolism). Only one other population in the world has been found to have a basal metabolic rate as high as that of the Korean diving women in winter: the Alaskan Eskimos. The available evidence indicates that the warmly clothed Eskimos do not, however, experience consistently severe cold stresses; their elevated basal rate is believed to arise from an exceptionally large amount of protein in their diet. We found that the protein intake of Korean diving women is not particularly high. It therefore seems probable that their elevated basal metabolic rate in winter is a direct reflection of their severe exposure to cold in that season, and that this in turn indicates a latent human mechanism of adaptation to cold that is evoked only under extreme cold stresses such as the Korean divers experience. The response is too feeble to give the divers any significant amount of protection in the winter water. It does, however, raise an interesting physiological question that we are pursuing with further studies, namely the possibility that severe exposure to winter cold may, as a general rule, stimulate the human thyroid gland to a seasonal elevation of activity.

The production of body heat is one aspect of the defense against cold; another is the body's insulation for retaining heat. Here the most important factor (but not the only one) is the layer of fat

BETWEEN DIVES the ama were persuaded to expire air into a large plastic gas bag in order to measure the rate at which oxygen is consumed in swimming and diving to produce heat. The water temperature in Pusan harbor at the time (January) was 50 degrees F. One of the authors (Hong) assists. Data obtained in this way were used to construct the graph at the top of the preceding page.

under the skin. The heat conductivity of fatty tissue is only about half that of muscle tissue; in other words, it is twice as good an insulator. Whales and seals owe their ability to live in arctic and antarctic waters to their very thick layers of subcutaneous fat. Similarly, subcutaneous fat explains why women dominate the diving profession of Korea and Japan; they are more generously endowed with this protection than men are.

Donald W. Rennie of the State University of New York at Buffalo collaborated with one of the authors of this article (Hong) in detailed measurements of the body insulation of Korean women, comparing divers with nondivers. The thickness of the subcutaneous fat can easily be determined by measuring the thickness of folds of skin in various parts of the body. This does not, however, tell the whole story of the body's thermal insulation. To measure this insulation in functional terms, we had our subjects lie in a tank of water for three hours with only the face out of the water. From measurements of the reduction in deep-body temperature and the body's heat production we were then able to calculate the degree of the subject's overall thermal insulation. These studies revealed three particularly interesting facts. They showed, for one thing, that with the same thickness of subcutaneous fat, divers had less heat loss than nondivers. This was taken to indicate that the divers' fatty insulation is supplemented by some kind of vascular adaptation that restricts the loss of heat from the blood vessels to the skin, particularly in the arms and legs. Secondly, the observations disclosed that in winter the diving women lose about half of their subcutaneous fat (although nondivers do not). Presumably this means that during the winter the divers' heat loss is so great that their food intake does not compensate for it sufficiently; in any case, their vascular adaptation helps them to maintain insulation. Thirdly, we found that diving women could tolerate lower water temperatures than nondiving women without shivering. The divers did not shiver when they lay for three hours in water at 82.8 degrees F.; nondivers began to shiver at a temperature of 86 degrees. (Male nondivers shivered at 88 degrees.) It appears that the diving women's resistance to shivering arises from some hardening aspect of their training that inhibits shiver-triggering impulses from the skin. The inhibition of shivering is an advantage because shivering speeds up the emission of body heat. L. G. Pugh, a British physiologist who has studied long-distance swimmers, discovered the interesting additional fact that swimmers, whether fat or thin, lose heat more rapidly while swimming than while lying motionless in the water. The whole subject of the body's thermal insulation is obviously a rather complicated one that will not be easy to unravel. As a general conclusion, however, it is very clearly established that women are far better insulated than men against cold.



AMA'S THERMAL INSULATION (mainly fat) was measured by having the subjects lie in a tank of water for three hours. From measurements of the reduction of deep-body temperature and the body's heat production the authors were able to calculate the degree of the subject's overall thermal insulation. Once again Hong (*left*) keeps a close eye on the operation.

As a concluding observation we should note that the 1,500-year-old diving occupation in Korea and Japan is now declining. The number of divers has dwindled during the past few decades, and by the end of this century the profession may disappear altogether, chiefly because more remunerative and less arduous ways of making a living are arising. Nonetheless, for the 30,000 practitioners still active in the diving profession (at least in summer) diving remains a proud calling and necessary livelihood. By adopting scuba gear and other modern underwater equipment the divers could greatly increase their production; the present harvest could be obtained by not much more than a tenth of the present number of divers. This would raise havoc, however, with employment and the economy in the hundreds of small villages whose women daily go forth to seek their families' existence on the sea bottom. For that reason innovations are fiercely resisted. Indeed, many villages in Japan have outlawed the foam-rubber suit for divers to prevent too easy and too rapid harvesting of the local waters.

Small Systems of Nerve Cells

In some invertebrate animals complete behavioral functions may be controlled by a very few cells. This makes it possible to trace out the interactions of the cells and so to investigate nervous integration

by Donald Kennedy

The nervous system of a man comprises between 10 billion and 100 billion cells, and the "lower" mammals men study in an effort to understand their own brains may have two or three billion nerve cells. Even specialized parts of vertebrate nervous systems have an awesome number of elements: the retina of the eye has about 130 million receptor cells and sends more than a million nerve fibers to the brain; a single segment of spinal cord controls the few muscles it operates through several thousand motoneurons, or motor nerve cells, which in turn receive instructions from a larger number of sensory elements.

These vast populations of cells present a formidable challenge to biologists trying to understand how the nervous system works. Since the system is made up of cells, one would like to understand it in terms of cellular activities, and by examining the activity of single nerve cells investigators have been able to learn a great deal about the nature of the nerve impulse and about the generation and transmission of the patterns of impulses that constitute nervous signals. The ultimate object must be, however, to understand not only the activities of single cells but also the rules of their interaction. Since one cannot expect to understand even the most restricted systems by predicting the possible interactions of an inadequately sampled population of cells, mammalian physiologists have devised ingenious ways of circumventing the superabundance of elements, involving particularly biochemical studies of regions of the brain and sophisticated computer analyses of brain waves. The trouble is that most of these methods treat cells as anonymous members of a population rather than as interacting individuals.

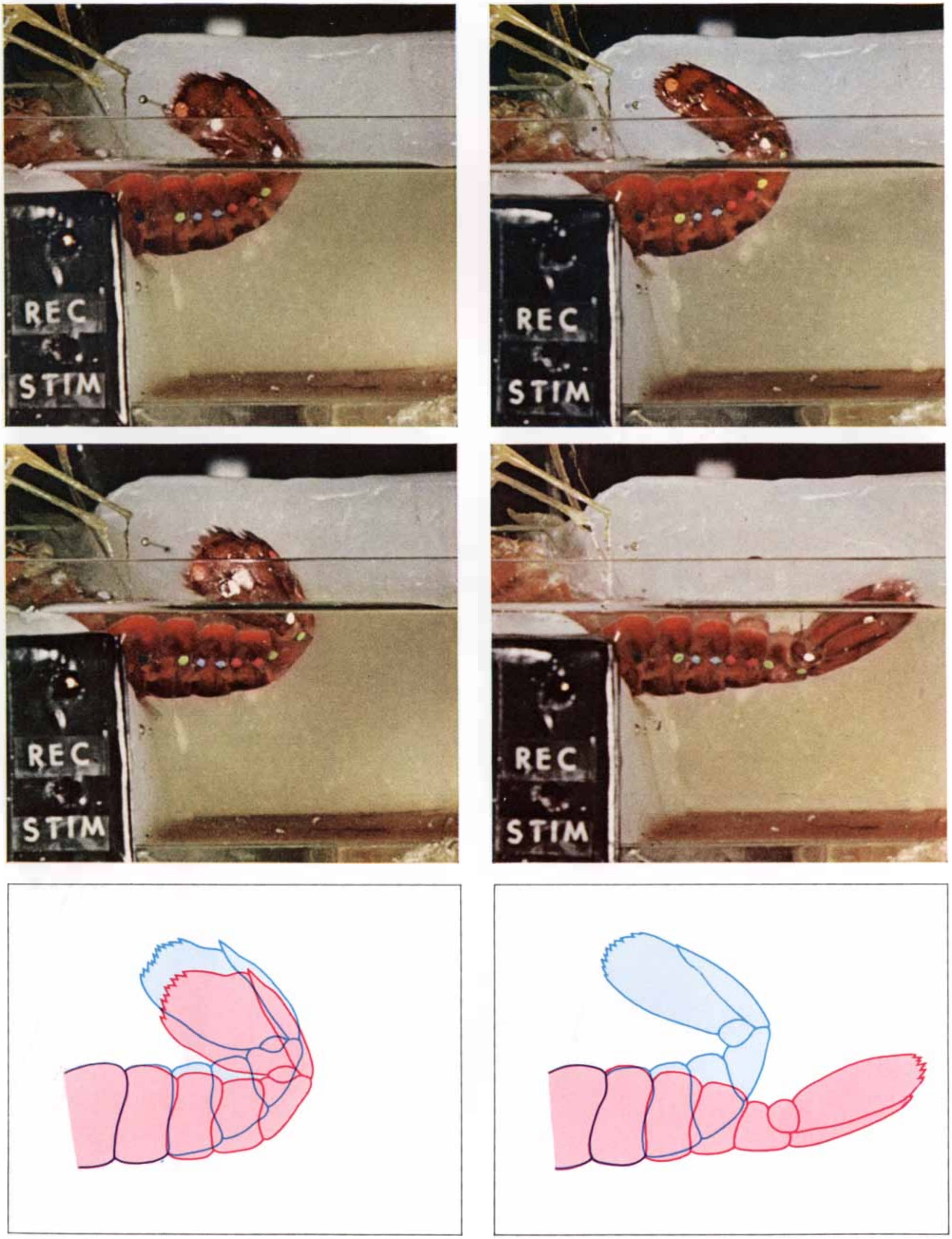
Some biologists are taking a different approach, one that retains the individual nerve cell as the focus of attention and yet attempts to deal with groups of them. This approach is made possible by the availability of animals that have fewer nerve cells than any vertebrate and that nonetheless display reasonably complex behavior. The claw-bearing limb of the shore crab, for example, shows impressive coordination and range of movement, made possible by six movable joints with pairs of muscles acting in opposition to each other. As a mechanical device it is in most ways the equal of a mammalian limb, yet the crab operates all this machinery with about two dozen motor nerve cells. A mammal of comparable size would employ several thousand for the analogous purpose.

Nor is such parsimony confined to the motor apparatus: in contrast to the several billion cells of the entire mammalian nervous system, the crab has only half a million or so. The real utility of such systems to the investigator becomes apparent only when one concentrates on the nerve cells belonging to one functional unit such as a reflex pathway, a special sense organ or a particular pattern of behavior. Indeed, the nervous systems of some of the higher invertebrate animals are so economically built that for certain functions one may hope to specify the activity of every individual cell.

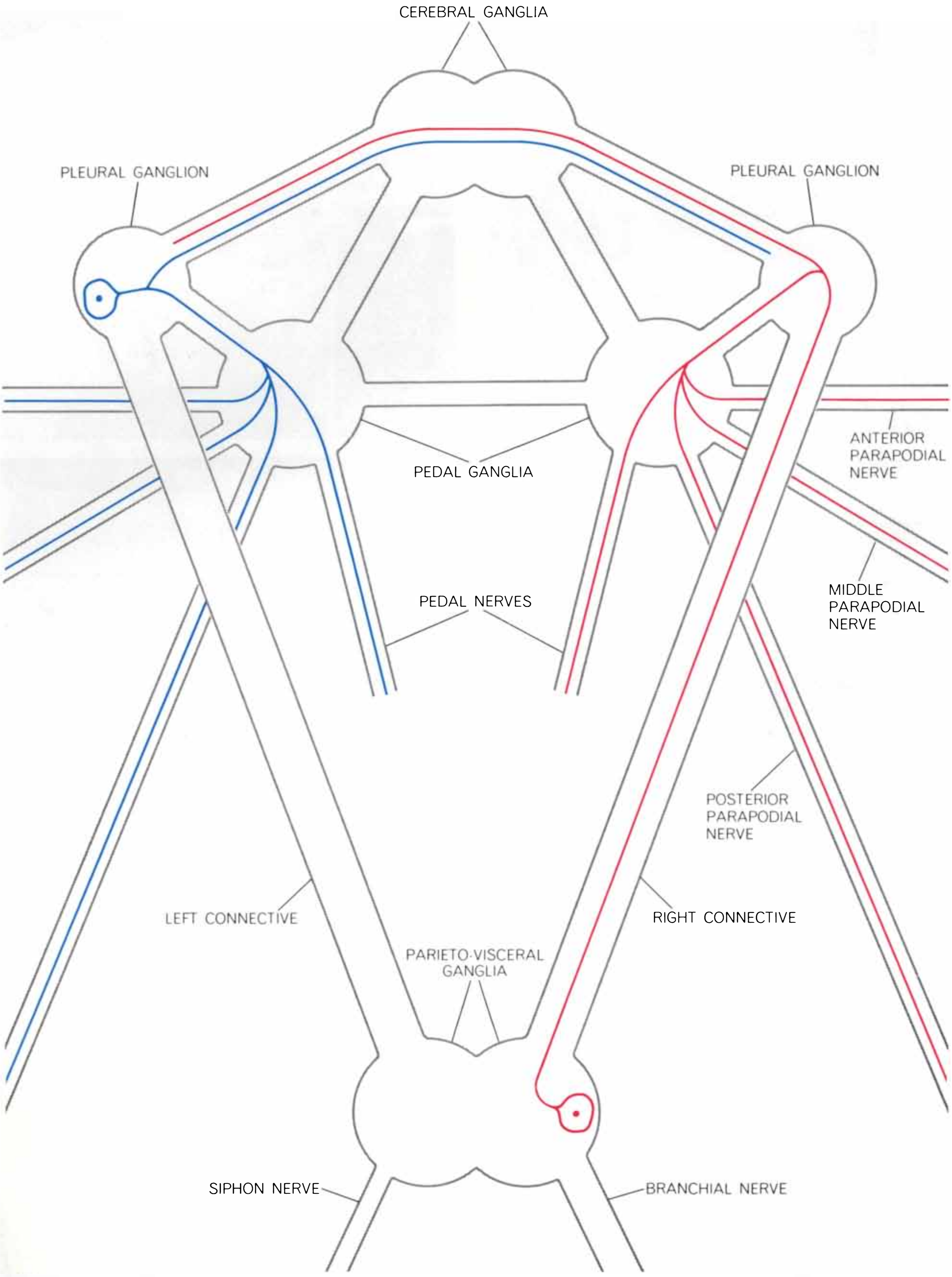
This achievement would be a hollow one insofar as learning about mammalian nervous systems is concerned if the additional complexity of more "advanced" systems depended heavily on new capabilities of the individual cells comprising them. All the evidence, however, indicates that the performance limits of the single nerve cell are already reached in relatively simple animals. The central nervous elements found in the lobster or the sluglike "sea hare" nearly equal those of mammals in size, quantity of input and structural complexity. The marvelous performance of the mammalian brain is, it appears, not so dependent on the individual capabilities of its cells as it is on their greater number and the resulting opportunities for permutation. Therefore an understanding of the connections underlying behavior in a simple system can lead to useful conclusions about the organization of much more complicated ones.

The difficulty lies in the choice of appropriate experimental objects. Ideally one needs a nervous system that produces a reasonably complex repertory of behavior and has only a few cells, each of which can be recognized and located time after time. In certain animals specialized giant cells offer this ready identifiability. The giant axons, or nerve fibers, of the squid and the lobster are an example, and biophysicists have long exploited them for experiments on the properties of nerve-cell membranes. A student of integrative processes in the nervous system needs more; he wants to specify individual properties for each cell in an entire functional assembly.

Two different kinds of nervous system seem particularly promising for this purpose: that of mollusks and that of arthropods. The most thoroughly studied mollusk is the sea hare *Aplysia*, a snail that has only a vestigial shell and leads a somewhat more mobile life than its relatives. Its nervous system is concentrated in a few large ganglia connected by nerve trunks. Several features of the cells are advantageous. The cell bodies are unusually large, some with a diameter of .8 millimeter and the rest well sorted in size below this maximum. They contain



CRAYFISH ABDOMEN responds in complex and specific ways to stimulation of different single cells in the central nervous system. Frames from a motion-picture film made by Benjamin Dane in the author's laboratory record the effects of two different "command fibers"; the drawings specify the initial (*blue*) and the final (*red*) positions of the abdomen. One fiber evoked activity primarily in the forward segments (*left*); the other produced extension in all segments (*right*). Colored spots on the abdomen facilitated precise measurement of segment angles. Visible effects were confirmed by recording the activity of motor nerve fibers in the first segment.



NERVOUS SYSTEM of the "sea hare" *Aplysia*, a mollusk, lends itself to investigation because its cells are few, large and identifiable. Here the entire system is diagrammed and the paths of two nerve cells are shown in color. One of them (*red*) is cell No. 1 in the ganglion illustrated on the opposite page. The routes of a large number of *Aplysia* cells were worked out by L. Tauc of the Centre National de Recherche Scientifique in Paris and G. M. Hughes of Bristol University by recording from individual nerve cell bodies.

a variety of yellow and orange pigments in different proportions. Particular cells are consistent in position from one animal to the next. Several dozen cells can therefore be reliably recognized in different individuals by their size, color and position [*see illustrations on this page*].

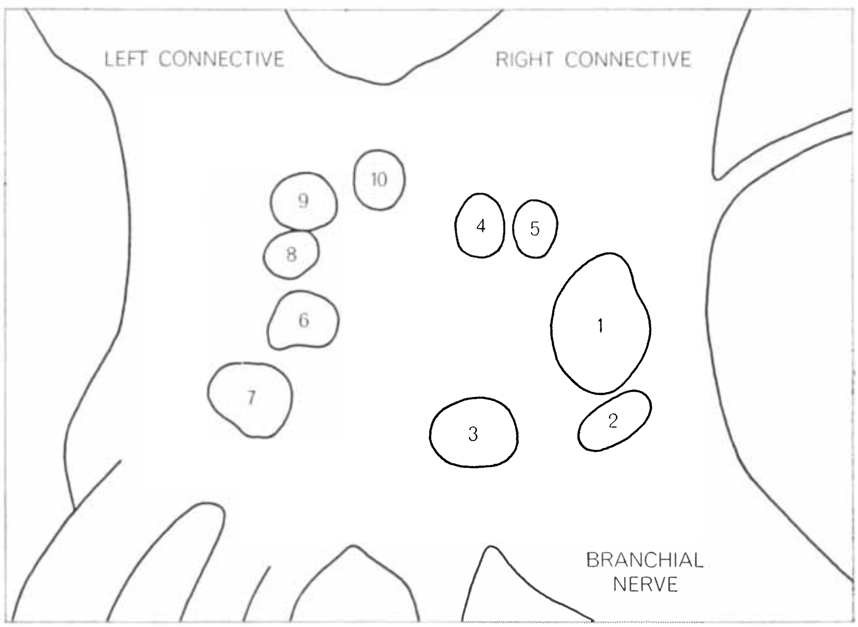
Aplysia was first intensively studied in the late 1940's by A. Arvanitaki-Chalazonitis in her laboratory in Monaco. It has since attracted a number of investigators, notably L. Tauc of the Centre National de Recherche Scientifique in Paris, Eric R. Kandel of New York University and Felix Strumwasser of the California Institute of Technology. Tauc and his collaborators, notably G. M. Hughes of Bristol University, have constructed ingenious physiological maps of several *Aplysia* cells [*see illustration on opposite page*]. They accomplished this by inserting a glass microelectrode into a cell body and placing wire electrodes on all the nerve trunks connecting with the ganglion in which the cell body was located. If a particular nerve contained an axon of the cell in which the microelectrode was located, the microelectrode recorded an impulse when that nerve was stimulated with a brief electric shock. The branches of the axons may be arranged in an extremely complex way, but each cell is characterized by a constant arrangement of branches.

Other workers have demonstrated that the connections made in turn by such branches with other nerve cells are also constant. Microelectrodes were inserted in several identified cells, and one microelectrode was used to stimulate the cell it had penetrated while the others recorded impulse activity. A particular cell produced either of two kinds of effect in a nerve cell to which it was connected: an excitation, sometimes strong enough to evoke an impulse in the second cell, or an inhibition, which opposed the discharge of impulses. Strumwasser and Kandel have demonstrated that a single cell can directly excite some cells and inhibit others, and that a certain set of identifiable cells is always excited by a given cell and another set always inhibited.

The ganglia of *Aplysia* have been used in the investigation of two other important problems in nerve physiology: the cellular modifications that take place during "conditioning" and the origin of "discharge rhythms." To investigate the first, Kandel and Tauc recorded from an identifiable cell with a microelectrode while stimulating two nerve trunks containing nerve fibers that excited the recorded cell. A shock delivered to one of these nerves produced strong excitation, indicating that it was the more effective pathway; the other produced only a weak effect. If the shocks to the two pathways were repeatedly paired so that the weak followed the strong at a fixed, short interval, the response to the weak pathway became "conditioned" to the strong excitation; the response increased dramatically and stayed elevated for 15 minutes or more after the conditioning period. If the same number of shocks was delivered to both pathways for the same period but at random intervals, conditioning did not occur; the response to the weak pathway was not affected. Such systems promise that electrophysiological studies on learning may at last be brought down to the cellular level.

Nerve cells often discharge rhythmically, in bursts that last for a few seconds and are separated by longer intervals. Strumwasser discovered a particularly dramatic instance of rhythmicity

PARIETO-VISCERAL GANGLION of *Aplysia*, photographed unstained by Felix Strumwasser of the California Institute of Technology, measures about 2.5 millimeters across.



INDIVIDUAL CELLS that are consistently identifiable in the ganglion are diagrammed. Not all are clearly seen in the photograph, in which a microelectrode points to cell No. 3.

EYE OF *HERMISSENDA* is enlarged about 900 diameters in a photomicrograph made by the late John Barth at Stanford University. The longitudinal section shows the lens (*concentric rings*) and the retina below it. The granular gray structure just below and to the left of the black pigment screening the retina is the nucleus of one of the five receptor cells.

in a certain *Aplysia* cell whose activity—recorded over long periods of time in an isolated ganglion—exhibits a "circadian," or approximately 24-hour, rhythm. Its most active period is a few hours before what would be sunset on a normal light schedule. This inherent periodicity, like that of other biological clocks, is maintained even if such environmental variables as light and temperature are held constant. Strumwasser is now investigating the chemical changes that are correlated with the discharge cycle.

The large size and small number of nerve cells in certain mollusks makes them convenient systems in which to study a number of sensory phenomena. The mollusk *Hermissenda*, for example, has provided information on the nerve-cell interactions that underlie the processing of visual information in a simple "camera" eye: an eye in which a single lens focuses light on a retina of receptor cells. Vertebrate camera eyes have too many cells for such analysis, and so investigators have relied largely on simpler compound eyes, in which a number of independent elements, each with its own lens and sensory cells, send fibers to the central nervous system. Studies of such compound eyes, particularly in the horseshoe crab *Limulus*, revealed the existence of one especially important process in visual systems: H. K. Hartline and his associates at the Rockefeller Institute found that when a given visual element is illuminated, it not only sends a train of impulses to the central nervous system along its own nerve fiber; it also inhibits the discharge of neighboring elements in the eye. This "lateral inhibition" decreases with distance from the visual element, and it functions to raise the level of contrast at boundaries of stimulus intensity [see "How Cells Receive Stimuli," by William H. Miller, Floyd Ratliff and H. K. Hartline; SCIENTIFIC AMERICAN, September, 1961].

Is lateral inhibition also an essential component of image-formation in other kinds of eye? What is the minimum number of light-receptor cells necessary to form a useful spatial representation of the visual field? What rules are followed in connecting them? These are among the questions investigated in our laboratory at Stanford University, first by the late John Barth and more recently by Michael Dennis, in the course of a study of the eye of *Hermissenda*. The eye measures less than .1 millimeter in its long dimension and consists of a lens, a cup of black pigment to ensure that light enters only from the right direction, and an underlying retina of receptor cells. The remarkable feature of this miniature camera eye is that its retina consists of only five receptor cells, each one large enough to be penetrated with microelectrodes.

Barth found that cells exposed to light might respond in one of three ways: with an accelerated discharge, with a slower rate of firing followed by an "off" discharge (signaling the cessation of illumination) or with some complex mixture of the two. Dennis' experiments show clearly that this differentiation is not the result of separate classes of receptors. Both the excitatory response and the inhibitory one show similar peaks of sensitivity across the visible spectrum, indicating that they depend on the same light-absorbing pigment. When the activity of a pair (or a trio) of cells is recorded simultaneously, each impulse in one cell is followed by inhibition in the other (or the other two), indicating the presence of cross-connections among them [*see upper illustration on opposite page*]. Since this situation always holds, we conclude that the inhibitory network connects every cell with all four others.

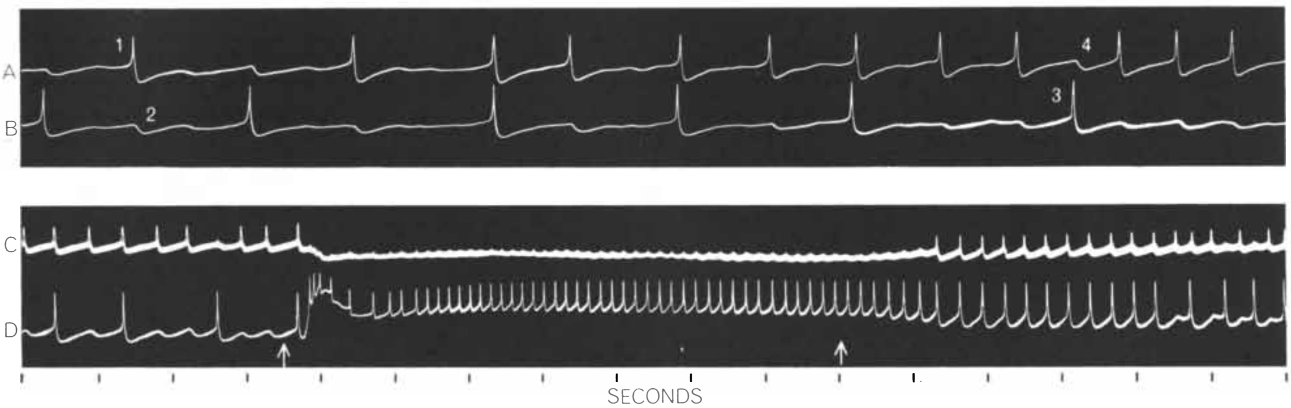
We originally doubted that a mosaic of only five cells could actually form images as larger camera eyes do, but Dennis has demonstrated that the mosaic does indeed have the ability to detect the position of small light sources in the visual field. In one experiment a spot of light five degrees in diameter was moved from right to left and back again on a screen facing the eye [*see lower illustration on opposite page*]. Two of the five receptor cells were impaled with microelectrodes; one, whose activity is shown in the lower trace of each record, responded more strongly when the spot was moved to the left, and held its neighbor, whose activity is shown in the upper trace, under effective inhibitory check. When the light was at the right, the discharge ratio had been such that both cells were firing at almost the same frequency, and it returned to this former value when the spot was moved back to the right. Clearly the relative intensities impinging on the two cells must have been different for the two positions of the light. With the light at the left, the lower cell was more strongly illuminated and consequently fed a stronger inhibition to its neighbor; with the light at the right, the intensities were presumably nearly balanced. In addition, it may be that specific cells display individual personalities even under perfectly homogeneous illumination; those with comparatively little light-sensitive pigment or with relatively strong inhibitory input, for example, would be particularly likely to respond in a predominantly inhibitory fashion and so would be characterized as "off" cells.

As the records show, there is a strong tendency for pairs of cells to fire at the same instant, even when their frequencies of discharge are quite different. This behavior cannot be accounted for on the basis of the inhibitory interaction alone, and it turns out that there is an additional kind of interaction of cells. It is of an excitatory nature, is very brief and is probably mediated by direct electrical connections between two cells. It promotes simultaneous discharge by acting as a trigger for the initiation of impulses in neighboring cells that are nearly ready to fire anyway. The resulting tendency to synchronize may be of value to the region of the brain that receives the visual messages.

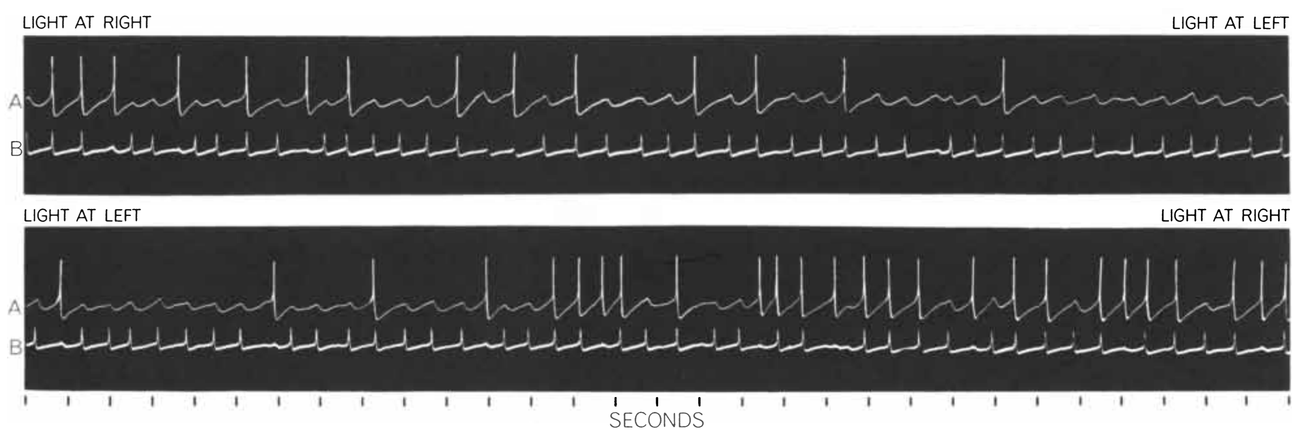
These results indicate the technical advantage of small systems of nerve cells to the physiologist. In a larger sense they illustrate how a few elements connected in simple ways can serve an organism remarkably well. It appears that with five receptor cells, a modest optical system and two types of interaction *Hermissenda* can build a crude image-forming system capable of enhancing contrast at boundaries and—at least theoretically—of measuring the speed and direction of moving objects.

The nerve cells of some crustaceans and insects are also easy to recognize individually, and there are relatively few of them. (They are not so spectacularly large as those in *Aplysia*, and instead of recording from the cells with microelectrodes most investigators dissect single axons from the connective nerves that run between central ganglia.) In such nervous systems a very few cells sometimes control a specific, anatomically restricted process. A network of this kind is found, for example, in the hearts of crabs and lobsters, where the beat is triggered and spread by an assembly of only nine to 11 cells embedded in the heart muscle. Some of these cells are "pacemakers," which initiate impulses spontaneously at regular intervals; others are "followers" activated by the pacemakers. Connections among the follower cells marshal their responses into a burst of activity that grows and then subsides until the next pacemaker signals arrive. Activity from the followers also has a subtle feedback effect on the pacemaker frequency. With this system Theodore H. Bullock and his collaborators at the University of California at Los Angeles have pioneered in examining restricted ensembles of nerve cells to establish principles of nervous integration.

Can such analyses be expanded to deal with larger groups of nerve cells that control entire systems of muscles, or even control behavior complex enough to orient an animal in its environment or move the animal through it? They can, provided that the controlling cells are in-



"ON" AND "OFF" responses are seen in records made simultaneously in two *Hermissenda* receptor cells. An impulse from either cell *A* or *B* (*1, 3*) produces an inhibitory hyperpolarization in the other cell (*2, 4*). The illumination of cell *D* (*interval between arrows*) makes it fire faster, inhibiting cell *C*. When the light is turned off, cell *C* is released from inhibition and discharges again.



POSITION IS DETECTED by the differential responses of two receptor cells in *Hermissenda*. The discharge rates of cells *A* and *B* were about the same when a light was placed to the right of the field of view. As the light was moved to the left cell *B* discharged relatively more rapidly, effectively inhibiting cell *A*. When the light was moved back again, the former discharge ratio was reestablished.

dividually unique and are identifiable by the experimenter. The feasibility of such studies has been demonstrated primarily by C. A. G. Wiersma and his co-workers at the California Institute of Technology. In a series of investigations spanning the past three decades Wiersma has concerned himself with crustacean muscles and the motor-nerve axons that innervate them. The motor axons—which are remarkably few in number—can be distinguished from one another by their different electrical effects on the muscle and by the kinds of contraction they evoke. Some produce quick twitches by generating large, abrupt depolarizations (reductions in membrane potential that lead to excitation) in the muscle fibers; others make the muscle contract in a more sustained way by producing small and gradually augmenting depolarizations; still others prevent contraction. The number of nerve fibers serving any given muscle is small enough so that one can distinguish the impulses of each one in an electrical record from the entire nerve and correlate these impulses with events in the muscle.

Wiersma has exposed an even more remarkable differentiation of elements in the central nervous system of the crayfish. Single interneurons—nerve cells that collect information from a number of sensory fibers—can be isolated for electrical recording from a part of the central nervous system in the abdomen; elsewhere such a cell runs its normal course, making connections by branching in each of several different ganglia. Wiersma has prepared maps that give the distribution over the animal's surface of the sensory receptors that will excite each such cell. He has shown that each interneuron is uniquely connected with a set of sensory-nerve fibers, so that a cell with a specific map is always found in the same anatomical location in the central nervous system.

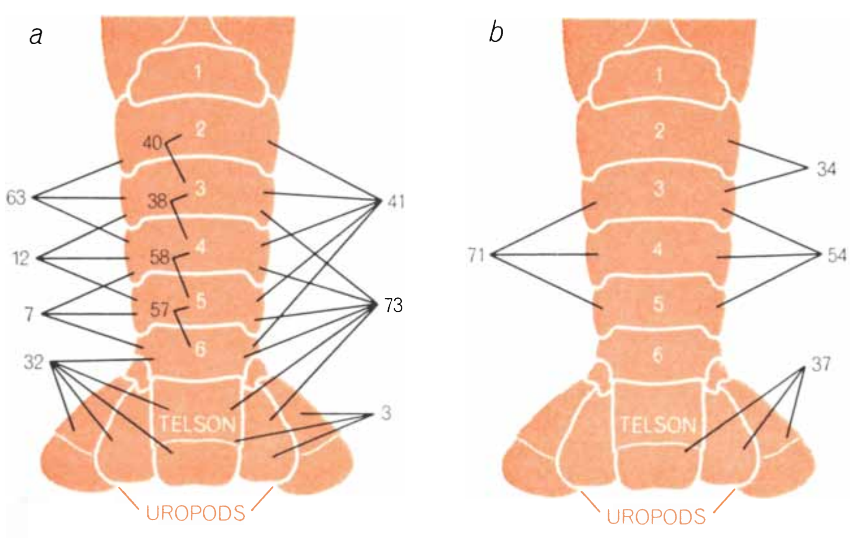
A particular group of touch-sensitive hairs on the back of the fourth abdominal segment, for example, might connect with a dozen different central interneurons. Each interneuron, however, responds to some unique combination of that group of hair receptors and other groups. One interneuron, for instance, might be excited by the fourth-segment group alone; another might be activated by the corresponding group on segment No. 5 as well as by the hairs on segment No. 4; another by those on Nos. 6, 5 and 4; another by those on all segments on one side or on both sides, and so forth. Precise duplication of function is apparently absent; each element encodes a unique spatial combination of sensory inputs [*see illustration below*].

This specificity suggests that the position and connection pattern of each central nerve cell is precisely determined in the course of differentiation of the nervous system. The reliability of this mechanism has been demonstrated impressively by Melvin J. Cohen and his colleagues at the University of Oregon, who have analyzed the organization of central ganglia in the cockroach. Cohen has located the cell bodies of specific motoneurons by taking advantage of a striking response shown by such cells when their axons are cut: If a motor nerve is severed at the periphery, even very near the muscle, each cell body supplying an axon in that nerve quickly develops a dense ring around its nucleus. This response, which can be detected with suitable stains, occurs within 12 hours [*see illustration on page 52*]. The new material comprising the ring has been identified as ribonucleic acid (RNA). Presumably it is required for the protein synthesis associated with regeneration; in any event, the ring provides an unambiguous label for associating a specific central cell with the peripheral destination of its axon.

By cutting individual motor nerves and locating their cell bodies in this way, Cohen has constructed a map that gives the positions for most of the motoneurons in a ganglion. The maps of ganglia from different individuals appear to be almost identical; indeed, specific cells are in nearly perfect register when sections of corresponding ganglia from several animals are superposed. Not only are the cell bodies of motoneurons that serve particular muscles precisely arrayed; they also appear to have rather specific biochemical personalities. Some motoneurons show the ring reaction especially strongly and others show it quite weakly, and these differences are consistently associated with particular cells—as judged by the position of the cell body and the peripheral destination of its axon.

In our own laboratory we have analyzed how the central nervous system of the crayfish deploys a limited array of identifiable nerve cells to control the posture of the abdomen. This structure consists of five segments with joints between them. Its shape is continuously and delicately varied by the action of thin sheets of muscle operating in antagonistic pairs—extensor and flexor—at each of the five joints. Both sets of muscles are symmetrical on each side of the abdomen. The extensors of each half-segment receive six nerve fibers, as do the flexors; the nerve fibers, like the muscles, are repeated almost identically in each segment.

Each individual motor nerve cell can be identified by the size of its impulses

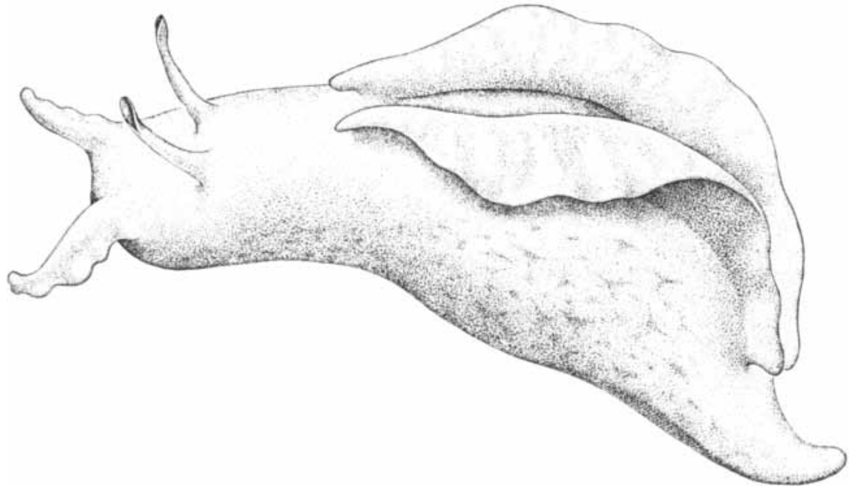


SPECIFIC GROUPS of touch-sensitive hairs on the segments of the crayfish abdomen excite specific interneurons located within the central nervous system. The receptive field of each interneuron listed here (*black numbers*) was mapped by C. A. G. Wiersma's group at Cal Tech. Each responds to stimulation of hair receptors on a unique combination of segments (*white numbers*), as shown by the pointers. The system is bilaterally symmetrical, with an interneuron No. 40, for instance, on each side. Neurons mapped at *a* respond to stimuli delivered to the same side of the animal. Of those mapped at *b*, those listed at the right respond to stimuli on the side opposite them; No. 71 responds to stimuli on either side.

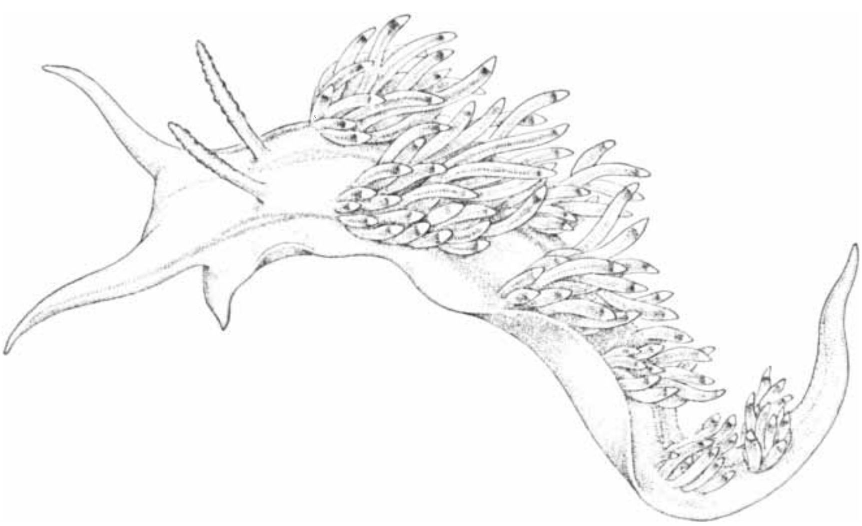
in an electrical record obtained from the nerve bundles that run to flexor or extensor muscles. As one might expect, particular reflexes activate the nerves and muscles in rather stereotyped ways. If, for example, one forcibly flexes the abdomen of a crayfish while holding its thorax clamped and then releases it, the segments extend to approximately their former position. Howard Fields of our laboratory found that this action depends on a pair of receptors that span the dorsal joints in the abdomen. Flexion lengthens the muscle strands associated with these receptor cells, and the cells then discharge impulses that travel toward the central nervous system and activate motoneurons supplying the extensor muscles, which are thereby caused to contract against the imposed load. Such "resistance reflexes" are known in a variety of other systems, including the limbs of mammals and of crabs; in the crayfish they can be studied in a simplified situation, with a single receptor cell and six well-characterized motor cells constituting the entire neural equipment for the reflex loop.

Since only about 120 motoneurons are involved in the regulation of the entire abdomen's position, and since we were able to identify each of them, William H. Evoy and I decided to analyze the central control system for abdominal posture. While recording the motor discharge in several segments at once, we isolated and then stimulated single interneurons located within the central nervous system.

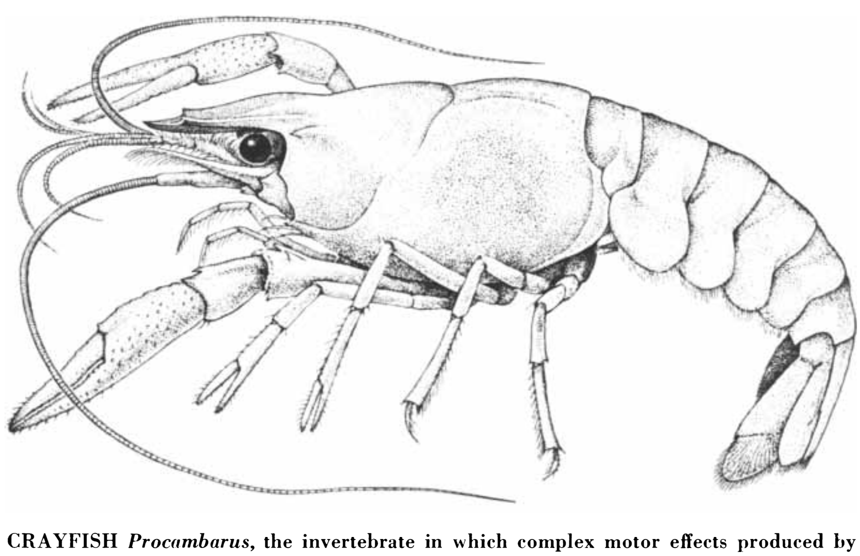
As we had anticipated, most cells had no effect on motor discharge, but we encountered some that regularly released intense, fully coordinated motor-output patterns when we stimulated them with a series of electric shocks. In every case the output was reciprocal: flexors were excited while extensors were inhibited, or vice versa, and the response was similar in several segments. Although equally complex behavior can be produced in many animals by localized stimulation of central nervous structures, it is likely that in most such cases many cells—perhaps thousands—are simultaneously activated by the comparatively gross stimulating procedure that is employed. In the crayfish abdomen, however, we have been able to demonstrate directly that a complete behavioral output can be the result of activity in a single central interneuron. Motor effects produced by stimulation of such central neurons in crayfish had been described earlier by Wiersma and K. Ikeda, who coined the term "command fiber" for those inter-



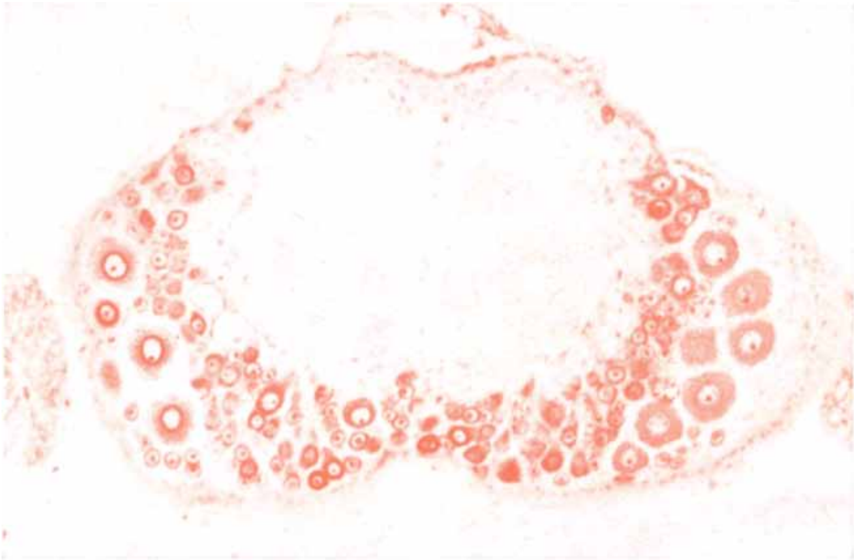
SEA HARE *APLYSIA* is a mollusk with a vestigial shell under the mantle between the winglike parapodia, which are used for locomotion. The animal is about 10 inches long.



***HERMISSENDA*, another mollusk, is only one to three inches long. The "camera" eyes are embedded just behind the rhinophores, the two upright stalks near the left end of the animal.**



CRAYFISH *Procambarus*, the invertebrate in which complex motor effects produced by single cells are studied by Wiersma and by the author, is from three to five inches long.



DENSE RINGS of ribonucleic acid surround the nuclei of the cells on one side *(left)* of a stained section of a cockroach ganglion about a millimeter across. Two days before the photograph was made by Melvin J. Cohen of the University of Oregon, all peripheral nerves from one side of this ganglion had been cut. The rings appear in the cells on that side.

neuron axons that produce stereotyped, complex motor effects.

When we compared, in single animals, a series of central nerve cells that produce extension, we found that each produced a special distribution of motor output in different segments. One strongly influenced the last two segments but had a weak effect on segments farther forward; another yielded an almost even balance of output; another activated the forward segments more strongly, and so on. This result led naturally to the inference that individual command elements might each code for a unique combination of segmental actions and thereby produce specific movements or positions. In collaboration with Benjamin Dane, who is now at Tufts University, we filmed the maneuvers of the abdomen that occurred when command fibers were stimulated, while simultaneously recording the discharge of motoneurons supplying muscles in one of the segments. This experiment confirmed the neurophysiological predictions: the films show that two command elements with a generally similar action affect the segments in different ratios and so produce unique abdominal postures [*see illustration on page 45*].

These results indicate that the coordination of at least some behavior is based on the intrinsic "wiring" of a nervous center and can be released by single-cell triggers. Such a conclusion would have been more surprising a decade ago than it is now. It was once thought that complex sequential behavior such as locomotion depended for its organization on a series of instructions fed back to the central nervous system from peripheral sensory cells. Each new act, according to this view, was initiated by proprioceptive sense organs that were excited by the animal's own movement and signaled that one response had been completed; the whole sequence was likened to a chain of reflexes successively activated by the continuous inflow of sensory signals from the periphery. In recent years biologists have become more convinced that the connections among interneurons at the nervous center, selected by evolution and precisely made during the developmental process, contain most of the organization inherent in such behavior, and that sense organs play a role that is more permissive than instructive.

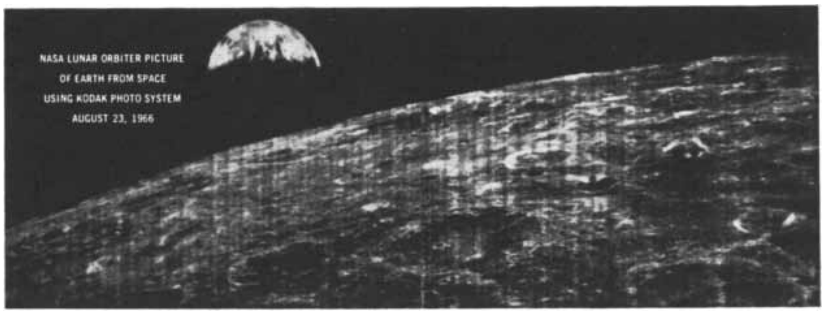
One of the most convincing demonstrations of the importance of these central connections was provided by the experiments of Donald M. Wilson of the University of California at Berkeley on the flight of locusts. This behavior pattern consists of a sequence of actions in the muscles that elevate, depress and twist the wings. Since these muscles are served by only one or two motor nerve cells, one can obtain a record of the activity of each cell by inserting fine wires into the muscles of a relatively intact animal. In this way Wilson and Torkel Weis-Fogh were able to define the impulse sequences, along various motor nerves, characteristic of normal flight.

The pattern can be triggered in several ways. When the insect is stimulated by having air blown on its head, the motor activity characteristic of flight is frequently released, but Wilson has shown that the output pattern has no relation to the timing of the input. Indeed, when he stimulated one of the central connectives electrically at random intervals, the flight motor output still had its normal frequency and pattern.

Associated with the base of each wing of the locust there is a sensory-nerve cell that responds with single impulses or a short burst when the wing comes to the top of its upstroke. It had been supposed that these receptors might be providing phase information about the wingbeat cycle and perhaps initiating activity in the motor nerves controlling the downstroke. Wilson eliminated these receptors and found that although the frequency of flight motor output dropped somewhat, its repetitive character and the sequence of events within a single cycle were unimpaired. This showed that the stretch receptors, although they participate in a reflex that controls frequency, do not provide any information about the phase relations within a single cycle. Since the entire pattern of behavior can be produced by a central nervous system isolated from peripheral structures—as long as enough excitation of some kind is supplied—it must be concluded that all the information for the flight sequence is stored in a set of central connections.

At this point one can only assume that the sequential events of the flight pattern, like the motions that result in postural changes in the crayfish abdomen, are released by activity in central "command" elements. Some single interneurons are known to release similar complex, sequential behavior in the crayfish. One, for example, produces a sequence of flexions that ascends slowly from segment to segment until it reaches the forward end of the abdomen and then begins again at the back. Another causes an intricate series of movements in the appendages of the tail. We wonder how such central command neurons are activated during voluntary movements, whether they are organized entirely in parallel or in part as a hierarchy of related elements, and what kinds of sensory stimulus excite them. While it would be premature to assume that all these questions can be answered or that we can apply the results to other systems, it is the peculiar advantage of small networks of nerve cells that such a prospect does not seem hopeless.

The hope of doing each other some good prompts these advertisements



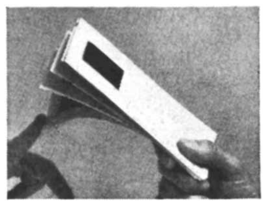
Earth photography: what to do with it

When we displayed this now familiar photograph in 18 x 60-foot size in New York's Grand Central Terminal, more than one scurrying commuter was overheard speculating as to which was the moon and which the earth. In stimulating widespread thought about questions like that, the picture was fulfilling a purpose. For the moment it also fixes one end of the scale for available photography of the earth's surface. For such other purposes as urban and agricultural planning, photogeology, ecological studies, resource assessment, and all the rest, photography of a less majestic scale is also available and more serviceable.

As the camera gets closer and detail becomes easier to resolve, another problem presses in: the sheer physical volume of film to keep track of. More and more of the earth's surface is being photographed in finer and finer detail for more and more purposes.

For those perversely glad that coverage is not more complete because theirs is the responsibility of making sure that existing coverage is available for use, there is still time to take steps while the men in airplanes assiduously fill more warehouse space with more long rolls of aerial negative.

We can help. We hereby announce a new service. We are prepared to move in on a collection of aerial negatives and convert it from the ancient scroll format in which it emerges from the camera into far more accessible modern unitized form on the familiar aperture cards, such as nowadays carry engineering drawings for storage and retrieval. At last we have the right film for the job, which is more demanding photographically than the microfilming of drawings. It processes to deliver a negative directly, like the negative it sees. Eliminating the positive saves one step of degradation. Positive prints projected back from the small negative have fooled experts asked to distinguish them from those contact-printed from the original camera negative.



To keep that kind of reproduction quality, we suggest that the mechanical sorting from data punched on the card be done from a "slave deck" that's just as easy to generate at the time we prepare the card that carries the microfilm negative to a file drawer, where it awaits retrieval by a nimble-fingered lady.

Consultation can commence now with Eastman Kodak Company, Business Systems Division, Rochester, N. Y. 14650. Ask about RECORDAK *Air-Photo Microfilm Service.*

Patience rewarded

We have been addressing readers in this vein on this page for years. Evidence exists of phenomenal patience among the populace in persisting with these thousands of words in hope of striking something personally useful, or at least interesting. Photography, we know for sure, does interest lots of people. That fortunate fact gives us a chance to raise our score. Following is a list of Kodak publications of various sizes, styles, and depths. Many of our dealers stock many of them. If you insist on denying yourself the pleasure of a visit to a camera shop, we'll send you *any five* of the following free (even if you have never read one of these ads before and intend never to read one again) on request to Department 454, Eastman Kodak Company, Rochester, N. Y. 14650.

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Photography of Television Images
Composition
Notes for the Photo Traveler Abroad
Astrophotography with Your Camera
Pictures Outdoors at Night
Underwater Photography with Black-and-White and Color Films
Picturetaking through Binoculars
Taking Pictures from Airliners
Exposure with Portable Electronic Flash Units
Sources of Motion Picture Services and Equipment—16mm, 8mm, and Super 8
Titling Your Movies
Editing Your Movies
Care of Processed Kodachrome Movies
Close-up Movies
Making an Outdoor Movie
Making an Indoor Movie
Making Movies More Interesting
Prevention and Removal of Fungus on Processed Film
Printing Color Films Developed as Black-and-White
Mounting Slides in Glass
How to Check Your Exposure Meter and Camera
Equivalent Exposure Meter Settings
How to Develop and Print Your Films
Sensitizer for Paper, Cloth, and Similar Fabrics
Making a Photographic Emulsion
Darkroom Design for Amateur Photographers
Basic Copying
Lunar-Eclipse Photography
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Small sample and further information about cellulose-coated CHROMAGRAM *Sheet from Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company). (Another* CHROMAGRAM *Sheet for partition TLC, this one bearing microporous polyamide, is imported from our French affiliate for resale here at $25.30 for twenty 20cm x 20cm sheets to those who wish to experiment with it, but no samples and not much information can be supplied.)*

Price subject to change without notice.

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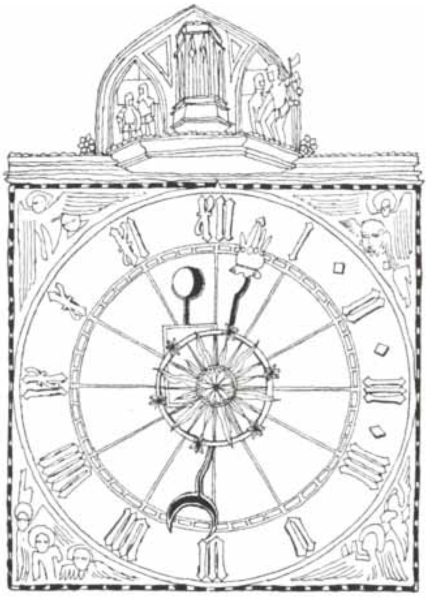
SCIENCE AND



Class, Race and the Draft

The "public presumption" that selective service operates with a bias against men of lower socioeconomic class has "an important element of truth," according to Morris Janowitz of the University of Chicago. In an article in *Trans-action* Janowitz examines the social and demographic factors involved in the operation of the draft and concludes that a broad system of national service, with a lottery to select men for military service, would tend to eliminate the social injustices.

Selective service, the Chicago sociologist points out, was reinstituted in 1950 during the Korean war to meet a need for partial mobilization, and so it provided for occupational and educational deferments. The burdens of the war, particularly the incidence of casualties, fell disproportionately on the lower socioeconomic groups, in part because of the social bias of the draft and in part because of the pattern of manpower utilization in the armed forces. Better education led to advanced training and specialized assignments, whereas soldiers with limited education went largely into infantry units. Among noncommissioned officers and enlisted men in the ground forces, soldiers from the lowest-income group had four times the casualty rate of those in the highest-income group; the casualty rate among Negroes was twice as high as it was among whites.

Between the Korean war and the intensification of fighting in Vietnam in 1965 selective service operated "with relative fairness." Educational level was the primary determinant. Of men whose education ranged from nine years of school to the completion of college, about 70 percent saw military service. Only a third of those with less than an eighth-grade education served, and only a quarter of those who went on to graduate school. During this period Negroes were actually underrepresented in the armed forces. Their overall participation rose to 9 percent in 1965 and is now likely to continue rising, Janowitz writes. The major reason is the higher reenlistment rate among Negroes: 45.1 percent in 1965 as opposed to 17.1 percent for whites. Negroes have tended to concentrate in the combat branches (some airborne units are nearly 40 percent Negro), and from 1961 to 1965, 14.6 percent of the U.S. casualties in Vietnam were among Negroes.

Smooth Sea of Cosmic Radiation

Evidence has been accumulating that the earth is bathed in microwave radiation left over from a primeval fireball that gave rise to the universe as we see it today. Several billion years after the primordial event the temperature of this cosmic radiation has cooled to about three degrees Kelvin (degrees centigrade above absolute zero). This hypothesis has now received further support from the finding that the radiation is very nearly isotropic, that is, its intensity is very nearly constant when measured in any direction. The finding is published in *Physical Review Letters* by R. B. Partridge and David T. Wilkinson, members of a group working with Robert H. Dicke at Princeton University.

The Princeton workers measured the background radiation at a wavelength of 3.2 centimeters with a specially designed radio telescope that was pointed steadily in the direction of the celestial equator. As the earth turned, the instrument swept a 360-degree path through the sky. During 15 minutes of each half hour a large aluminum reflector was placed in the antenna beam so that the incoming radiation was received from the region of the north celestial pole. By measuring the difference in the readings from these two directions the effects of solar heating on the apparatus and on the atmosphere were canceled out. Fifty-five runs extending over most of a year were analyzed statistically to see if the data concealed a 12-hour or 24-hour periodicity. The 24-hour periodicity was found to be negligible: less than .1 percent. There was, however, a small 12-hour periodicity, amounting to about .2 percent, that the Princeton workers suspect may be significant. Its cause is unknown, but it may represent a real anisotropy of the universe early in its history.

The Princeton measurements can be used to estimate a kind of "absolute" motion of the earth: the velocity of the solar system with respect to the mean motion of the radiation produced by the primeval fireball. If the solar system were moving relative to this radiation, the radiation would seem to be a little hotter measured in the forward direction and a little cooler measured in the backward direction. The present measurements place an upper limit of about 300 kilometers per second on the velocity of the solar system relative to the background radiation. This value seems remarkably low, considering that the earth travels around the sun at 30 kilometers per second and that the sun travels around the center of the galaxy at about 300 kilometers per second.

The data were also analyzed for clues to the homogeneity of matter in the universe. The results place an upper limit of ±10 percent on variations of density large enough to extend over a few billion light-years.

Five-Year Plan for Biologists

July will mark the beginning of an international program of biological research aimed at providing answers to many urgent questions concerning man's effect on the balance of nature. The concept of an all-out effort in biology, modeled after the International Geophysical Year, was first put forward in 1959 by officers of the International Union of Biological Sciences and the International Council of Scientific Unions. By 1963 the two groups had devised and endorsed a five-year program, "The Biological Basis of Productivity and Human Welfare," covering seven areas of inquiry. These include investigations of the productivity of living communities on land, in fresh water and in the oceans, of the conservation of land communities, of the processes of organic productivity (for example the virtually unknown process of nitrogen fixation, a vital factor in soil fertility), of man's use and management of biological resources, and finally of man's own adaptability in the face of such factors as disease, chronic malnutrition and the exponential increase in human population.

Thirty-eight nations—including the U.S.S.R. and the other countries of eastern Europe—will participate in the IBP. Albania, North Korea, North Vietnam and China are not enrolled. Also absent from the program are most of the world's underdeveloped countries. Only one Latin-American nation—Mexico—and only five of Africa's countries are participating.

Tuning Laser Beams

Significant advances in the ability to tune the output of oscillators pumped by lasers were reported at a Symposium on Modern Optics held recently in New York. These devices, known as optical parametric oscillators, convert the intense beam of a laser into two laser-like beams whose combined frequencies are equal to the pumping, or input, frequency. Thus an oscillator pumped by a laser source whose wavelength is 5,300 angstrom units will produce two beams whose wavelengths are tunable over a region centered at 10,600 angstroms. The active element in an optical parametric oscillator is a piezoelectric, double-refracting crystal such as lithium niobate.

About two years ago J. A. Giordmaine and Robert C. Miller of the Bell Telephone Laboratories found that the output of a lithium niobate oscillator could be tuned over a considerable frequency range by changing the temperature of the crystal. Independently Rem Khoklov of the University of Moscow reported that he had developed oscillators incorporating a more common crystal, potassium dihydrogen phosphate, that could be tuned simply by rotating the crystal. At the New York meeting he described an oscillator pumped by a laser beam whose wavelength is in the near-ultraviolet part of the spectrum (3,500 angstroms) that produces a signal that can be tuned over two wavelength regions: between 4,800 and 5,900 angstroms and between 8,500 and 12,800 angstroms. The input beam, obtained by two stages of laser amplification, has a power of 20 megawatts. Khoklov also reported that an oscillator pumped at 5,300 angstroms had achieved the remarkable conversion efficiency of 3 percent, with signal outputs varying from 9,600 to 11,800 angstroms. The pumping beam was three megawatts and the output signal was 100 kilowatts.

Meanwhile at the Bell Laboratories, Miller and W. A. Nordland have been continuing work with lithium niobate oscillators and have shown that by rotating the crystal the signal output can be varied from 6,840 angstroms to 23,550 angstroms, when the pumping frequency is 5,300 angstroms. This is the greatest frequency range that has yet been reported from a single optical parametric oscillator.

Commenting on the new developments, Nicolaas Bloembergen of Harvard University predicted that the new oscillators would "revolutionize" the field of spectroscopy. Tunable oscillators could be used to examine the absorption characteristics of chemical and biological materials with greater precision than is possible with existing techniques.

The Assembly of a Virus

Two biologists at the California Institute of Technology have determined the sequence of steps by which a complex virus puts itself together and have succeeded in assembling intact, infective virus in the test tube. A virus is a package of nucleic acid (DNA or RNA) wrapped in a more or less complex protein coat. Simple viruses are built up of identical protein subunits that can apparently assemble themselves without any outside assistance; one such virus, the one that causes the tobacco mosaic disease, was taken apart and then reassembled in the test tube more than 10 years ago. More complicated viruses are apparently assembled only with the help of "morphopoietic" genes that somehow specify their shape [see "The Genetic Control of the Shape of a Virus," by Edouard Kellenberger; SCIENTIFIC AMERICAN, December, 1966]. For example, the bacteriophage T4, a virus that infects the bacterium *Escherichia coli*, consists of a polyhedral head filled with DNA, to which is attached an elaborate tail assembly with a number of specialized components. Of its 100-odd genes, a large number have been identified that have shape-specifying functions.

Most of these genes have been identified by R. S. Edgar and his associates at Cal Tech and at the University of Geneva. Working with mutant strains of T4, they developed a genetic map and associated specific genes with the

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manufacture of specific parts of the virus [see "The Genetics of a Bacterial Virus," by R. S. Edgar and R. H. Epstein; SCIENTIFIC AMERICAN, February, 1965]. Now Edgar and William Wood have performed a more detailed analysis. As Edgar reports in Cal Tech's publication *Engineering and Science,* the assembly process is more complicated than had been expected. It apparently involves three pathways: one for the head, one for the main part of the tail and one for the six hairlike fibers that complete the tail. Each step in each pathway is controlled by a particular gene; if any gene is missing, the precursor materials of the step it controls pile up in the bacterial preparation.

At least eight genes make proteins for the head; eight more somehow finish the head and two more enable the head to be joined to the tail. The pronged "end plate" that forms the base of the tail requires 15 genes; two other genes make proteins for the "core" of the tail and for fixing it to the end plate. Three genes then make proteins for a "sheath" that fits around the core. The fibers are built independently by five genes and are attached to the end plate by another gene. Edgar and Wood can infect bacteria with viruses carrying mutations in single shape-specifying genes; the resulting lysates, or cell debris, will contain virus parts rather than complete viruses. If all these parts are then combined in a suitable solution, the parts assemble themselves into normal viruses capable of reproducing themselves by infecting bacteria.

How do the shape-specifying genes work? Edgar thinks that some of them may make the proteins for some kind of scaffolding on which the virus parts are assembled; there is evidence, for example, that the polyhedral heads are formed on protein cores. Other genes may direct the synthesis of tiny protein "nuts and bolts" that become part of the virus or of "glues" that play temporary accessory roles and are not incorporated in the completed virus particle.

Lymphatic Kidney?

An artificial kidney that processes lymph rather than blood is being studied by Harry E. Sarles and several co-workers at the University of Texas. Sarles and investigators in other institutions are also exploring the possibility that reducing the number of lymphocytes (the white cells of the lymph) will control the body's tendency to reject transplanted tissues. He and his colleagues reported on their work at a meeting in April of the American Society for Artificial Internal Organs.

In the usual kind of artificial kidney waste products are removed by dialyzing the blood; the blood is tapped from an artery, passed along a synthetic membrane through which the waste products diffuse and pumped back into the body through a vein. The procedure has been extremely useful, but it has remained cumbersome and costly, largely because it is necessary to monitor the blood's pressure and temperature and the integrity of its constituents. Sarles estimates that the dialysis of lymph, the circulatory fluid that returns to the bloodstream substances that diffuse out of the capillaries, can be accomplished at about a tenth of the cost of blood dialysis because the lymph method uses less fluid and requires less monitoring. The technique involves drawing lymph from the thoracic duct, which is the largest vessel of the lymphatic system, passing it through a dialyzer and returning it to the bloodstream through the right jugular vein. Sarles said his group had performed lymph dialysis on a number of patients with imperfect but promising results.

An effect of lymph dialysis is to kill a number of lymphocytes, which are involved in the body's defenses against foreign substances and accordingly play a role in the rejection of transplanted tissue. This effect led Sarles and his colleagues to explore the possibility of increasing tolerance for transplanted organs by means of lymph dialysis or diversion. In reporting the work Sarles said it had appeared successful in skin grafts on several patients. He expressed cautious optimism that it could prove valuable in the transplantation of organs such as the kidney.

The U.S. and the Automobile

Two recent developments indicate a further enlargement of the Federal Government's interest in automotive affairs. The U.S. Public Health Service has opened a driving research laboratory in Providence, R.I. The Federal Power Commission, responding to a request from a Senate subcommittee studying air pollution, has issued a report asserting that the technology now exists for extensive production of electrically powered vehicles for short-range operation.

The driving laboratory, which is the first such institution to be operated by the Federal Government, will devote itself exclusively to exploring the human factors in automobile accidents. Its key equipment consists of two electronic

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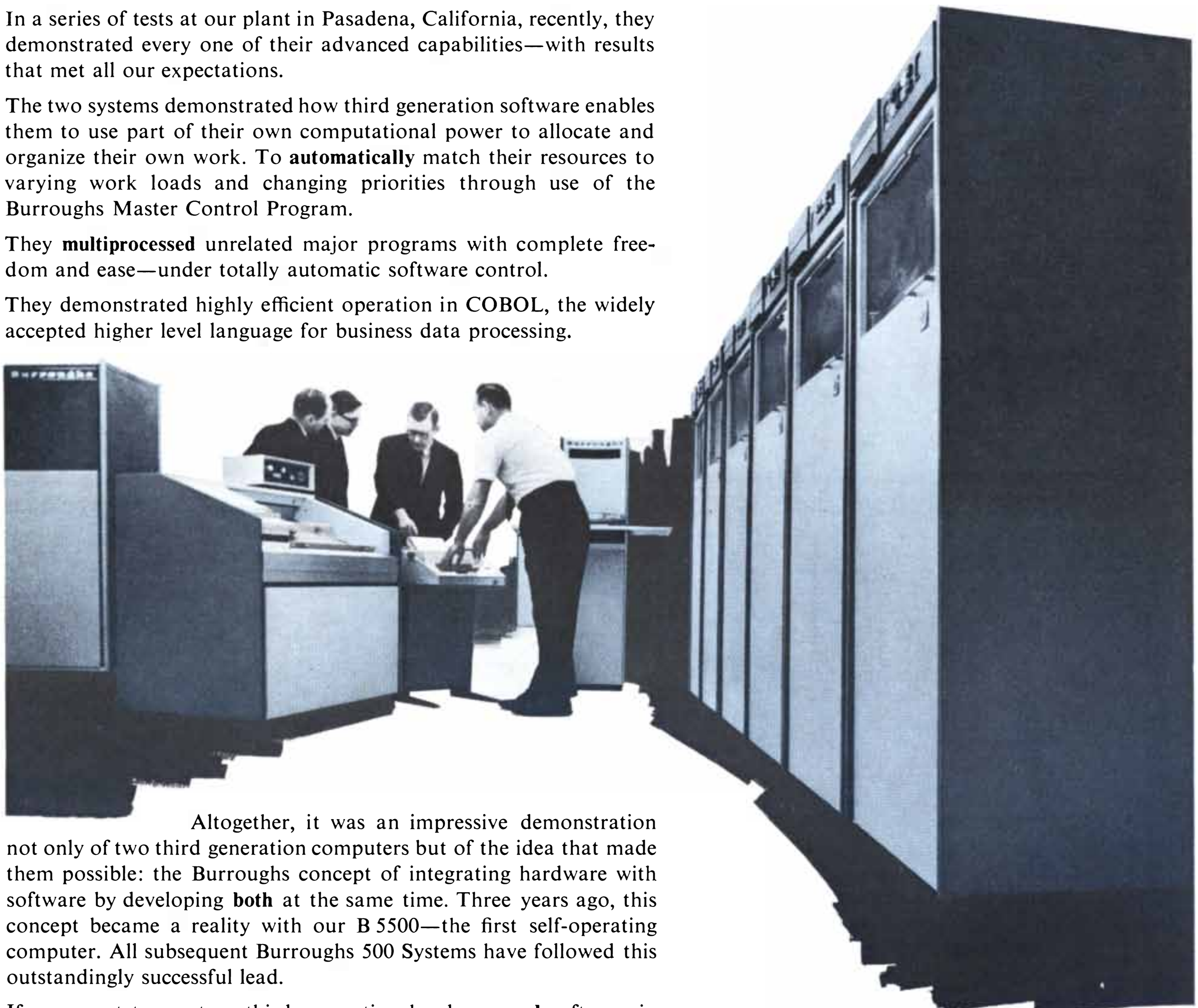

Altogether, it was an impressive demonstration not only of two third generation computers but of the idea that made them possible: the Burroughs concept of integrating hardware with software by developing **both** at the same time. Three years ago, this concept became a reality with our B 5500—the first self-operating computer. All subsequent Burroughs 500 Systems have followed this outstandingly successful lead.

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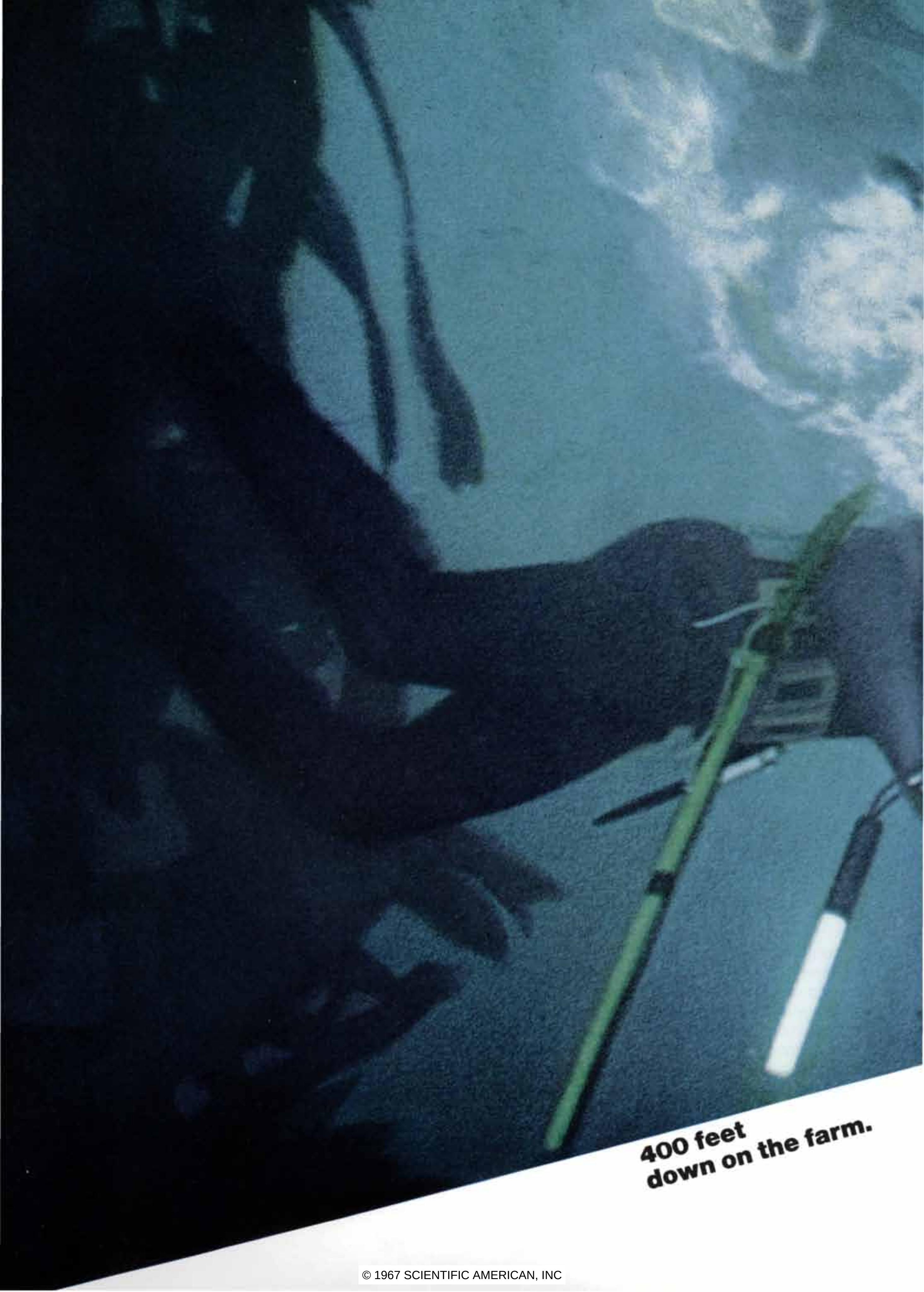
simulators in which, according to a spokesman, "drivers can be exposed to the most hazardous driving conditions with an accurate recording of their responses, all within the safety of the laboratory." The laboratory will use residents of the Providence area as subjects, paying them for their work. Its results are expected to help in the establishment of standards for licensing drivers and for training in better driving practices.

The FPC looked into the electric-vehicle situation because the Senate subcommittee wanted to know how feasible it would be to combat air pollution by encouraging the use of electric propulsion. The commission found that if manufacturers made use of present technology, electric vehicles could be put into use at a rate of two million a year by about 1980. Such vehicles probably would be used mainly in urban and suburban areas because of limited range and speed. On the question of electric vehicles that could travel long distances at high speeds the commission said: "The present scale of the research effort is not likely to result in the necessary technological advances in the reasonably near future."

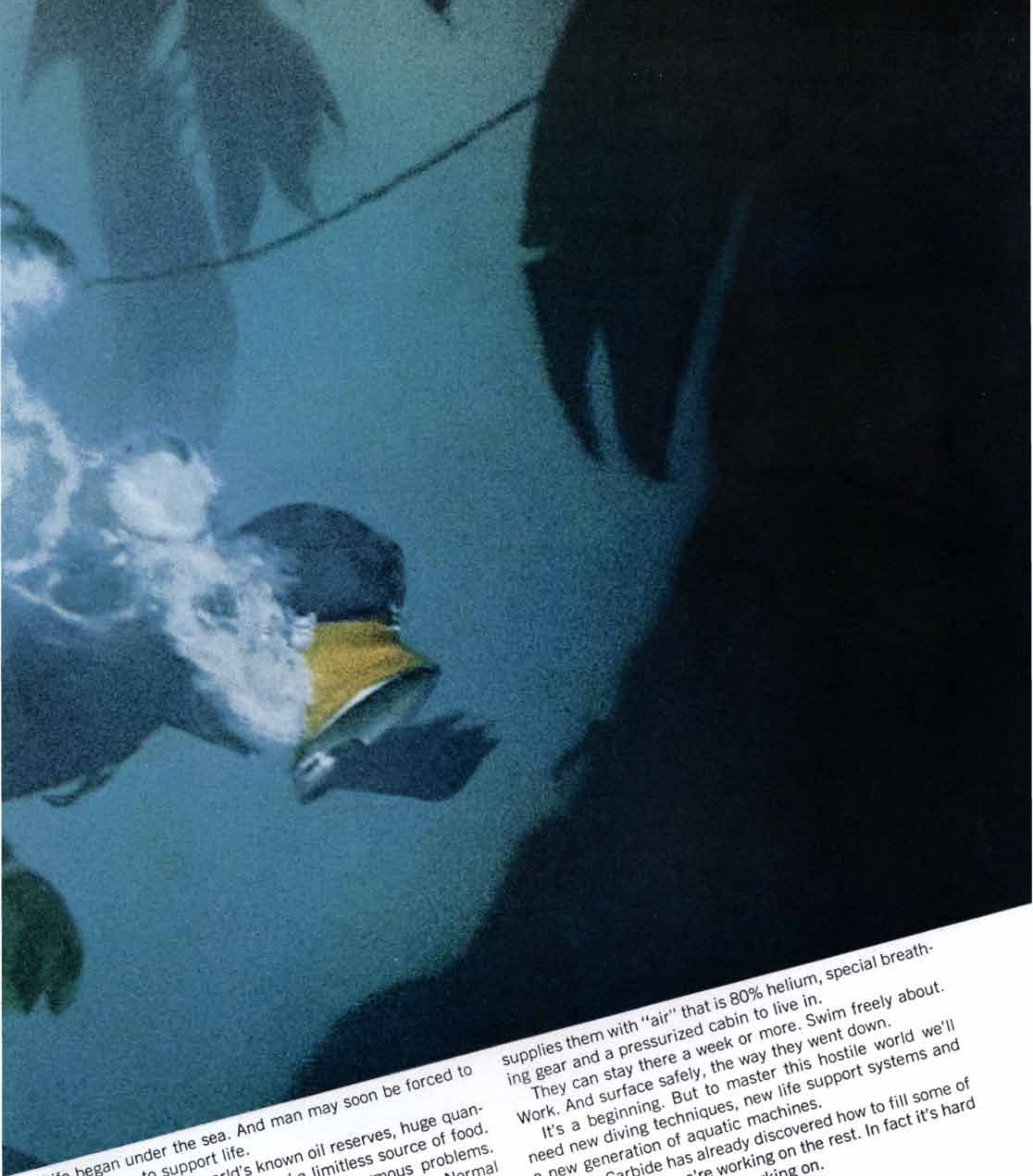
Man v. Mouse in 2500 B.C.

Although it is doubtful that many people were beating a path to the upland valley of Bampur in southeastern Iran during the third millennium B.C., this Neolithic community apparently did build a better mousetrap. Writing in *Antiquity*, Beatrice de Cardi of the Council for British Archaeology reports that last year a group of her co-workers found fragments of the ingenuous device among many other examples of Bampur ceramics. The trap was basically a horizontal pot with a sliding door at the end. The door appears to have been suspended by a string that passed over a horizontal bar (held on two forked sticks), entered the pot through a slot and emerged through a second slot. The string was probably anchored in the second slot by a knot just a trifle too large to pass through the slot. The bait was fastened to the string inside the pot between the two slots. When a mouse or some other small animal tugged at the bait, the knot pulled through the second slot and the door fell like a portcullis.

A pottery mousetrap was used in the great Harappan city of Mohenjo-daro, some 400 miles east of Bampur, at about the same period. The remains of such traps indicate that they were more primitive than the Bampur one; they trapped their quarry by means of a noose.



400 feet
down on the farm.



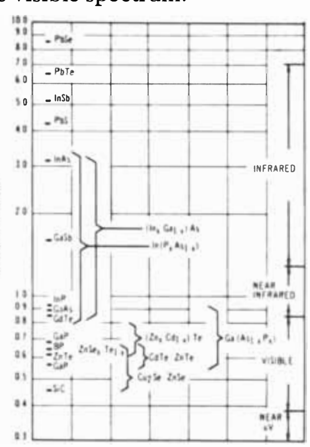
Here (simulated) is a commercial aircraft which uses a semiconductor light source as a "sixth sense" to pulse a beam of light through heavy fog. Normal light sources under these conditions are made useless by the Rayleigh scattering—caused by the inter-relationship of the number of particles of moisture in suspension in the path of a light beam and the wavelength of the light itself. But a pulsed solid-state laser light source—working in conjunction with gated RCA conversion tubes (as indicated schematically in Fig. 4 on the facing page)—could be used to develop a new flight instrument that will be able to pierce the heaviest fog and provide clear vision of the airport runways during landing approach. Such techniques could also be applied to automotive and naval applications to permit safe operation under poor visibility conditions.

Man has been improving his light sources ever since he first illuminated his way by night. (The embers of his fire gave way to the oil of his lamp; then candles, of higher efficiency, were superseded by the gas flame and its mantle which, in turn, were replaced by the electric bulb—incandescent and fluorescent.) Now RCA technology has conceived and developed the newest approach to light generation, using solid-state optical devices as light emitters.

To create light this revolutionary way, RCA starts with a p-n junction diode—a tiny solid-state device made of one or more alloys. Forward current injects minority carriers into space charge region, resulting in an excess of hole-electron pairs. When recombination occurs, "light" is emitted. Careful control of the internal geometry of the diode results in a theoretical output of up to 1.5 watts per ampere for unity quantum efficiency—if all the power generated in the junction area of the diode could exit. The result is a unique electro-optic component for high-efficiency light emission that is economical, small-sized... and practical for industrial applications.

The application of sufficient forward bias current produces an incoherent light beam—one in which radiation is random and out-of-phase. Still further control of bias current and control of crystal geometry results in laser action, producing a *coherent* beam of light. An array of laser light sources can be used to form a single, higher-powered beam.

In the case of both coherent and incoherent sources, the specific wavelength of their emitted light is controlled by the basic alloy(s) of which the device is produced. Gallium arsenide, for example, produces light in the infrared portion of the spectrum; gallium phosphide emits radiation at shorter wavelengths, and silicon carbide produces light at the blue end of the visible spectrum.



SPECTRUM OF LIGHT EMITTING DIODES

Fig. 1

By using different alloys in the III-V and II-VI groups of the periodic table, or lead salts in a series of junctions, RCA has now produced a series of light emitters which generate wavelengths from 80,000 angstroms (well above infrared) to 4,000 Å in the blue (visible) range. *Fig. 1* shows the spectral response of several different alloys now under examination at RCA. Each semiconductor, including the mixed crystals, has its own band gap energy and emits a characteristic wavelength.

No matter where in the spectrum an optical semiconductor device emits light, to circuit and equipment designers it has marked advantages over other light sources for specific applications. Compare it, for example, with the ordinary tungsten lamp which must be operated at high temperatures, is fragile, and therefore has a limited life. Furthermore, the bulb's emitted light covers a *wide band* within the spectrum—an inherent source of inefficiency of even the best incandescent and fluorescent lamps, since specific applications often need use only a small portion of the total emitted spectrum.

Optical semiconductor devices, on the other hand, operate at ambient temperatures... and at light-emission levels controlled closely to provide narrow and controlled spectra—precisely governed by the alloy(s) of which the device is made.

Both current and voltage used to operate RCA optical devices are fully compatible with solid-state electronic supporting apparatus, such as power supplies. RCA has successfully created light from incoherent optical semiconductor devices using currents as small as 0.1 mA, as well as laser beams with input current in the 10-12 ampere range—substantially lower than the current required by other industry devices to induce laser action.

RCA optical semiconductor devices are ready to leave the laboratory and take on practical, everyday assignments. New devices and newly-developed circuits using solid-state light sources will find wide application in the fields of specialized illumination, control circuits (particularly in computers and ancillary equipment), and in low-cost, short-range communication and display equipment, both for military and general use.

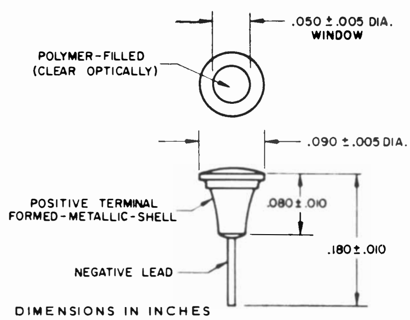


Fig. 2

One such application of an optical diode is in a card read-out for computer data input. In use, it replaces tungsten-filament lamps, proven to be a continuing source of computer failure and costly downtime because of frequent burn-out and the need for replacements. *Fig. 2* shows the RCA TA7008 optical diode, suitable for use in this application, in dimensional cross-section. The unit is provided to

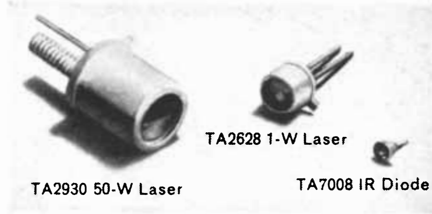


Fig. 3

equipment manufacturers in a reliable plastic-type package, with a built-in parabolic reflector. *Fig. 3* shows this same unit along with two other RCA solid-state GaAs optical devices. RCA has these developmental devices available now.

RCA GaAs laser diodes can now provide peak power output per junction of 10 watts or more. RCA knows the electronics required to make them operable... and RCA engineering skills can help you develop practical, everyday systems to take advantage of this new concept in light generation—from infrared to visible emanations.

RCA has accumulated a wide knowledge of device fabrication and application potentials in the process of "shepherding" optical devices from experimental types to practical units. One typical application possibility is in panel instrumentation with fail-proof illumination, for use in jet and hypersonic aircraft. Lighting for manned space-flight vehicles could readily use solid-state light sources to take advantage of their greater durability and longer potential life. A solid-state source of light, together with necessary optics, can also be used to replace presently-used

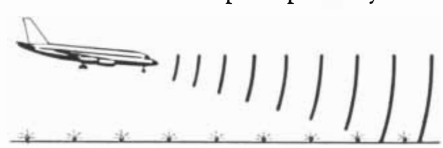


Fig. 4

types of tubes in alpha-numeric read-out devices and operate at improved levels of visibility. Properly pulsed, optical devices also can supply high-efficiency pulsed light for illumination applications.

Fig. 4 indicates one potential avionics application of this capability. By pulsing a laser light source and gating an RCA image tube, both on the aircraft, an unobstructed view of the runway on approach can be obtained under adverse conditions since light backscatter from fog and smoke is shut out and only the desired information received.

Applications for optical semiconductor devices—and for the light they are able to emit in carefully-controlled portions of the spectrum—are as complex or as simple, as multiple or as unique as designers may care to make them. If you seek guidance, consult your RCA Field Representative or write RCA Commercial Engineering, Section E-95EC, Harrison, N.J. 07029.

RCA ELECTRONIC COMPONENTS AND DEVICES

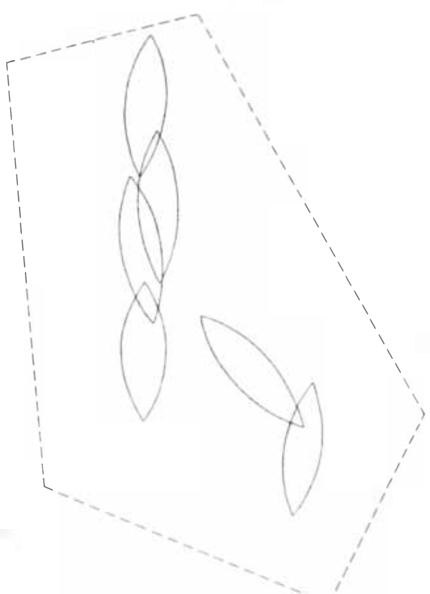
The Most Trusted Name in Electronics

THE VIKINGS

For 400 years beginning in the ninth century A.D. these seafaring nomads shaped history from the Middle East to North America. Such finds as coin hoards and buried ships trace their rise and decline

by Eric Oxenstierna

To most Americans, I would venture to say, the Vikings are known as redoubtable seafarers who raided England and France, colonized Iceland and Greenland and even landed in North America centuries before Columbus. Much less known are the Scandinavian traders and settlers who colonized parts of England and France and the whole of Sicily, established the first Russian state, traveled by inland waterways to the Black Sea and the Caspian, manned the Byzantine fleet and traded slaves and furs in the bazaars of Bagdad for Arab silver and Chinese silks.



WATERLOGGED HULLS of Viking ships, sunk 1,000 years ago to block the mouth of Roskilde Fjord in Denmark, appear in the aerial photograph on the opposite page. In 1962 a cofferdam was built around the stone-laden hulks, the seawater was pumped out and the timbers were salvaged from the muddy bottom. Positions of the six ships partly visible in the photograph are shown in the illustration above. Most of the Roskilde ships were freighters; the success of the Vikings in trade and war, however, depended more on their swift "dragon ships" (*see illustrations on pages 70–71 and page 73*).

In this article I shall emphasize these less familiar aspects of Viking history. A review of the subject is timely because much new archaeological evidence concerning these Scandinavian peoples has recently been uncovered, illuminating a period of history that is poorly represented in written records.

The Vikings emerged as a recognizable group at the end of a restless period, lasting almost 1,000 years, during which many peoples of northern Europe had migrated to almost every corner of the continent. For example, the Burgundians had moved to France from the island of Burgundarholm (now Bornholm) in the Baltic Sea. The Vandals had gone from Vandilsyssel in what is now Denmark all the way to Andalusia in southern Spain; the Lombards from the mouth of the Elbe on the Baltic to Lombardy in Italy, and the Angles and the Saxons from what is now northern Germany to England.

Not all these movements were to the south. A number of grave sites recently excavated on the Scandinavian peninsula indicate that early in the seventh century A.D. a farming population moved into mountain valleys and deep forests where no one had ever lived before. Even the poorest of these immigrant farmers had enough iron at his disposal—in terms of hoes, spades, plows, axes, knives and, not least, a good sword—to enable him to clear the forest and cultivate his fields. Within a few generations, however, the newly cleared forest soil was exhausted, and there was hunger all over Scandinavia.

During this same period a significant technological change took place: the oared galleys that had provided water transportation in Scandinavia were replaced by ships with sails. An excavation at Kvalsund in Norway shows that by about A.D. 600 sizable sailing vessels were being built. They were shallow-draft vessels with a planked deck but no keel.

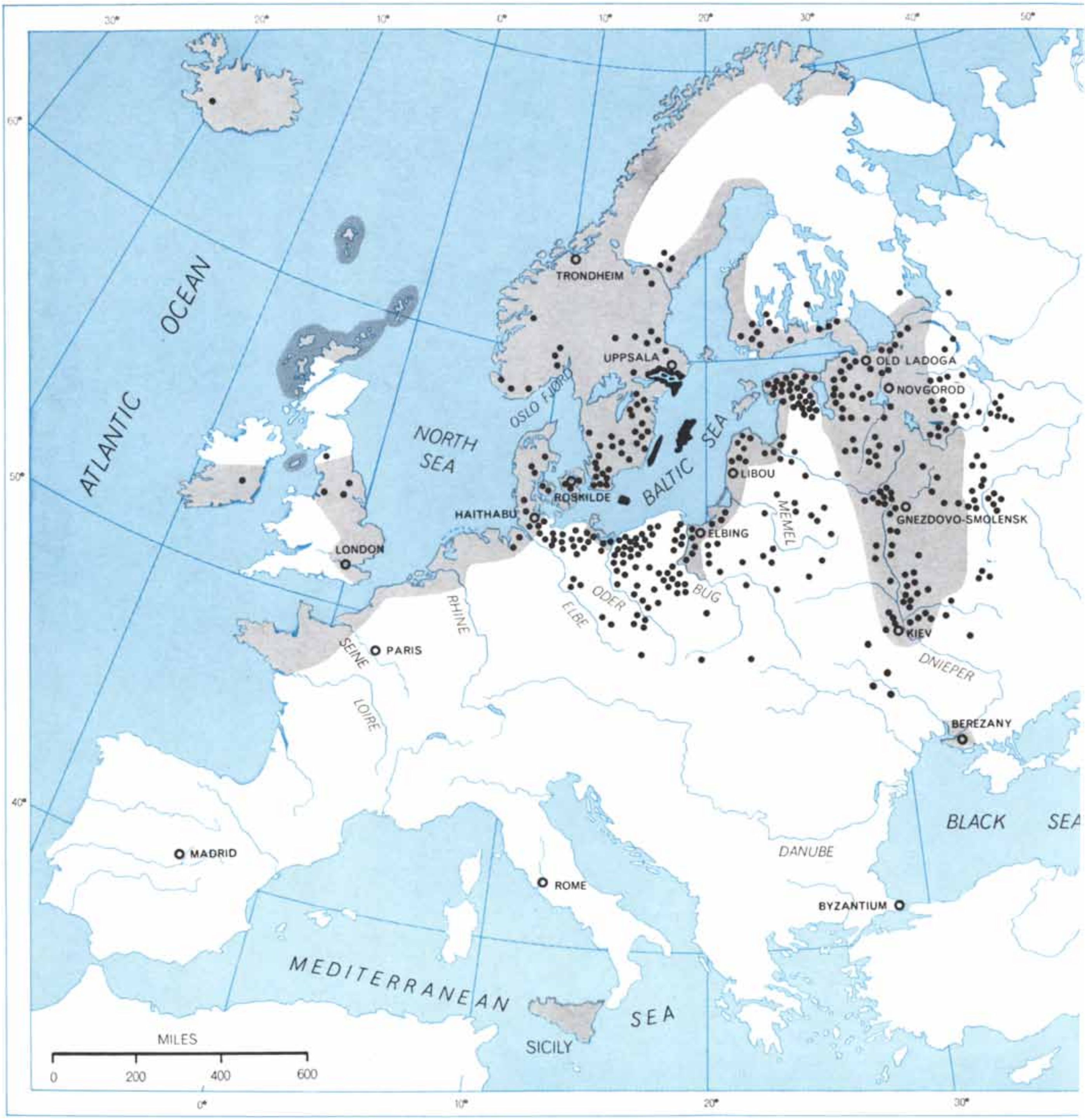
It is no accident that, at a time when a new mobility at sea coincided with hunger at home, history should record the first Viking raid. It occurred on June 8, 793. The action took place on the island of Lindisfarne, in the North Sea near the border of Scotland and England. The number of ships that came up over the horizon that day is not recorded, but the actions of their crews were noted in detail by the English monks who were their victims. The Vikings slaughtered the monastery's herd of cattle and loaded the carcasses into their ships. They killed anyone who resisted. After removing everything in the monastery that was made of silver and gold they set fire to all the buildings. From the Christian viewpoint the episode was an atrocity. For the pagan Vikings it had been a routine *strandhugg* (victualing raid) in which the unexpected haul of precious metal and the absence of armed resistance must have been agreeable surprises.

The word of the raiders' easy success evidently spread through Scandinavia like wildfire. The next summer "dragon ships" (named for their dragon-shaped figurehead) attacked two monasteries along the same North Sea coast of Britain. The summer after that monasteries on three islands off the western coast of Scotland—Rechru, Iona and Skye—were plundered. By A.D. 799 raids on the British Isles were common, and similar attacks on the Continent compelled the Emperor Charlemagne to organize a coast-watching force.

Thus began the activities that gained

the Vikings a reputation as pirates. As I have indicated, however, these peoples had other interests. Let us turn from the North Sea to the Baltic, particularly to the Svea people of the area around the modern Swedish city of Uppsala, to the inhabitants of the island of Gotland and to the petty kings who controlled the base of the peninsula of Jutland. Both the Svea and the Gotlanders had established coastal settlements in Latvia and elsewhere across the Baltic before the middle of the seventh century. Indeed, the excavation of a large seventh-century cemetery at Grobin in Latvia has uncovered ornaments typical of both Gotlander men and women—proof that their trans-Baltic enclave was a genuine colony inhabited by married couples and not a mere outpost.

From the trans-Baltic settlements trade goods (the most important were furs) flowed back to Gotland and the main Svea centers of commerce: the island towns of Helgö and Birka in Lake Mälar, near modern Stockholm. Excavations at Helgö have revealed trade goods manufactured far to the south (for example glassware made in Cologne on the Rhine) that had no doubt been received



VIKING SPHERE during four centuries of trade, settlement and piracy extended from the Volga River and the Caspian Sea in Asia, through the Mediterranean and western Europe to the British Isles, Iceland and beyond (*see illustrations on page 76*). The areas where the Vikings established permanent colonies are indicated in gray; areas of passing conquest or other brief residence have been omit-

in exchange for pelts or for the iron that also was an export of the Svea.

Items of even more distant origin have been uncovered by the digging at Helgö, which began in 1953. The bronze head of a crosier—the ornate shepherd's crook carried by abbots, bishops and other church officials as a symbol of their pastoral duties—is among the finds. It is of Irish manufacture; we can assume that it reached the Norwegian coast as part of some raider's loot and was then traded eastward to Helgö. A greater surprise was the discovery in 1955 of a small bronze figure of Buddha, complete with a golden caste mark on the forehead.

ted. The pervasive effect of Viking trade with the East is shown by the wide distribution of Arab coins (*dots mark coin finds*).

One of the way stations along this trade route between the north and Charlemagne's Europe was a Danish town at the base of the Jutland peninsula. Founded by King Godfred in A.D. 808, it stood near the present Kiel Canal at a point where only eight miles of land separate the Treene River and the North Sea from the Schlei River and the Baltic. Not only could goods moving north and south be easily transshipped here; the light dragon ships could themselves be hauled from one sea to the other on log rollers or mattresses of brushwood.

On all this traffic the Danes levied a profitable tariff. The town was Haithabu (modern Hedeby) and by A.D. 1000 it had grown as large as Cologne. Some of this area, which today lies in West Germany, was excavated before World War II; the work was resumed in 1960. Haithabu's cosmopolitan character during the last centuries of the first millennium can be judged by the kinds of objects that have been uncovered there. The excavators found, for example, a gold coin from Byzantium minted during the rule of the joint emperors Theophilus and Constantine (A.D. 829 to 842) in association with a gold-plated bronze buckle acquired in a raid on Ireland.

In 829 Charlemagne's son Louis the Pious received an embassy from the king of the Svea at a conclave that assembled at Worms on the Rhine. A regularization of trade was probably in the minds of both parties. In any case, Louis took advantage of the Svea delegation's return to Uppsala to send with them a missionary, a Benedictine monk. Accounts of the monk's mission indicate that he built a church but was not very successful in winning converts among the Vikings.

Overland to Byzantium

Meanwhile in their colonies across the Baltic the Svea were doing more than farming and trading. They advanced in their light ships across eastern Europe as if its meadows and forests were the open sea. Sailing up the Düna and Memel rivers, they beached their shallow-draft vessels and carried them overland to launch them again in rivers flowing south—the Dnieper and the Volga. Scarcely 10 years after the Svea embassy had visited the Emperor of the West at Worms, Vikings who had sailed the inland waterways to the Black Sea paid

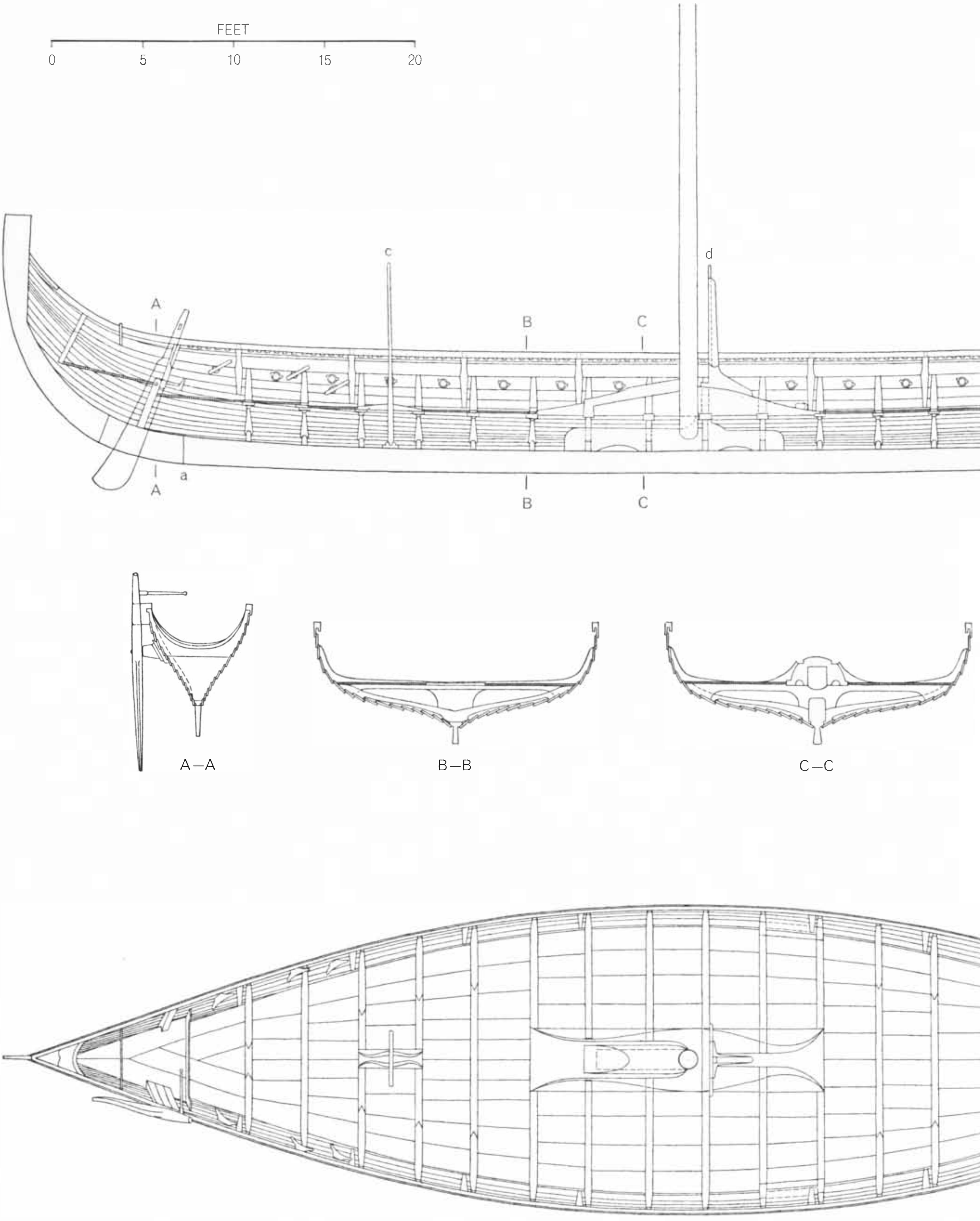
	NUMBER OF COINS	
YEAR	ARABIC 	GERMAN 
950–980	2,336	22
980–1000	738	457
1000–1020	129	1,184
1020–1050	20	2,994
1050–1070	4	3,030

ARAB AND GERMAN COINS found in Danish hoards show that Viking trade with the East via Russian waterways collapsed between A.D. 970 and 1070 (*see illustration at left*). During this interval the proportion of Arab coins to German coins fell from more than 99 percent to less than 1 percent.

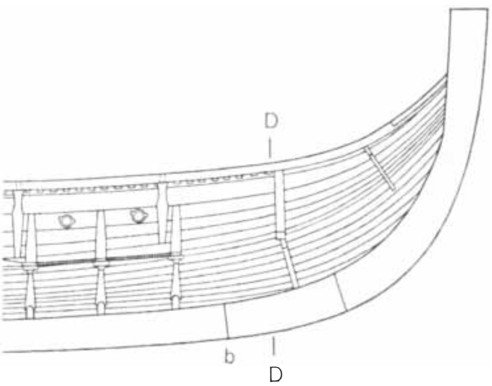
their respects to the Emperor of the East at Byzantium. Indeed, one such Svea group traveled back to its own land not the way it had come but by way of the Mediterranean and Italy, traveling with the Eastern emperor's embassy to the new ruler of the West (Lothar, who succeeded Louis the Pious in 840). A contemporary chronicle introduces us to a new word: the returning Svea are referred to as "some men calling themselves and their people Rus."

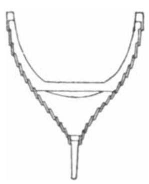
It is worth a digression to consider this word. The coastal district east of Uppsala in Sweden is Roslagen, and to this day its inhabitants are called Rospiggar. (The word *rus* itself means "oarsman.") The Svea kings certainly raised levies in this district, each locality traditionally furnishing a ship and crew. It is at least plausible to suggest that the trans-Baltic Viking settlements included many such complements of *rus* from Roslagen. Further weight is lent to this suggestion by the fact that the Finnish name for Sweden is Ruotsi. It is not surprising, therefore, that the oldest political entity in eastern Europe, the city of Kiev and its surrounding lands on the Dnieper, should have come to be known as Rusland and eventually as Russia.

In czarist times, and even today, some Russian scholars have challenged this derivation of "Russia." In my view the archaeological record strongly supports the Viking origin of "Rusland." As in the Gotland graves in Latvia, graves in Russia have yielded a large number of women's ornaments that show typical Svea workmanship. Nearly 100 oval Svea

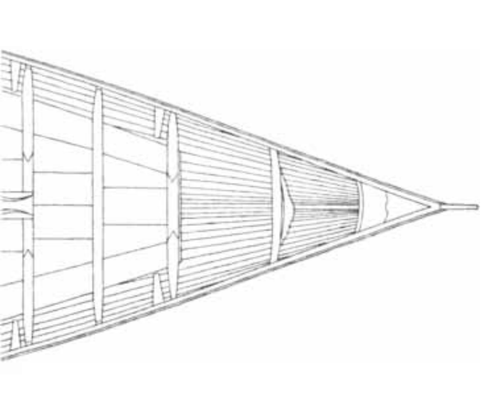


GOKSTAD SHIP, smaller than most of the dragon ships with which the Vikings harried the British Isles and western Europe, preserves their main features. For the better part of its 78-foot length (*from "a" to "b"*) the keel is one piece of oak, hewn from a tree that must have stood more than 75 feet high. The ship had 16 pairs of oars, and 32 overlapping shields filled the spaces between the oar holes on each side when the ship was in port. The three uprights (*"c," "d" and "e"*) may have supported tentlike shelters in





D—D



foul weather. Little is known, however, about the accommodations the Vikings enjoyed while at sea, how the ships' sails were rigged or what rigging braced their masts.

clasps have been unearthed, for example. I take this to be clear proof that the same Viking warrior-merchants who traveled the inland waterways also settled, with their wives, the fertile Russian countryside. Moreover, an excavation in Kiev has uncovered a chamber tomb of typical Svea design, and on the chest of the entombed man was found a Svea "Thor's hammer." It takes little imagination to reach the conclusion that the man was a worshiper of the Norse gods and in all probability a Viking colonist.

At least at first, however, the inland voyagers must have considered trade more important than colonization. Soon many of the Svea knew all the details of the journey southward from Kiev. They knew the names of the seven rapids of the Dnieper where travelers had to portage, and had chosen an island (Berezany) in the Dnieper delta as a place to stop before sailing on across the Black Sea. Soon treaties were written between the Byzantine authorities and the Svea, mainly to restrict the voyagers' freedom of action. The Vikings were not allowed to spend the winter in Byzantium. No more than 50 Vikings at a time could enter the city, and then only unarmed. Purchases of silk, a highly prized commodity, were not to exceed 50 aurei in value. The traders may not have spent long periods at the island of Berezany, but one of them found time to leave a memorial stone there. Its runic inscription reads: "Grane raised this arch for his comrade Karl."

Contact with Islam

The route to Byzantium down the Dnieper was only one of the inland waterways used by the Viking traders. They also reached the Volga by way of the Gulf of Finland and Lake Ladoga, and descended to the Caspian Sea, a gateway to the world of the Turks and the Arabs. It was not even necessary to go all the way to the Caspian; at a halfway point on the Volga stood the rich trading city of Bolgar. The 10th-century Arab geographer Muqqadasi names some of the goods sold in the market there: "Sable, squirrel, ermine, corsac, martin, foxes, beaver pelts, colorful hare, goatskin, wax, arrows, birchbark, caps, fish-lime, fish teeth, beaver-gall, amber, horny leather, honey, hazel nuts, hawks, swords, armor, acorns, Slavonic slaves, small cattle and oxen—all this from Bolgar."

Another market town, at the mouth of the Volga, was equally colorful. There, near present-day Astrakhan, a 10th-century representative of the Bagdad caliphate named ibn Fadlan met a Viking trading party. "I have never seen humans more nobly built," he wrote. "They are tall as palm trees, red blond, with light skins. The man wears a cape slung over one shoulder, so that one hand is free. Every man carries an axe, a dirk and a sword. Each one has a bench on which he sits with his beautiful slaves who are for sale. [To worship] a man goes up to [a wooden] pillar and throws himself down on the ground and says, 'O my god, I come from far off and bring with me so and so many women and so and so many skins of martin.... Grant me a purchaser who has many gold and silver coins and buys everything from me....' When a man possesses 10,000 silver coins he has a [necklace] made for his wife. If he has 20,000 she gets a second necklace.... Many chains therefore hang around the neck of a Rus woman."

There is no reason to doubt the importance of slaves as articles of trade. Who the slaves were is suggested by the fact that the Svea word for such human chattels, *trälar*, was soon abandoned in favor of the word *slavar*. Evidently most of the slaves were Slavs. Yet the Vikings' slaves would not have been exclusively Slavs; one wonders how many Franks, Irish and Anglo-Saxons served as involuntary oarsmen on the dragon ships' homeward voyages and then moved on to the slave markets of the Scandinavian peninsula. Not all the slave markets were strictly in Viking country. Recent studies have shown that three of them were on the European mainland: Haithabu on the Baltic, Magdeburg on the Elbe and Regensburg on the Danube. One Viking merchant, called "Gille the Russian" because he always wore a Russian cap, was a common sight in the slave market of Göteborg, in what is now Sweden. His specialty was Irish girls; it is recorded that he sold one of them for three times the usual price, in spite of the fact that the girl was deaf. She must have been very beautiful.

The total number of Arab silver coins so far discovered in Scandinavia is about 57,000. The way in which these coins are distributed brings out an important fact about the various Viking groups and their separate areas of operations. It is apparent that the hoards were not a normal place of storage but a temporary refuge for treasure. Probably only when the possessors of precious metal believed they were about to be raided would they hastily dig a hole and hide their treasure, always in the expectation of reclaiming it when the trouble was past. This helps to explain why Gotland, which was a favorite target of raiders, has yielded not only the two largest hoards in Scandinavia but also the largest number of Arab coins—some 40,000 in all. Doubtless the hoards remained buried when their owners were victims of the very raids that caused them to hide their wealth.

In any case, only 17,000 additional Arab coins have been recovered from the Swedish mainland and modern Denmark, and Norway has yielded a mere 400. The geography of Scandinavia explains why this is so. For the Gotlanders and the peoples of the Swedish mainland the Baltic was virtually a private lake. They usually left it only to take to the inland waterways of Russia. The Danish peoples, on the other hand, faced both the North Sea and the Baltic. When they raided, England and the coast of Germany and France were their primary targets. When they traded, it was into the Baltic. It is not surprising that much Arab coinage should have come into Danish hands. As for the peoples of what is now Norway, their harbors on the North Sea were best suited to island-hopping operations that led them by way of the Shetland and the Orkney islands to the Irish Sea and the rich prizes along both its eastern and its western shore. It is therefore not surprising that they possessed very little Arab silver.

No one of these three main Viking spheres of influence was held exclusively. Consider the example of Harald Haadraade (Hard-Ruler), who commanded the Byzantine fleet under the Empress Zoë and even fought a naval engagement (off Monopoli, near Naples, in 1042) against fellow Vikings who had entered the Mediterranean from the west. Although a dominant figure among the eastern Vikings, Harald himself was a Norwegian who had spent his boyhood in Russia and had thus gravitated toward Byzantium. When he eventually returned home to occupy the Norwegian throne, he was no less active in western affairs. It was fighting off his raid on England in 1066 that wore out the English king Harold's troops and assured the Norman Conquest. Another example is provided by the Danish Vikings who moved into the normally Norwegian preserve of Ireland in the middle of the ninth century. The Danes fought beside the Irish to repulse the next Norwegian raiders to appear. On the whole, however, the Swedish Vikings stayed in the Baltic and the East, leaving the North Sea, the Atlantic and the parts of the Mediterranean that were unclaimed by Byzantium to the Norwegians and the Danes.

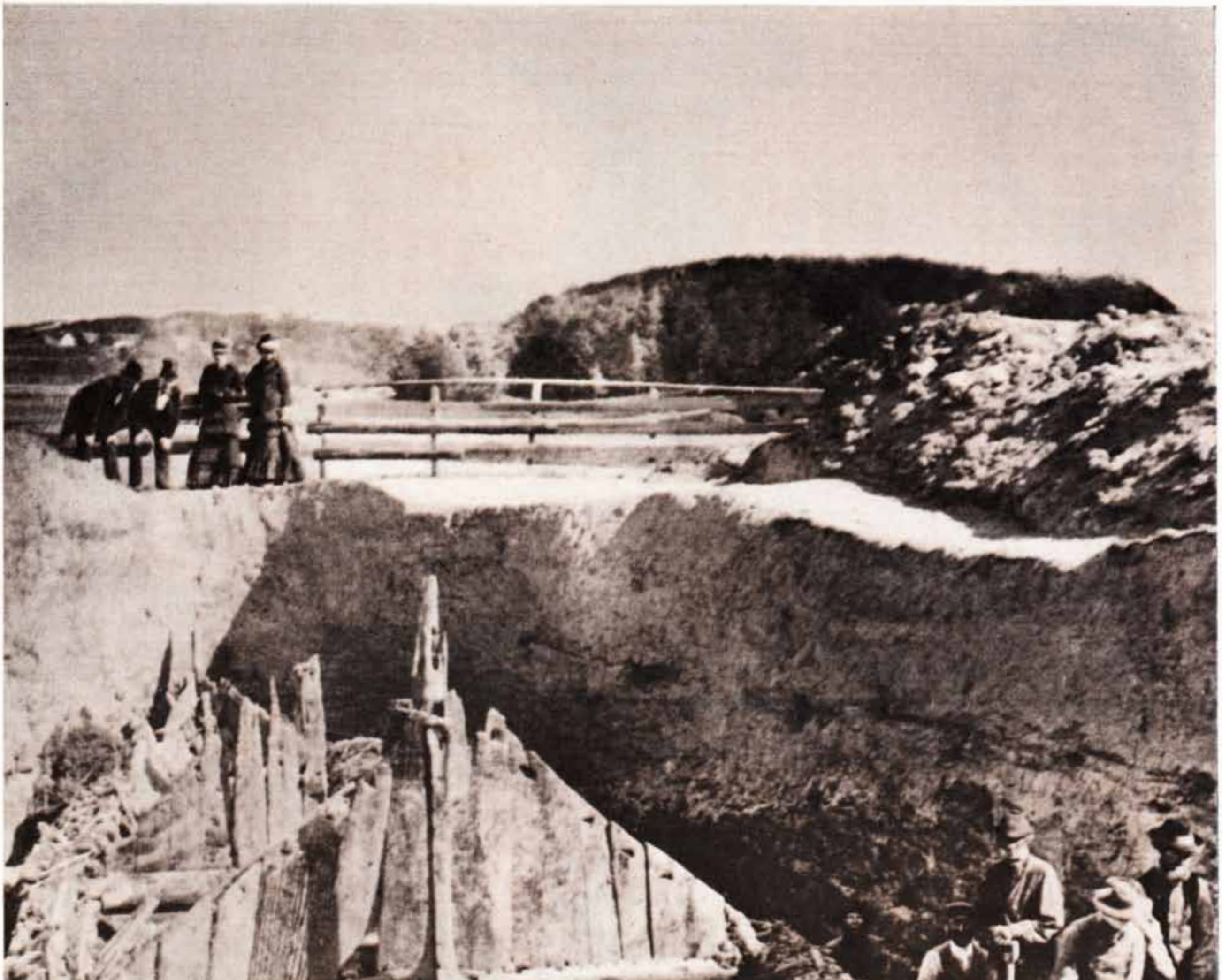
DRAGON HEAD carved out of wood provides an example of more intricate Viking workmanship than the stone carving shown on page 75. This is one of several dragon heads found aboard the ship in which a Norwegian Viking queen was buried near Oslo in A.D. 850.

The Norwegian and Danish Vikings

In describing the activities of the Norwegians and the Danes during the ninth century one can draw a legitimate distinction between the occasions when they were raiding and those in which they were colonizing. The Norwegians certainly settled the northern islands they used as stepping-stones to the Irish Sea. Once established in western waters, they founded settlements in the Hebrides and on the islands nearer the western coast of Scotland and also made the Isle of Man a base of operations. Although the Norwegians began raiding Ireland as early as 820, their intentions were more ambitious than mere piracy. By the middle of the century they had established a royal line in Dublin and held extensive Irish lands.

Nor were the Danes—who, as we shall see, were second to none as raiders—exclusively piratical. Ragnar Lodbrok (Hairy-Breeches) was clearly a man of large plans. One of the first Danish Vikings to take advantage of the civil strife that had divided Europe into three quarrelsome kingdoms after the death of Charlemagne, he gave the king of France, Charles the Bald, a bad scare in 845 by sailing a 120-ship force up the Seine and capturing Paris. Charles's army was divided by the river. Ragnar routed the French troops on one bank while their comrades-in-arms on the other bank did nothing. Whatever aggressiveness may have remained in the French ebbed away when Ragnar hanged more than 100 of his prisoners as a sacrifice to Odin. Shortly thereafter Charles the Bald sent Ragnar a gift of 7,000 pounds of silver and asked him to desist.

Yet Ragnar's three sons, with a minimum of bloodshed in 876, successfully seized and colonized the eastern part of England—a region called the Five Boroughs after the five strongholds (Lincoln, Stamford, Leicester, Derby and Nottingham) from which the Danes administered it. The district remained populous and prosperous until William the Conqueror—himself of Viking descent—found that a "harrying of the north" was necessary if his new kingdom was to



VIKING SHIP BURIAL, unearthed in 1880 at Gokstad in Norway, served as the grave of King Olaf, who died in 880. Although its royal treasure had been looted centuries earlier, the Gokstad ship's timbers were so well preserved that it could be reconstructed in full detail (*see illustration on pages 70 and 71*). The ship's single mast was secured to the hull by means of a set of interlocking braces that are visible amidships in the photograph. The twin sets of upright planks that form inverted *V*'s to the rear of the mast bracing were parts of the framework of the burial chamber rather than components of a deckhouse. The ship could carry a load of 20 tons.

SILVER PENDANTS are examples of simple and elaborate Viking work in metal. Both objects are so-called Thor hammers. The simple one recognizably mimics a socketed hammerhead mounted on a short shaft, but the maker of the ornate one did not attempt realism.

VIKING NECKLACE, found near Stockholm, shows the wide geographical range of Viking trade. Clockwise, the coin ("*a*," *at top*) is Byzantine, the silver fragment (*b*) is from an Arab bowl and the bronze flange (*c*) is a portion of a book mounting made in Great Britain.

be free from Scandinavian interference.

Ragnar was not the first Viking to raid mainland Europe. Four years earlier, in May of 841, a Danish force under one Asgeir sailed up the Seine toward Paris. It sacked Rouen and advanced as far as St. Denis before turning back. Two years later another Viking force with 67 ships sailed up the Loire, ravaged Nantes and sailed downstream again to pass the winter in Noirmontier at the river's mouth.

The Vikings remained active on the North Sea coast. The Frisian city of Dorestad was looted almost yearly. In 845, the same year in which Ragnar attacked Paris, another Viking force burned Hamburg. The chronicles of the unsuccessful defense of Hamburg state that the assault was mounted by 600 dragon ships. If we give each vessel a complement of 40 men, we must assume a Viking force of 24,000! It seems more likely that the Viking fleet numbered perhaps 60, rather than 600, vessels.

The year 845 also saw the customary Viking raids on Ireland and, far more significant, the dispatch of a fleet (said to number 100 ships) that sailed south past France and Spain into the Mediterranean to trade or raid along the coast of Arab North Africa. The record of this first entry into the Mediterranean by the western Vikings is obscure. More information is available on these activities four years later, in 859. In that year Ragnar's son Björn Ironsides, together with a Viking named Hastings, sailed 62 dragon ships into the Mediterranean for a raid that lasted 36 months. Using an island at the mouth of the Rhone as their base, they plundered Nîmes, Arles and Valence. Then, pushing eastward into Italy, they sacked Pisa, Fiesole and Luna (a harbor town that no longer exists). On the way home Björn's Vikings stopped at Pamplona in Spain. There they happened to find the Prince of Navarre, for whom they were given a large ransom. The Vikings counted it a successful voyage, even though they lost 40 of their ships in a storm off Gibraltar. Among other things, their peaceable visit to Morocco during the voyage resulted in the Maghreb caliphate's dispatching an ambassador to Denmark. It is reported that he did not enjoy his visit.

In the winter of 878, two years after Ragnar's three sons had established the Five Boroughs in England, other Viking raiders gathered to see what could be accomplished elsewhere in the British Isles. Fortunately for England, but unfortunately for the continent of Europe, Alfred, a young English ruler in Wessex, defeated the invading force at Ethandun. The following spring the defeated Vikings landed en masse at the mouth of the Schelde River, gradually assembled a "Great Army" that finally numbered 700 ships and 40,000 men, and proceeded to ravage the Continent for the next 13 years.

At last, having gathered all the loot it could and finding little prospect for more in a famine year, the Great Army withdrew. The Viking force then sailed for England once again, but Alfred (now known as "the Great") was more than ready for them, this time with his own fleet. By 896, in the final years of Alfred's reign, the remnants of the Great Army sailed back to the Continent, reduced to little more than a band of mercenaries.

In the opening years of the 10th century European towns were no longer regularly sacked by major Viking forces, but the Viking influence on the Continent remained considerable. Fresh Viking forces continued to leave Denmark and Norway, seeking lands to occupy. One such emigré—Rollo—eventually became leader of all western Europe's Vikings.

The king of France, Charles the Simple, saw a solution to the Viking problem. In exchange for Rollo's baptism and an oath of fealty in 911, Charles granted the Viking leader all Normandy. It was from this Viking enclave that a century and a half later emerged both the leader and the troops who conquered England and reshaped its history.

The Dragon Ships

What single element in Viking history can be deemed most responsible for these northerners' success in battle, trade and emigration? It must surely be the dragon ship. The tallies of the Viking fleets of the ninth and 10th centuries make it clear that these ships were built in large numbers, but the fact remains that only a few of the vessels uncovered by the archaeologist's spade are typical dragon ships. From the remains we have and from literary descriptions, however, it is possible to reconstruct the Vikings' seafaring warships with reasonable accuracy.

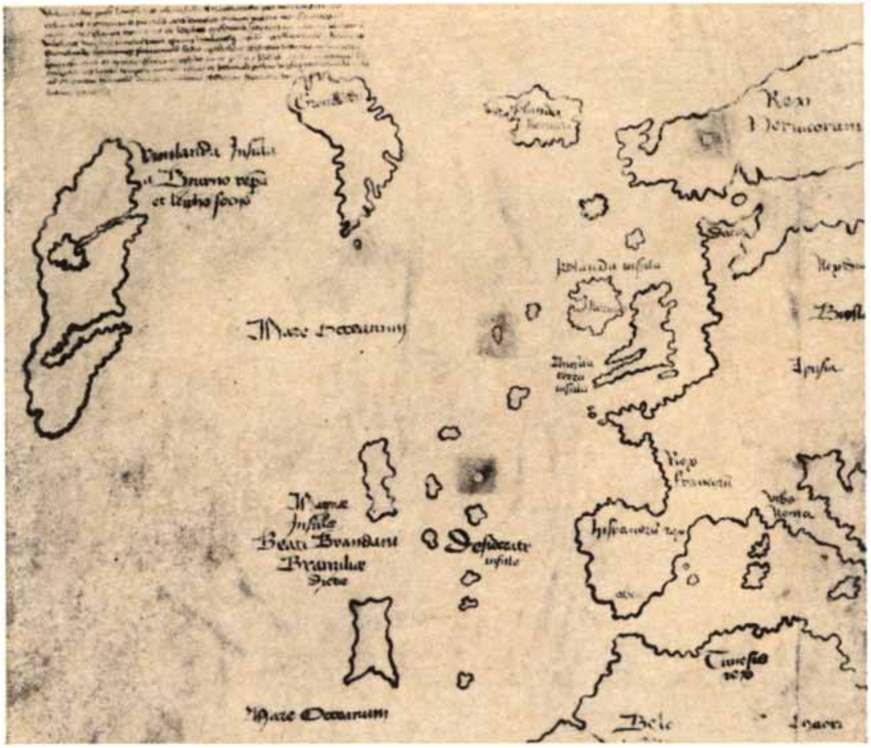
The earliest-known Scandinavian ship, uncovered on a moor near Nydam in Denmark, dates back to about A.D. 300. Built of oak planks, it had a rounded bottom and a comparatively deep draft; it had no keel or mast. There were positions for 30 oars—15 on each side—and therefore 15 oarsmen's benches. The second-known Scandinavian ship, built some 300 years later and unearthed at Kvalsund, I have already mentioned. It shows considerable evolution, being wider in beam and shallower in draft than the Nydam ship. Although it lacks a true keel, it has a deck and provision for a mast.

The finest Viking ships discovered so far are all from sites near Oslo in Norway: Gokstad and Oseberg on the western shore of Oslofjord and Tune on the eastern shore. The Gokstad ship, uncovered in 1880, is 78 feet long, has a mast and also a keel consisting of a single oak timber. Its carrying capacity is estimated at 20 tons. It has 16 rowing benches, 32 oars in all. The Norwegian notable whose grave it marks appears to be one Olaf, a king who lived from about 810 to 880.

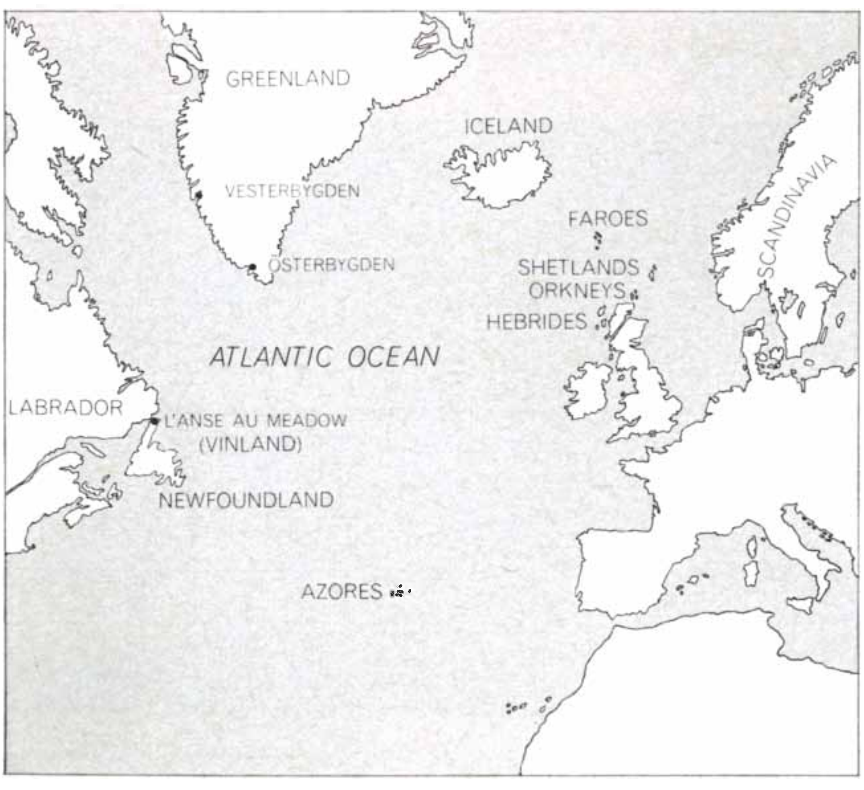
The Oseberg ship, which was discovered in 1904, is shorter by some six feet, has one less rowing bench and a mast that gives the impression of being small and weak. This ship is the burial place of Olaf's stepmother, Queen Asa, whose husband ruled from about 780 to 820. Both the ship and its contents are decorated with carvings of remarkable beauty and intricacy. Nonetheless, the Oseberg ship appears not to have been an oceangoing craft but a coastwise one. The third vessel, found near Tune in 1867, is the least well preserved of the three. It is estimated to have been some 66 feet long and to have had 11 or 12 rowing benches. All three vessels are preserved today in a special museum at Bygdöy, outside Oslo.

How closely do these Norwegian ves-

LEGEND OF SIEGFRIED, popular among the Vikings, is the subject of this Viking memorial inscription. The body of the huge dragon, Fafner, forms the lower margin of the rock carving; within its outline is a runic inscription honoring one Holmger. The legend starts (*lower right*) with Siegfried driving his sword into Fafner's body. Next (*left of center*) Siegfried sits cooking the dragon's heart on a spit. Burning his thumb with the hot fat, he puts the thumb in his mouth. The taste of dragon fat works wonders; he now understands animal languages and overhears the birds in the tree beside his horse (*right*). The birds are discussing the treacherous plans of the smith Regin. Siegfried at once slays Regin; the headless corpse (*far left*) is identified as the smith's by the hammer, tongs, anvil and bellows that lie nearby. The doglike animal above the smith's hammer is Rodmar's son, the otter; in its mouth is Nibelung's ring.



VINLAND MAP, drawn 52 years before Columbus discovered America, shows a surprisingly accurate outline of Greenland to the west of Iceland and a larger island, labeled Vinland, to the west of Greenland. A notation on the map, prepared for an ecclesiastical council at Basel in 1440, declares that Eric Gnuppson, a bishop of Greenland, visited "this very rich land" (Vinland) in 1118. The map maker dotted the Atlantic with fictitious islands.



MODERN MAP of the same regions shown in the Vinland map shows the remarkable correctness of the earlier document's outline of Greenland. Although the shape given to Vinland bears no obvious relation to the shape of northeastern North America, its two bays (*see top illustration*) may indicate a knowledge of Hudson Bay and the Gulf of St. Lawrence.

sels resemble the Viking dragon ships? The Gokstad ship has passed an impressive empirical test: a faithful replica of it was sailed across the Atlantic in 1893 to be exhibited at the Chicago World's Fair. Not only was the voyage successful but also the crew found they could make a speed of as much as 10 to 11 knots in a brisk wind. It is therefore possible that some dragon ships were as small as the Gokstad ship. On the basis of literary descriptions, however, it appears that most dragon ships were larger.

The ships built for royalty at the turn of the millennium, although known only through oral tradition, were apparently larger still. At the Battle of Svolder in A.D. 1000 King Olaf of Norway appeared aboard the *Ormen Lange* (*Long Snake*), which was some 164 feet long and had 34 rowing benches. The last of the royal Norwegian ships, built by the shipwrights of Trondheim in 1263, had three more rowing benches than the *Ormen Lange*. Sang a skald: "[It] shall carry thee, majestic friend, like a keen hawk on the quarterdeck. Never did more beautiful ship sail with more magnificent king."

Not all Viking vessels were dragon ships. Viking freighters, called *knarr*, were known only from literary references, however, until 1962. In that year Danish archaeologists recovered several incomplete Viking ships from Roskilde Fjord on the Danish island of Seeland. For reasons at which we can only guess, the people of Roskilde had blocked their harbor by filling several ships with stones and sinking them in the mouth of the fjord. One of them, 53 feet long, was apparently a fast cargo vessel. Another vessel is almost 65 feet long and is notable for its breadth of beam and the stoutness of its timbers. It was evidently a carrier of heavy freight. To judge by the low railing and the number of oar holes of the third ship, it may have been a fast passenger vessel. A fourth appears to be a onetime dragon ship that was converted into a freighter late in its career. The remains of the other Roskilde ships are too fragmentary to tell us much about them.

Meanwhile other ships that may belong to the Viking period have been found in northern Germany. In 1953 a volunteer diver working with the director of the Schleswig Museum located one large vessel and parts of a smaller one in the harbor of Haithabu. All of us who are particularly interested in such matters look forward to what will be learned from these remains when the funds necessary for their recovery become available.

When and why did Viking fortunes—in trade if not in war—decline? To the first of these questions Scandinavian archaeology provides a remarkably detailed answer. The silver hoards recovered in Denmark, for example, contained no coins but Arab ones until 950. The hoards of the next 30 years contain both Arab coins and a few German ones. A century later exactly the opposite is true: of some 3,000 silver coins found in hoards that were buried between 1050 and 1070 only four are Arab. Evidently Viking contacts with the Moslem world dwindled to nothing within the span of a century.

As to the question of why, it is probably pertinent to note three historical developments that fall within the same period. First, the silver mines of central Asia (on which the Moslem rulers of the East depended for their metal) seem to have become exhausted at about this time. Second, a general advance of Turkish tribes in the Middle East and Near East denied the Russian waterways to the Swedish Vikings and severed their connections with Byzantium. Finally, the European powers on the Mediterranean halted the advance of Islam during this period and soon no longer needed the hardy Viking merchant-warriors to act as middlemen.

The Vikings in North America

Our knowledge of one other important series of events in Viking history—the voyages west from Iceland—has also been increased as a result of recent archaeological research. The story of Eric the Red and his son Leif is too well known to need retelling here. Less well known, perhaps, is the tradition that another Greenlander, Thorfinn Karlsefni, took three ships and 160 men and in 1020 established a colony in what they called Vinland on the coast of North America. When Thorfinn's house in Greenland was excavated in 1930, the diggers came on a lump of anthracite coal that has been identified as having originated in the vicinity of Rhode Island.

At Brattalid, in Greenland's "eastern settlement," archaeologists have uncovered Leif Ericson's homestead. In 1965 these workers came on the remains of Leif's mother's chapel, a few hundred yards from the foundation of his house. Beside the chapel are 150 graves, from which 96 skeletons have been disinterred. It seems more than likely that one of them is Leif's.

For some centuries the New World

settlement established by Leif—called Leifsbodarna in the Viking sagas—had been sought, without success. During the 1950's, however, a Norwegian investigator, Helge Ingstad, began to reconnoiter the coasts of Labrador and Newfoundland with a fresh idea in mind. Could the "vin" in Vinland mean something other than "wine," as had been generally supposed? Ingstad preferred to think that it meant "grass" or "pasturage." In 1961, near the isolated fishing village of L'Anse au Meadow in northern Newfoundland, an expedition under Ingstad uncovered traces of several buildings, including the foundation of a "great hall" identical with the one Leif had built for himself in Greenland. Charcoal associated with iron and slag at the site—evidently the remains of a smithy—has yielded a carbon-14 date of A.D. 1060 ± 70, which agrees reasonably well with the dates that are given in the sagas.

Three years' work at the Newfoundland site has yielded Ingstad a number of architectural details but very few artifacts. Perhaps the most significant one is a spindle whorl—the weight that acts as a flywheel when a spindle is used to twist yarn from raw wool—made of soapstone. Soapstone spindle whorls are common at Norse sites in Greenland and Iceland, as well as in Scandinavia.

Greenland's Decline

The Greenland colonies from which the Viking visitors to North America came numbered some 300 homesteads at their height. They were cut off from contact with Iceland and Europe sometime during the 15th century, but before that they had had a bishop, two cloisters and 16 churches. They had even sent a tithe of walrus tusks to the Vatican (the record shows that 250 tusks were received in 1327). The only vessel regularly in the Greenland trade was wrecked in 1367 and not replaced, but archaeological evidence shows that contacts continued after that date. In Greenland graves are found woolen caps, peaked in a manner that became fashionable in Burgundy during the latter half of the 15th century.

Less than a century later, in 1540, a voyaging Icelander happened to sail past one of Greenland's settled fjords. He saw people, including a man lying dead on the ground, and decided not to land. A few years later a ship out of Hamburg called at Greenland but its captain was unable to find any signs of life.

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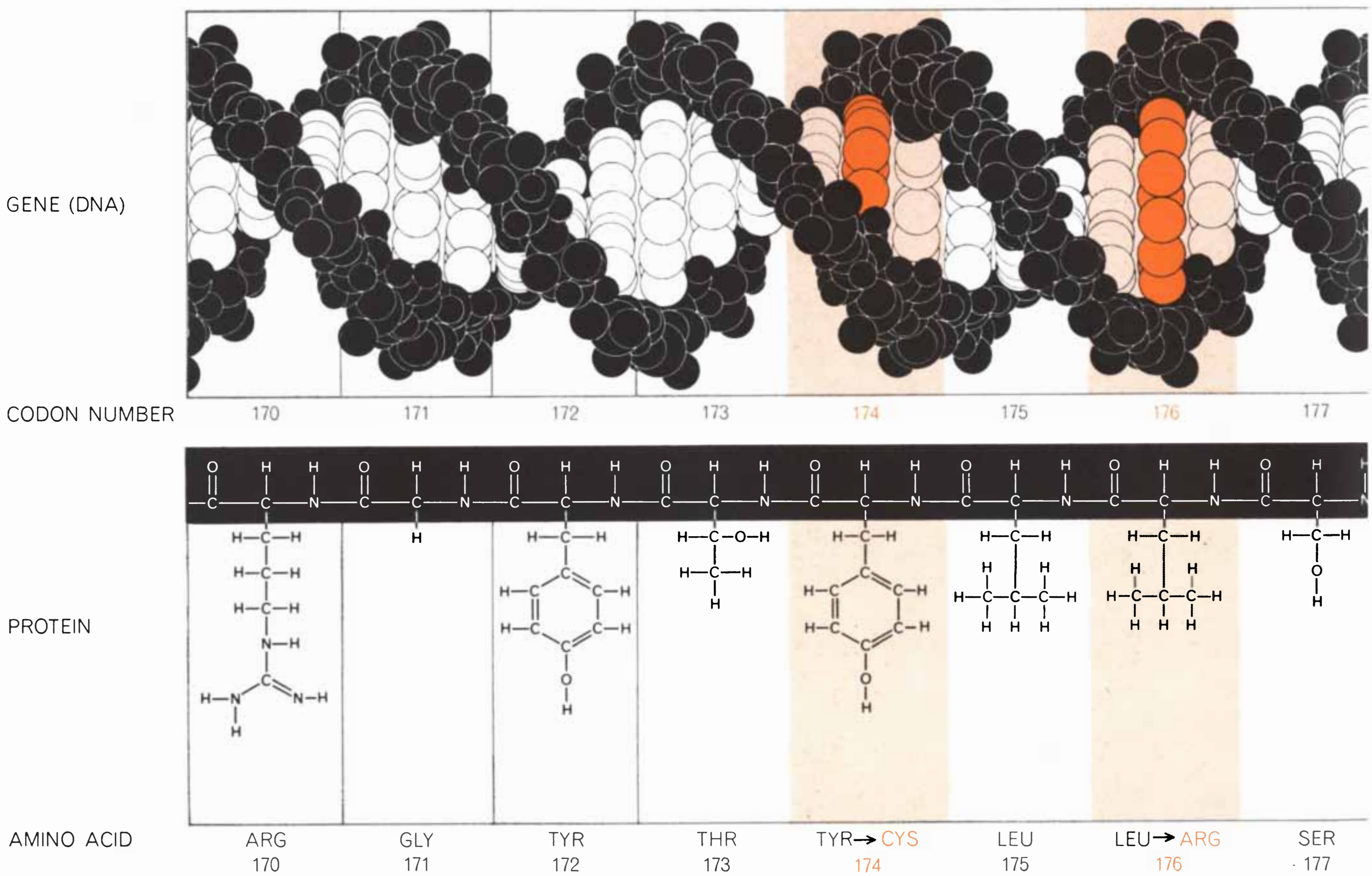
Gene Structure and Protein Structure

A linear correspondence between these two chainlike molecules was postulated more than a dozen years ago. Here is how the correspondence was finally demonstrated

by Charles Yanofsky

The present molecular theory of genetics, known irreverently as "the central dogma," is now 14 years old. Implicit in the theory from the outset was the notion that genetic information is coded in linear sequence in molecules of deoxyribonucleic acid (DNA) and that the sequence directly determines the linear sequence of amino acid units in molecules of protein. In other words, one expected the two molecules to be colinear. The problem was to prove that they were.

Over the same 14 years, as a consequence of an international effort, most of the predictions of the central dogma have been verified one by one. The results were recently summarized in these pages by F. H. C. Crick, who together with James D. Watson proposed the helical, two-strand structure for DNA on

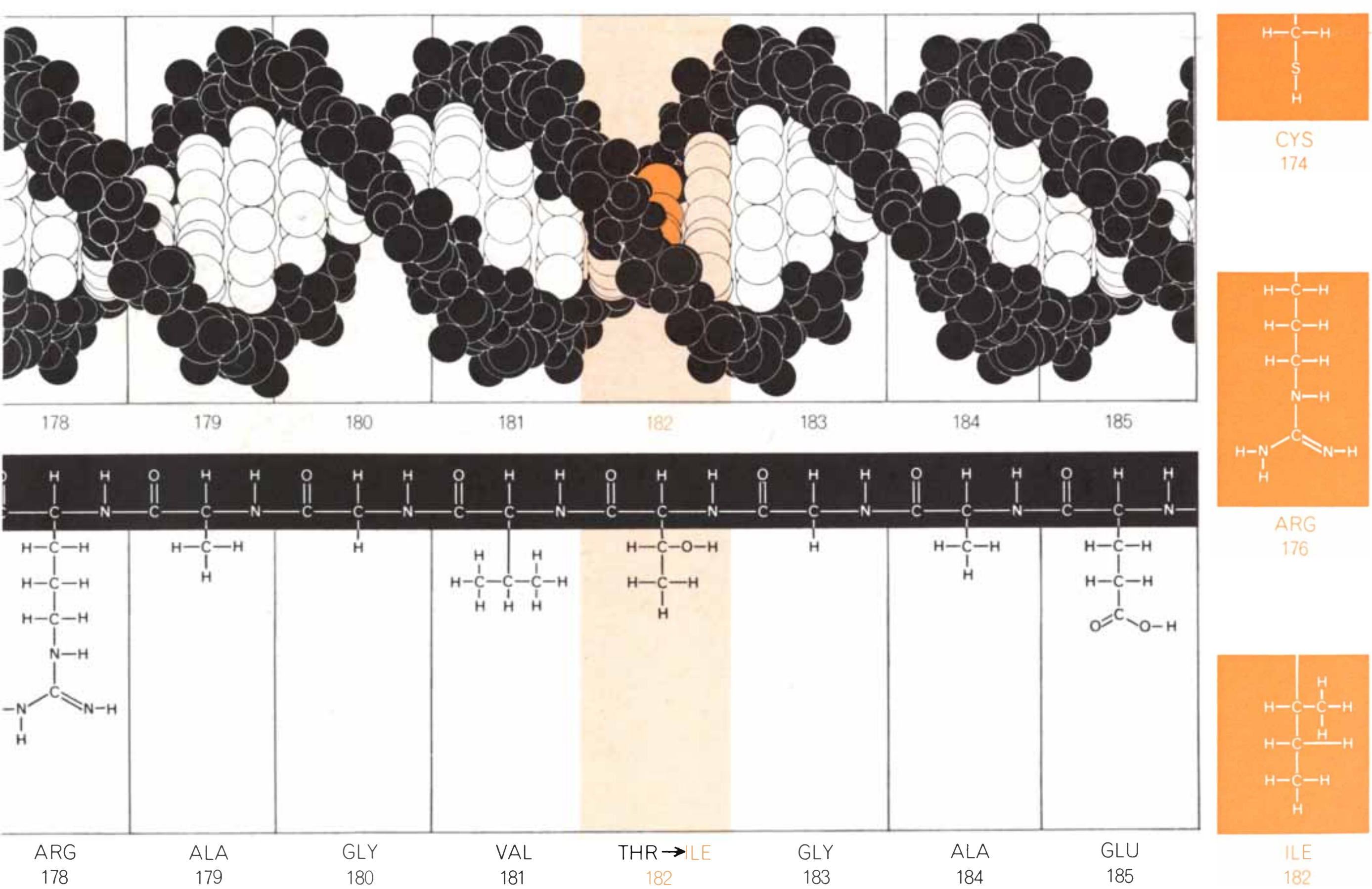


STRUCTURES OF GENE AND PROTEIN have been shown to bear a direct linear correspondence by the author and his colleagues at Stanford University. They demonstrated that a particular sequence of coding units (codons) in the genetic molecule deoxyribonucleic acid, or DNA (*top*), specifies a corresponding sequence of amino acid units in the structure of a protein molecule (*bottom*). In the DNA molecule depicted here the black spheres represent repeating units of deoxyribose sugar and phosphate, which form the helical backbones of the two-strand molecule. The white spheres connecting the two strands represent complementary pairs of the four kinds of base that provide the "letters" in which the genetic message is written. A sequence of three bases attached to which the central dogma is based [see "The Genetic Code: III," by F. H. C. Crick; SCIENTIFIC AMERICAN, October, 1966]. Here I shall describe in somewhat more detail how our studies at Stanford University demonstrated the colinearity of genetic structure (as embodied in DNA) and protein structure.

Let me begin with a brief review. The molecular subunits that provide the "letters" of the code alphabet in DNA are the four nitrogenous bases adenine (A), guanine (G), cytosine (C) and thymine (T). If the four letters were taken in pairs, they would provide only 16 different code words—too few to specify the 20 different amino acids commonly found in protein molecules. If they are taken in triplets, however, the four letters can provide 64 different code words, which would seem too many for the efficient specification of the 20 amino acids. Accordingly it was conceivable that the cell might employ fewer than the 64 possible triplets. We now know that nature not only has selected the triplet code but also makes use of most (if not all) of the 64 triplets, which are called codons. Each amino acid but one (tryptophan) is specified by at least two different codons, and a few amino acids are specified by as many as six codons. It is becoming clear that the living cell exploits this redundancy in subtle ways. Of the 64 codons, 61 have been shown to specify one or another of the 20 amino acids. The remaining three can act as "chain terminators," which signal the end of a genetic message.

A genetic message is defined as the amount of information in one gene; it is the information needed to specify the complete amino acid sequence in one polypeptide chain. This relation, which underlies the central dogma, is sometimes expressed as the one-gene-one-enzyme hypothesis. It was first clearly enunciated by George W. Beadle and Edward L. Tatum, as a result of their studies with the red bread mold *Neurospora crassa* around 1940. In some cases a single polypeptide chain constitutes a complete protein molecule, which often acts as an enzyme, or biological catalyst. Frequently, however, two or more polypeptide chains must join together in order to form an active protein. For example, tryptophan synthetase, the enzyme we used in our colinearity studies, consists of four polypeptide chains: two alpha chains and two beta chains.

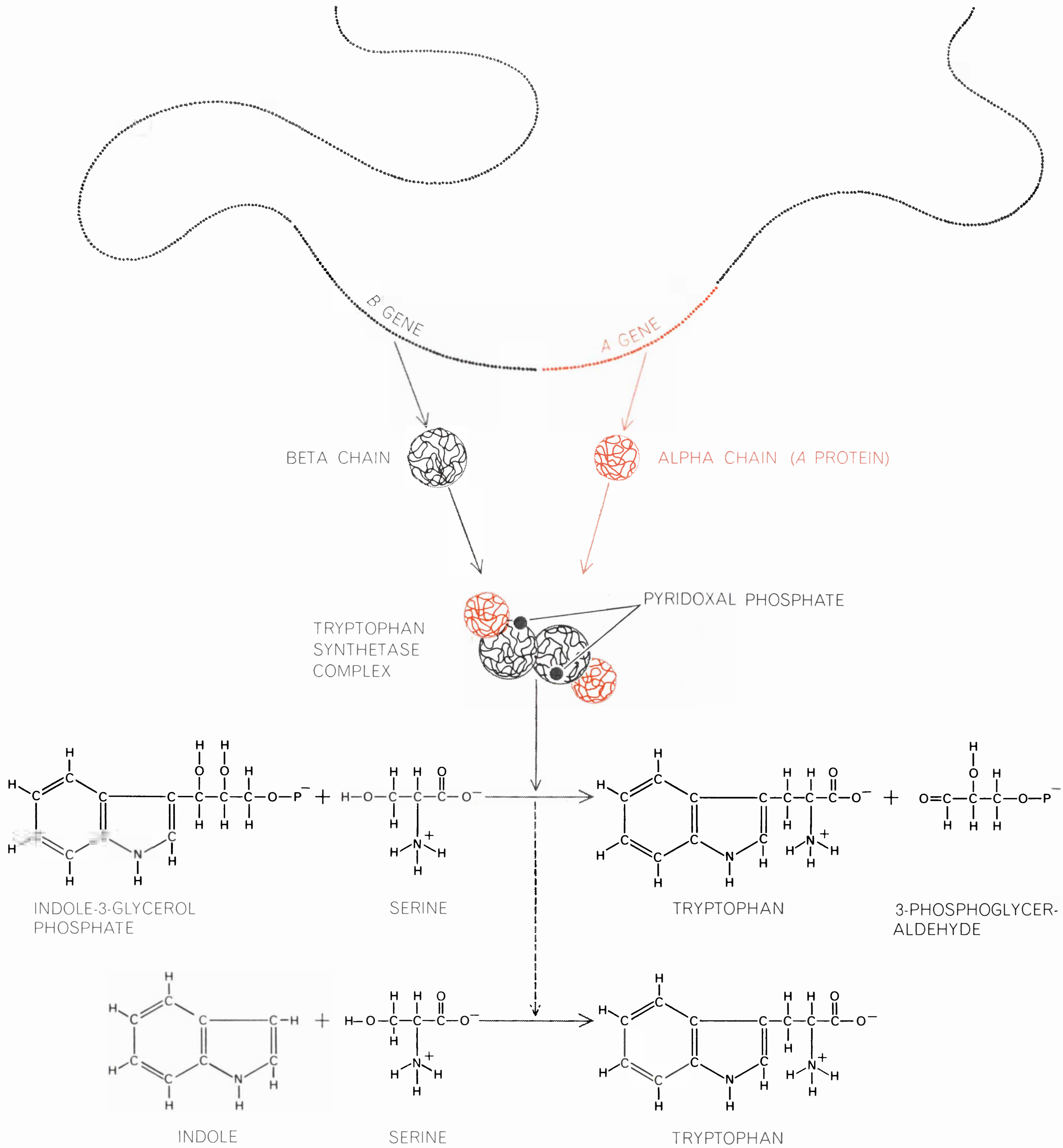
How might one establish the colinearity of codons in DNA and amino acid units in a polypeptide chain? The most direct approach would be to separate the two strands of DNA obtained from some organism and determine the base sequence of that portion of a strand which is presumed to be colinear with the amino acid sequence of a particular protein. If the amino acid sequence of the protein were not already known, it too would have to be established. One could then write the two sequences in adjacent columns and see if the same codon (or its synonym) always appeared adjacent to a particular amino acid. If it



one strand of DNA is a codon and specifies one amino acid. The amino acid sequence illustrated here is the region from position 170 through 185 in the *A* protein of the enzyme tryptophan synthetase produced by the bacterium *Escherichia coli*. It was found that mutations in the *A* gene of *E. coli* altered the amino acids at three places (*174, 176 and 182*) in this region of the *A* protein. (A key to the amino acid abbreviations can be found on page 87.) The three amino acids that replace the three normal ones as a result of mutation are shown at the extreme right. Each replacement is produced by a mutation at one site (*dark color*) in the DNA of the *A* gene. In all, the author and his associates correlated mutations at eight sites in the *A* gene with alterations in the *A* protein.

did, a colinear relation would be established. Unfortunately this direct approach cannot be taken because so far it has not been possible to isolate and identify individual genes. Even if one could isolate a single gene that specified a polypeptide made up of 150 amino acids (and not many polypeptides are that small), one would have to determine the sequence of units in a DNA strand consisting of some 450 bases.

It was necessary, therefore, to consider a more feasible way of attacking the problem. An approach that immediately suggests itself to a geneticist is to construct a genetic map, which is a representation of the information contained in the gene, and see if the map can be related to protein structure. A genetic map is constructed solely on the basis of information obtained by crossing individual organisms that differ in two or more hereditary respects (a refinement of the technique originally



GENETIC CONTROL OF CELL'S CHEMISTRY is exemplified by the two genes in *E. coli* that carry the instructions for making the enzyme tryptophan synthetase. The enzyme is actually a complex of four polypeptide chains: two alpha chains and two beta chains. The alpha chain is the *A* protein in which changes produced by mutations in the *A* gene have provided the evidence for gene-protein colinearity. One class of *A*-protein mutants retains the ability to associate with beta chains but the complex is no longer able to catalyze the normal biochemical reaction: the conversion of indole-3-glycerol phosphate and serine to tryptophan and 3-phosphoglyceraldehyde. But the complex can still catalyze a simpler nonphysiological reaction: the conversion of indole and serine to tryptophan.

SCIENCE/SCOPE

Experiments with the Applications Technology Satellites promise more far-reaching benefits to more people than any other space activity now foreseeable, in the opinion of many observers. A better understanding of global weather, for example, would immediately benefit agriculture and commerce. Yet methods for collecting data from literally thousands of weather stations around the world have lagged far behind recent advances in weather forecasting. The Wefax experiment, recently carried out aboard the Hughes-built ATS-1 satellite, demonstrated that facsimile data (tables, charts, pictures) can be swiftly relayed from the stations via satellite to very inexpensive ground receivers, so that even the underdeveloped nations could participate.

A computer the size of a table radio has been developed by Hughes for use in missiles, satellites, and military aircraft. Though it weighs only 13.3 lbs. including its power supply, it rivals the performance of many large business computers. It has a memory capacity of 8,192 words, expandable to 16,384, and an 18-bit word length. It carries out 125,000 operations (such as addition or subtraction) per second.

Hughes' new line of commercial-industrial lasers will be marketed in the U.S., its territories and possessions, and Canada by Beckman Instruments, Inc. Sales efforts will be concentrated on laboratories and academic institutions using lasers for research, experimental, or educational purposes. Hughes laser welders will continue to be marketed by the Airco Welding Products division of Air Reduction Co., Inc.

Eight "mini" electronics labs for on-the-spot maintenance of military communications equipment were delivered to the U.S. Army recently by Hughes for possible use in Southeast Asia. Equipment is housed in 7x7x11-foot shelters, which provide work stations for two men. Two-inch walls, surfaced with thin aluminum and filled with foam, insulate the interior against jungle heat or sub-zero cold. Complete labs weigh only 4,000 pounds and can be air-lifted by the Huey helicopters now used in Vietnam.

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ALPHATIZED STEEL

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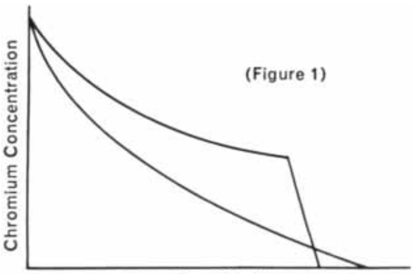
by Dr. Murray J. Roblin, Research Manager

The principal reason for selecting a particular alloy is often related to surface properties. Appearance, corrosion resistance, oxidation properties or resistance to wear can be so vital that the metallic system or alloy is chosen for these properties alone. Then, in many cases, the matrix properties are not suitable for the intended application, or are uneconomic.

Metallurgists have recognized this problem for some time and have devised a number of ways to alter surface properties to more suitably match matrix and surface properties. One example is case hardening of steels by carburizing, nitriding or cyaniding to provide a hard wear resistant surface and tough ductile matrix. Another approach is to coat the base material with another metal, plastic or oxide as in galvanizing, chrome plating, anodizing and enameling.

Considerable strides have been made in coating technology. However, the most important technical problem facing the researcher is obtaining good adhesion between surface layer and substrate. Most coatings are additive, and bonding is often not metallurgical in nature. Therefore the amount of deformation a coated product can undergo and still retain a continuous adherent layer is generally restricted. Thus, coating must often be the final operation in a product's manufacture.



(Figure 1)

One technique which overcomes these limitations is to coat the substrate with a metal which does not form intermetallic compounds or other brittle phases, and to diffuse the coating into the base metal. This provides a diffusion layer rich in the coating metal, one that is metallurgically bonded. Thus the base metal can be deformed rather extensively with the coating retaining adherence and uniformity.

Chromizing is one such system, and three separate processes are practiced today. All use gaseous media to provide chromium access to the part involved. In July, 1961 this process was modified by Gasalloy Steel Corporation to apply the process concepts to a sheet product in coil form.

The present Alphatizing technique is to place a large coil, wound with twisted wire between the wraps, into a high temperature furnace containing a chromium source. Once the steel reaches the required temperature under a deoxidizing atmosphere, a halide gas is introduced, and flows through the chromium source and between the wraps into both surfaces of the steel, where a chromium atom is deposited and an iron atom picked up. The latter is returned to the chromium source, where the process is repeated.

A uniform, chromium rich layer is built up on the surface and diffuses into the matrix. The surface chromium content is controlled by the chromium potential of the gas, and the depth of case by the length of time the process is carried out at temperature.

By carrying out the process above the austenitizing temperature (1670° F for iron) a chromium gradient can be achieved with a higher average chromium content than would be possible for the same period in the ferrite region (Figure 1). The reason for the double gradient is that the diffusion rate in austenite (γ iron) is much slower than in ferrite (α iron). Initially the base material is austenitic (γ iron) until the chromium concentration is built up to 13% at or near the surface when the structure transforms to ferrite (α iron) and the velocity of diffusion increases.

Figure 2 shows that the structure of the chromium rich case is columnar. Although on etching the coating appears to have a sharply defined boundary, this is purely an etching effect. The coating has a gradual change of composition with distance and should be distinguished from electro-deposits, vapor coating and others where it is abrupt. It is this integration of the coating with the base and the high average chromium concentration of the case which result in the remarkable properties of Alphatized steel.

(Figure 2)

Alphatized steel has a surface chromium concentration greater than 26%, an average chromium content of 19% and a case 1.5 mils thick as measured to a 10-12% chromium concentration. Thus it has surface properties—appearance and oxidation and corrosion resistance—similar to a chromium stainless steel, with the forming characteristics of a low carbon steel sheet. The coating is ductile, adherent and does not spall or flake upon severe deformation of the base.

The process is not limited to chromium deposition. While much additional research will be necessary, the process can be applied to any system which forms a gaseous metal halide. This could extend the process to many systems providing specialized surface properties for a wide variety of applications.

This work in extending the versatility of steel is a small part of the 24-hour-a-day research at Youngstown. If you believe Youngstown can help you solve a steel problem, call at your convenience or write Department 251A7.

Youngstown Steel

THE YOUNGSTOWN SHEET AND TUBE COMPANY · YOUNGSTOWN, OHIO 44501 used by Gregor Mendel to demonstrate how characteristics are inherited).

By using bacteria and bacterial viruses in such studies one can catalogue the results of crosses involving millions of individual organisms and thereby deduce the actual distances separating the sites of mutational changes in a single gene. The distances are inferred from the frequency with which parent organisms, each with at least one mutation in the same gene, give rise to offspring in which neither mutation is present. As a result of the recombination of genetic material the offspring can inherit a gene that is assembled from the mutation-free portions of each parental gene. If the mutational markers lie far apart on the parental genes, recombination will frequently produce mutation-free progeny. If the markers are close together, mutation-free progeny will be rare [*see bottom illustration on next page*].

In his elegant studies with the "*r*II" region of the chromosome of the bacterial virus designated T4, Seymour Benzer, then at Purdue University, showed that the number of genetically distinguishable mutation sites on the map of the gene approaches the estimated number of base pairs in the DNA molecule corresponding to that gene. (Mutations involve pairs of bases because the bases in each of the two entwined strands of the DNA molecule are paired with and are complementary to the bases in the other strand. If a mutation alters one base in the DNA molecule, its partner is eventually changed too during DNA replication.) Benzer also showed that the only type of genetic map consistent with his data is a map on which the sites altered by mutation are arranged linearly. Subsequently A. D. Kaiser and David Hogness of Stanford University demonstrated with another bacterial virus that there is a linear correspondence between the sites on a genetic map and the altered regions of a DNA molecule isolated from the virus. Thus there is direct experimental evidence indicating that the genetic map is a valid representation of DNA structure and that the map can be employed as a substitute for information about base sequence.

This, then, provided the basis of our approach. We would pick a suitable organism and isolate a large number of mutant individuals with mutations in the same gene. From recombination studies we would make a fine-structure genetic map relating the sites of the mutations. In addition we would have to be able to isolate the protein specified by that gene and determine its amino acid sequence. Finally we would have to analyze the protein produced by each mutant (assuming a protein were still produced) in order to find the position of the amino acid change brought about in its amino acid sequence by the mutation. If gene structure and protein structure were colinear, the positions at which amino acid changes occur in the protein should be in the same order as the positions of the corresponding mutationally altered sites on the genetic map. Although this approach to the question of colinearity would require a great deal of work and much luck, it was logical and experimentally feasible. Several research groups besides our own set out to find a suitable system for a study of this kind.

The essential requirement of a suitable system was that a genetically

ALA	ALANINE	GLY	GLYCINE	PRO	PROLINE
ARG	ARGININE	HIS	HISTIDINE	SER	SERINE
ASN	ASPARAGINE	ILE	ISOLEUCINE	THR	THREONINE
ASP	ASPARTIC ACID	LEU	LEUCINE	TRP	TRYPTOPHAN
CYS	CYSTEINE	LYS	LYSINE	TYR	TYROSINE
GLN	GLUTAMINE	MET	METHIONINE	VAL	VALINE
GLU	GLUTAMIC ACID	PHE	PHENYLALANINE		

AMINO ACID ABBREVIATIONS identify the 20 amino acids commonly found in all proteins. Each amino acid is specified by a triplet codon in the DNA molecule (*see below*).

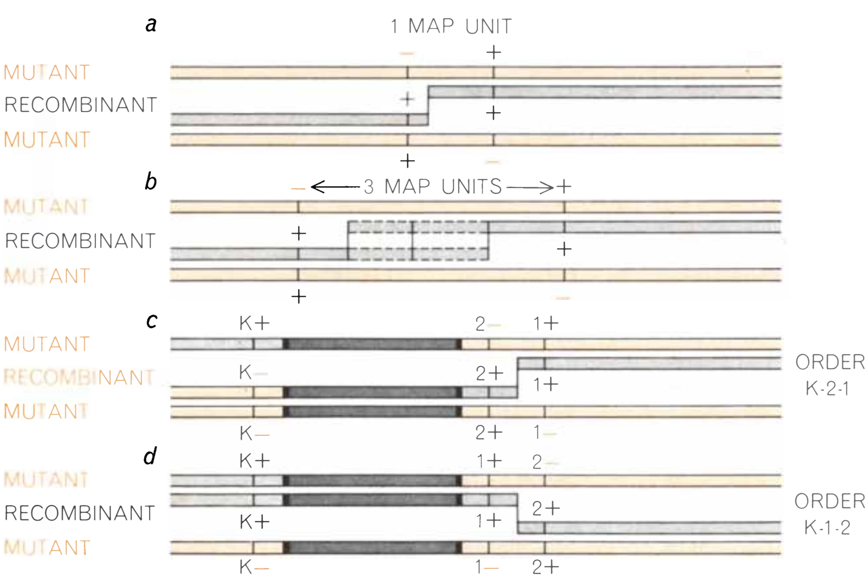
NORMAL DNA	GAG	GTT	CCT	AAA	CCT	TAA	AGC	CGG
	CTC	CAA	GGA	TTT	GGA	ATT	TCG	GCC
MUTANT 1 DNA	GCG	GTT	CCT	AAA	CCT	TAA	AGC	CGG
	CGC	CAA	GGA	TTT	GGA	ATT	TCG	GCC
MUTANT 2 DNA	GAG	GTT	CTT	AAA	CCT	TAA	AGC	CGG
	CTC	CAA	GAA	TTT	GGA	ATT	TCG	GCC
MUTANT 3 DNA	GAG	GTT	CCT	AAA	CAT	TAA	AGC	CGG
	CTC	CAA	GGA	TTT	GTA	ATT	TCG	GCC
MUTANT 4 DNA	GAG	GTT	CCT	AAA	CCT	TAA	ACC	CGG
	CTC	CAA	GGA	TTT	GGA	ATT	TGG	GCC

GENETIC MAP

NORMAL PROTEIN	LEU	GLN	GLY	PHE	GLY	ILE	SER	ALA
MUTANT 1 PROTEIN	ARG	GLN	GLY	PHE	GLY	ILE	SER	ALA
MUTANT 2 PROTEIN	LEU	GLN	GLU	PHE	GLY	ILE	SER	ALA
MUTANT 3 PROTEIN	LEU	GLN	GLY	PHE	VAL	ILE	SER	ALA
MUTANT 4 PROTEIN	LEU	GLN	GLY	PHE	GLY	ILE	TRP	ALA

GENETIC MUTATIONS can result from the alteration of a single base in a DNA codon. The letters stand for the four bases: adenine (A), thymine (T), guanine (G) and cytosine (C). Since the DNA molecule consists of two complementary strands, a base change in one strand involves a complementary change in the second strand. In the four mutant DNA sequences shown here (*top*) a pair of bases (*color*) is different from that in the normal sequence. By genetic studies one can map the sequence and approximate spacing of the four mutations (*middle*). By chemical studies of the proteins produced by the normal and mutant DNA sequences (*bottom*) one can establish the corresponding amino acid changes.

"DELETION" MUTANTS provide one approach to making a genetic map. Here (*a*) normal DNA and mutant *A* differ by only one base pair (*C–G* has replaced *T–A*) in a certain portion of the *A* gene (*colored area*). In deletion mutant 1 a sequence of 10 base pairs, including six pairs from the *A* gene, has been spontaneously deleted. In deletion mutant 2, 22 base pairs, including 15 pairs from the *A* gene, have been deleted. By crossing mutant *A* with the two different deletion mutants in separate experiments (*b, c*), one can tell whether the mutated site (*C–G*) in the *A* gene falls inside or outside the deleted regions. A normal-type recombinant will appear (*b*) only if the altered base pair falls outside the deleted region.



OTHER MAPPING METHODS involve determination of recombination frequency (*a, b*) and the distribution of outside markers (*c, d*). The site of a mutational alteration is indicated by "—," the corresponding unaltered site by "+." If the altered sites are widely spaced (*b*), normal recombinants will appear more often than if the altered sites are close together (*a*). In the second method the mutants are linked to another gene that is either normal (K^+) or mutated (K^-). Recombinant strains that contain 1^+ and 2^+ will carry the K^- gene if the correct order is *K*–2–1. They will carry the K^+ gene if the order is *K*–1–2.

mappable gene should specify a protein whose amino acid sequence could be determined. Since no such system was known we had to gamble on a choice of our own. Fortunately we were studying at the time how the bacterium *Escherichia coli* synthesizes the amino acid tryptophan. Irving Crawford and I observed that the enzyme that catalyzed the last step in tryptophan synthesis could be readily separated into two different protein species, or subunits, one of which could be clearly isolated from the thousands of other proteins synthesized by *E. coli.* This protein, called the tryptophan synthetase *A* protein, had a molecular weight indicating that it had slightly fewer than 300 amino acid units. Furthermore, we already knew how to force *E. coli* to produce comparatively large amounts of the protein—up to 2 percent of the total cell protein—and we also had a collection of mutants in which the activity of the tryptophan synthetase *A* protein was lacking. Finally, the bacterial strain we were using was one for which genetic procedures for preparing fine-structure maps had already been developed. Thus we could hope to map the *A* gene that presumably controlled the structure of the *A* protein.

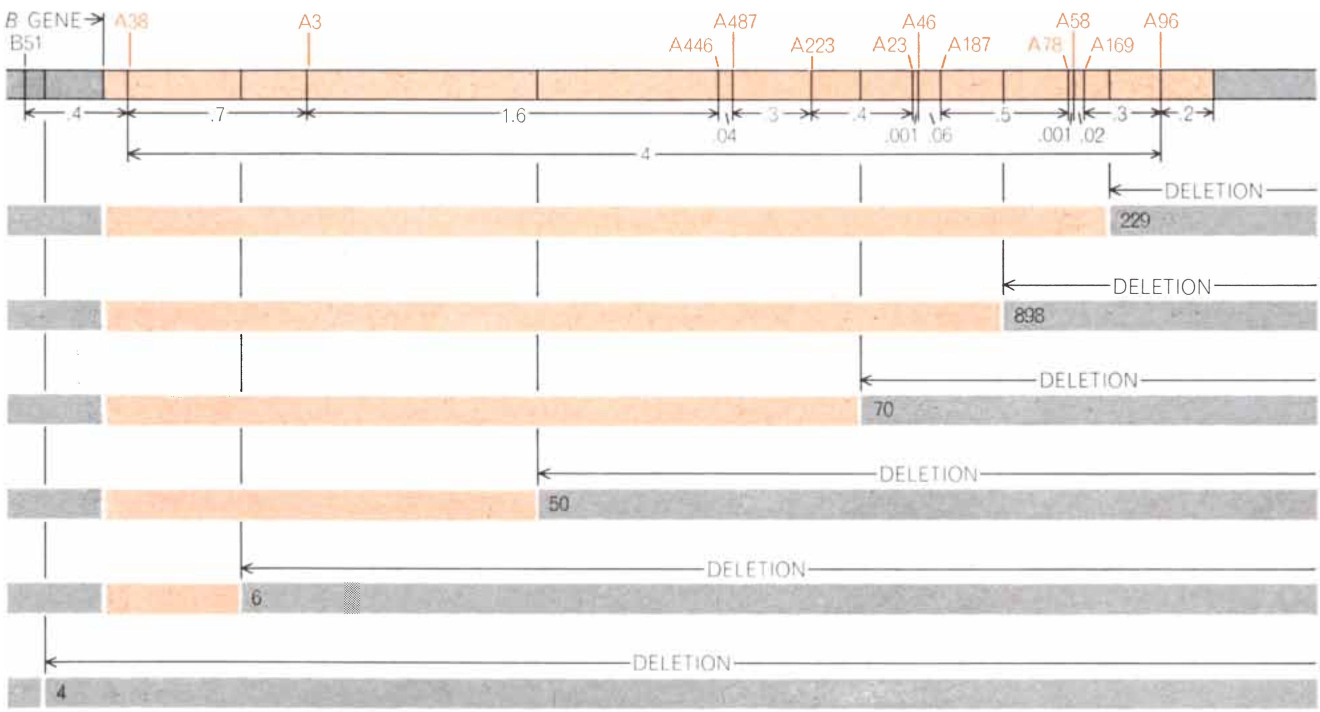
To accomplish the mapping we needed a set of bacterial mutants with mutational alterations at many different sites on the *A* gene. If we could determine the amino acid change in the *A* protein of each of these mutants, and discover its position in the linear sequence of amino acids in the protein, we could test the concept of colinearity. Here again we were fortunate in the nature of the complex of subunits represented by tryptophan synthetase.

The normal complex consists of two *A*-protein subunits (the alpha chains) and one subunit consisting of two beta chains. Within the bacterial cell the complex acts as an enzyme to catalyze the reaction of indole-3-glycerol phosphate and serine to produce tryptophan and 3-phosphoglyceraldehyde [*see illustration on page 82*]. If the *A* protein undergoes certain kinds of mutations, it is still able to form a complex with the beta chains, but the complex loses the ability to catalyze the reaction. It retains the ability, however, to catalyze a simpler reaction when it is tested outside the cell: it will convert indole and serine to tryptophan. There are still other kinds of *A*-gene mutants that evidently lack the ability to form an *A* protein that can combine with beta chains; thus these strains are not able to catalyze even the simpler reaction. The first class of mutants—those that produce an *A* protein that is still able to combine with beta chains and exhibit catalytic activity when they are tested outside the cell—proved to be the most important for our study.

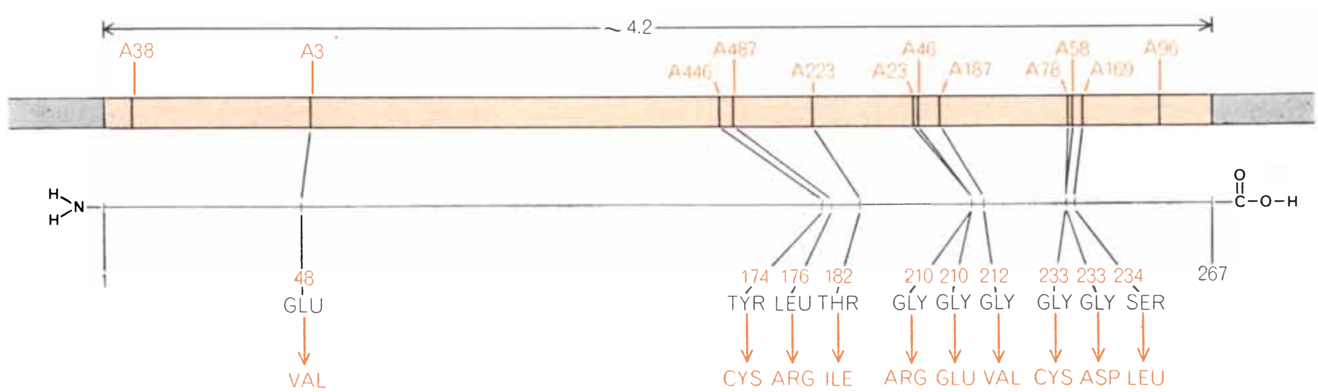
A fine-structure map of the *A* gene was constructed on the basis of genetic crosses performed by the process called transduction. This employs a particular bacterial virus known as transducing phage *P1kc*. When this virus multiplies in a bacterium, it occasionally incorporates a segment of the bacterial DNA within its own coat of protein. When the virus progeny infect other bacteria, genetic material of the donor bacteria is introduced into some of the recipient cells. A fraction of the recipients survive the infection. In these survivors segments of the bacterium's own genetic material pair with like segments of the "foreign" genetic material and recombination between the two takes place. As a result the offspring of an infected bacterium can contain characteristics inherited from its remote parent as well as from its immediate one.

In order to establish the order of mutationally altered sites in the *A* gene we have relied partly on a set of mutant bacteria in which one end of a deleted segment of DNA lies within the *A* gene. In each of these "deletion" mutants a segment of the genetic material of the bacterium was deleted spontaneously. Thus each deletion mutant in the set retains a different segment of the *A* gene. This set of mutants can now be crossed with any other mutant in which the *A* gene is altered at only a single site. Recombination can give rise to a normal gene only if the altered site does not fall within the region of the *A* gene that is missing in the deletion mutant [*see top illustration on opposite page*]. By crossing many *A*-protein mutants with the set of deletion mutants one can establish the linear order of many of the mutated sites in the *A* gene. The ordering is limited only by the number of deletion mutants at one's disposal.

A second method, which more closely



MAP OF *A* GENE shows the location of mutationally altered sites, drawn to scale, as determined by the three genetic-mapping methods illustrated on the opposite page. The total length of the *A* gene is slightly over four map units (probably 4.2). Below map are six deletion mutants that made it possible to assign each of the 12 *A*-gene mutants to one of six regions within the gene. The more sensitive mapping methods were employed to establish the order of mutations and the distance between mutation sites within each region.



COLINEARITY OF GENE AND PROTEIN can be inferred by comparing the *A*-gene map (*top*) with the various amino acid changes in the *A* protein (*bottom*), both drawn to scale. The amino acid changes associated with 10 of the 12 mutations are also shown.

MET – GLN – ARG – TYR – GLU – SER – LEU – PHE – ALA – GLN – LEU – LYS – GLU – ARG – LYS – GLU – GLY – ALA – PHE – VAL –
1 ... 20

PRO – PHE – VAL – THR – LEU – GLY – ASP – PRO – GLY – ILE – GLU – GLN – SER – LEU – LYS – ILE – ASP – THR – LEU – ILE –
21 ... 40

GLU – ALA – GLY – ALA – ASP – ALA – LEU – GLU (A3: → VAL) – LEU – GLY – ILE – PRO – PHE – SER – ASP – PRO – LEU – ALA – ASP – GLY –
41 ... 60

PRO – THR – ILE – GLN – ASN – ALA – THR – LEU – ARG – ALA – PHE – ALA – ALA – GLY – VAL – THR – PRO – ALA – GLN – CYS –
61 ... 80

PHE – GLU – MET – LEU – ALA – LEU – ILE – ARG – GLN – LYS – HIS – PRO – THR – ILE – PRO – ILE – GLY – LEU – LEU – MET –
71 ... 100

TYR – ALA – ASN – LEU – VAL – PHE – ASN – LYS – GLY – ILE – ASP – GLU – PHE – TYR – ALA – GLN – CYS – GLU – LYS – VAL –
101 ... 120

GLY – VAL – ASP – SER – VAL – LEU – VAL – ALA – ASP – VAL – PRO – VAL – GLN – GLU – SER – ALA – PRO – PHE – ARG – GLN –
121 ... 140

ALA – ALA – LEU – ARG – HIS – ASN – VAL – ALA – PRO – ILE – PHE – ILE – CYS – PRO – PRO – ASP – ALA – ASP – ASP – ASP –
141 ... 160

LEU – LEU – ARG – GLN – ILE – ALA – SER – TYR – GLY – ARG – GLY – TYR – THR – TYR (A446: → CYS) – LEU – LEU (A487: → ARG) – SER – ARG – ALA – GLY –
161 ... 180

VAL – THR (A223: → ILE) – GLY – ALA – GLU – ASN – ARG – ALA – ALA – LEU – PRO – LEU – ASN – HIS – LEU – VAL – ALA – LYS – LEU – LYS –
181 ... 200

GLU – TYR – ASN – ALA – ALA – PRO – PRO – LEU – GLN – GLY (A23: → ARG; A46: → GLU) – PHE – GLY (A187: → VAL) – ILE – SER – ALA – PRO – ASP – GLN – VAL – LYS –
201 ... 220

ALA – ALA – ILE – ASP – ALA – GLY – ALA – ALA – GLY – ALA – ILE – SER – GLY (A78: → CYS; A58: → ASP) – SER (A169: → LEU) – ALA – ILE – VAL – LYS – ILE – ILE –
221 ... 240

GLU – GLN – HIS – ASN – ILE – GLU – PRO – GLU – LYS – MET – LEU – ALA – ALA – LEU – LYS – VAL – PHE – VAL – GLN – PRO –
241 ... 260

MET – LYS – ALA – ALA – THR – ARG – SER
261 ... 267

AMINO ACID SEQUENCE OF *A* PROTEIN is shown side by side with a ribbon representing the DNA of the *A* gene. It can be seen that 10 different mutations in the gene produced alterations in the amino acids at only eight different places in the *A* protein. The explanation is that at two of them, 210 and 233, there were a total of four alterations. Thus at No. 210 the mutation designated A23 changed glycine to arginine, whereas mutation A46 changed glycine to glutamic acid. At No. 233 glycine was changed to cysteine by one mutation (A78) and to aspartic acid by another mutation (A58). On the genetic map A23 and A46, like A78 and A58, are very close.

resembles traditional genetic procedures, relies on recombination frequencies to establish the order of the mutationally altered sites in the *A* gene with respect to one another. By this method one can assign relative distances—map distances—to the regions between altered sites. The method is often of little use, however, when the distances are very close.

In such cases we have used a third method that involves a mutationally altered gene, or genetic marker, close to the *A* gene. This marker produces a recognizable genetic trait unrelated to the *A* protein. What this does, in effect, is provide a reading direction so that one can tell whether two closely spaced mutants, say No. 58 and No. 78, lie in the order 58–78, reading from the left on the map, or vice versa [*see bottom illustration on page 88*].

With these procedures we were able to construct a genetic map relating the altered sites in a group of mutants responsible for altered *A* proteins that could themselves be isolated for study. Some of the sites were very close together, whereas others were far apart [*see upper illustration on page 89*]. The next step was to determine the nature of the amino acid changes in each of the mutationally altered proteins.

SEGMENT OF PROTEIN	MUTANT H11	C140	B17	B272	H32	B278	C137	H36	A489	C208	NORMAL
I	+	+	+	+	+	+	+	+	+	+	+
II	−	+	+	+	+	+	+	+	+	+	+
III	−	−	+	+	+	+	+	+	+	+	+
IV	−	−	−	+	+	+	+	+	+	+	+
V	−	−	−	−	+	+	+	+	+	+	+
VI	−	−	−	−	−	+	+	+	+	+	+
VII	−	−	−	−	−	−	+	+	+	+	+
VIII	−	−	−	−	−	−	−	+	+	+	+
IX	−	−	−	−	−	−	−	−	+	+	+
X	−	−	−	−	−	−	−	−	−	+	+
XI	−	−	−	−	−	−	−	−	−	−	+

GENETIC MAP: H11 C140 B17 B272 H32 B278 C137 H36 A489 C208

INDEPENDENT EVIDENCE FOR COLINEARITY of gene and protein structure has been obtained from studies of the protein that forms the head of the bacterial virus T4D. Sydney Brenner and his co-workers at the University of Cambridge have found that mutations in the gene for the head protein alter the length of head-protein fragments. In the table "+" indicates that a given segment of the head protein is produced by a particular mutant; "—" indicates that the segment is not produced. When the genetic map was plotted, it was found that the farther to the right a mutation appears, the longer the fragment of head protein.

It was expected that each mutant of the *A* protein would have a localized change, probably involving only one amino acid. Before we could hope to identify such a specific change we would have to know the sequence of amino acids in the unmutated *A* protein. This was determined by John R. Guest, Gabriel R. Drapeau, Bruce C. Carlton and me, by means of a well-established procedure. The procedure involves breaking the protein molecule into many short fragments by digesting it with a suitable enzyme. Since any particular protein rarely has repeating sequences of amino acids, each digested fragment is likely to be unique. Moreover, the fragments are short enough—typically between two and two dozen amino acids in length—so that careful further treatments can release one amino acid at a time for analysis. In this way one can identify all the amino acids in all the fragments, but the sequential order of the fragments is still unknown. This can be established by digesting the complete protein molecule with a different enzyme that cleaves it into a uniquely different set of fragments. These are again analyzed in detail. With two fully analyzed sets of fragments in hand, it is not difficult to find short sequences of amino acids that are grouped together in the fragment of one set but that are divided between two fragments in the other. This provides the clue for putting the two sets of fragments in order. In this way we ultimately determined the identity and location of each of the 267 amino acids in the unmutated *A* protein of tryptophan synthetase.

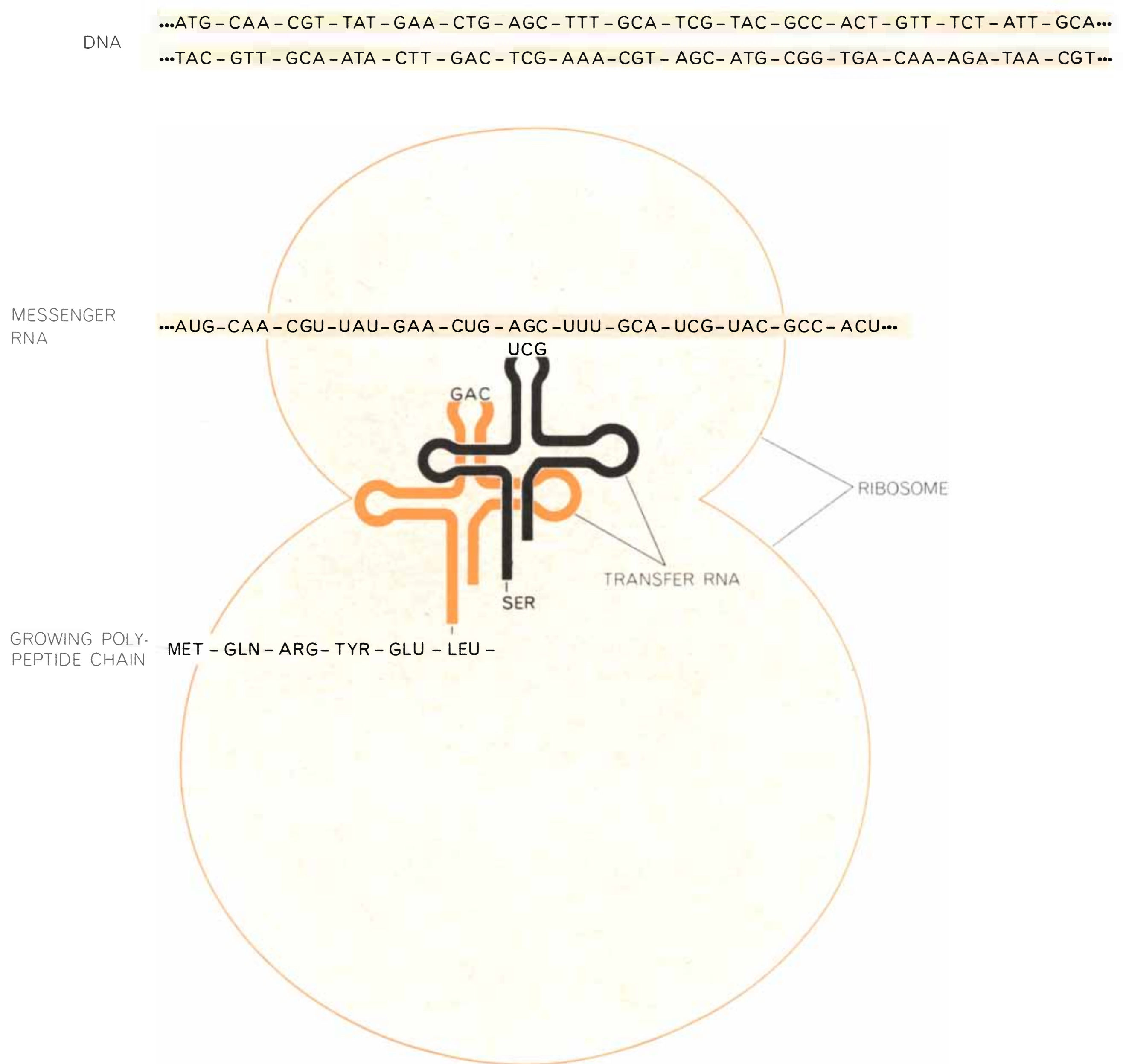
Simultaneously my colleagues and I were examining the mutants of the *A* protein to identify the specific sites of mutational changes. For this work we used a procedure first developed by Vernon M. Ingram, now at the Massachusetts Institute of Technology, in his studies of naturally occurring abnormal forms of human hemoglobin. This procedure also uses an enzyme (trypsin) to break the protein chain into peptides, or polypeptide fragments. If the peptides are placed on filter paper wetted with certain solvents, they will migrate across the paper at different rates; if an electric potential is applied across the paper, the peptides will be dispersed even more, depending on whether they are negatively charged, positively charged or uncharged under controlled conditions of acidity. The former separation process is chromatography; the latter, electrophoresis. When they are employed in combination, they produce a unique "fingerprint" for each set of peptides obtained by digesting the *A* protein from a particular mutant bacterium. The positions of the peptides are located by spraying the filter paper with a solution of ninhydrin and heating it for a few minutes at about 70 degrees centigrade. Each peptide reacts to yield a characteristic shade of yellow, gray or blue.

When the fingerprints of mutationally altered *A* proteins were compared with the fingerprint of the unmutated protein, they were found to be remarkably similar. In each case, however, there was a difference. The mutant fingerprint usually lacked one peptide spot that appears in the nonmutant fingerprint and exhibited a spot that the nonmutant fingerprint lacks. The two peptides would presumably be related to each other with the exception of the change resulting from the mutational event. One can isolate each of the peptides and compare their amino acid composition. Guest, Drapeau, Carlton and I, together with D. R. Helinski and U. Henning, identified the amino acid substitutions in each of a variety of altered *A* proteins.

The final step was to compare the locations of these changes in the *A* protein with the genetic map of the mutationally altered sites. There could be no doubt that the amino acid sequence of the *A* protein and the map of the *A* gene are in fact colinear [*see lower illustration on page 89*].

One can also see that the distances between mutational sites on the map of the *A* gene correspond quite closely to the distances separating the corresponding amino acid changes in the *A* protein. In two instances two separate mutational changes, so close as to be almost at the same point on the genetic map, led to changes of the same amino acid in the unmutated protein. This is to be expected if a codon of three bases in DNA is required to specify a single amino acid in a protein. Evidently the most closely spaced mutational sites in our genetic map represent alterations in two bases within a single codon.

Thus our studies have shown that each



SCHEME OF PROTEIN SYNTHESIS, according to the current view, involves the following steps. Genetic information is transcribed from double-strand DNA into single-strand messenger ribonucleic acid (RNA), which becomes associated with a ribosome. Amino acids are delivered to the ribosome by molecules of transfer RNA, which embody codons complementary to the codons in messenger RNA. The next to the last molecule of transfer RNA to arrive (*color*) holds the growing polypeptide chain while the arriving molecule of transfer RNA (*black*) delivers the amino acid that is to be added to the chain next (serine in this example). The completed polypeptide chain, either alone or in association with other chains, is the protein whose specification was originally embodied in DNA.

AGY (170) — AGX (177) — AGY (178) — AGY (187)

CGZ GGZ UAX ACZ UAX XUZ CUZ UCZ CGZ GCZ GGZ GUZ ACW GGZ GCZ GAY AAX CGZ GCZ GCZ XUZ

– ARG – GLY – TYR – THR – TYR – LEU – LEU – SER – ARG – ALA – GLY – VAL – THR – GLY – ALA – GLU – ASN – ARG – ALA – ALA – LEU –

170 … 190

CCZ XUZ AAX CAX XUZ GUZ GCZ AAY XUZ AAY GAY UAX AAX GCZ GCZ CCZ CCZ XUZ CAY GGA

PRO – LEU – ASN – HIS – LEU – VAL – ALA – LYS – LEU – LYS – GLU – TYR – ASN – ALA – ALA – PRO – PRO – LEU – GLN – GLY –

191 … 210

AGX (213)

UUX GGZ AUW UCZ GCZ CCZ GAX CAY GUZ AAY GCZ GCZ AUW GAX GCZ GGZ GCZ GCZ GGZ GCZ

PHE – GLY – ILE – SER – ALA – PRO – ASP – GLN – VAL – LYS – ALA – ALA – ILE – ASP – ALA – GLY – ALA – ALA – GLY – ALA –

211 … 230

AGX (232)

AUW UCZ GGX UCZ GCZ AUW GUZ AAY AUW AUW GAY CAY CAX AAX AUW GAY CCZ GAY AAY AUG

ILE – SER – GLY – SER – ALA – ILE – VAL – LYS – ILE – ILE – GLU – GLN – HIS – ASN – ILE – GLU – PRO – GLU – LYS – MET –

231 … 250

W = U, C or A   X = U or C   Y = A or G   Z = U, C, A or G

PROBABLE CODONS IN MESSENGER RNA that determines the sequence of amino acids in the *A* protein are shown for 81 of the protein's 267 amino acid units. The region includes seven of the eight mutationally altered positions (*colored boxes*) in the *A* protein. The codons were selected from those assigned to the amino acids by Marshall Nirenberg and his associates at the National Institutes of Health and by H. Gobind Khorana and his associates at the University of Wisconsin. Codons for the remaining 186 amino acids in the *A* protein can be supplied similarly. In most cases the last base in the codon cannot be specified because there are usually several synonymous codons for each amino acid. With a few exceptions the synonyms differ from each other only in the third position.

unique sequence of bases in DNA—a sequence constituting a gene—is ultimately translated into a corresponding unique linear sequence of amino acids—a sequence constituting a polypeptide chain. Such chains, either by themselves or in conjunction with other chains, fold into the three-dimensional structures we recognize as protein molecules. In the great majority of cases these proteins act as biological catalysts and are therefore classed as enzymes.

The colinear relation between a genetic map and the corresponding protein has also been convincingly demonstrated by Sydney Brenner and his co-workers at the University of Cambridge. The protein they studied was not an enzyme but a protein that forms the head of the bacterial virus T4. One class of mutants of this virus produces fragments of the head protein that are related to one another in a curious way: much of their amino acid sequence appears to be identical, but the fragments are of various lengths. Brenner and his group found that when the chemically similar regions in fragments produced by many mutants were matched, the fragments could be arranged in order of increasing length. When they made a genetic map of the mutants that produced these fragments, they found that the mutationally altered sites on the genetic map were in the same order as the termination points in the protein fragments. Thus the length of the fragment of the head protein produced by a mutant increased as the site of mutation was displaced farther from one end of the genetic map [*see illustration on page 91*].

The details of how the living cell translates information coded in gene structure into protein structure are now reasonably well known. The base sequence of one strand of DNA is transcribed into a single-strand molecule of messenger ribonucleic acid (RNA), in which each base is complementary to one in DNA. Each strand of messenger RNA corresponds to relatively few genes; hence there are a great many different messenger molecules in each cell. These messengers become associated with the small cellular bodies called ribosomes, which are the actual site of protein synthesis [*see illustration on page 92*]. In the ribosome the bases on the messenger RNA are read in groups of three and translated into the appropriate amino acid, which is attached to the growing polypeptide chain. The messenger also contains in code a precise starting point and stopping point for each polypeptide.

From the studies of Marshall Nirenberg and his colleagues at the National Institutes of Health and of H. Gobind Khorana and his group at the University of Wisconsin the RNA codons corresponding to each of the amino acids are known. By using their genetic code dictionary we can indicate approximately two-thirds of the bases in the messenger RNA that specifies the structure of the *A*-protein molecule. The remaining third cannot be filled in because synonyms in the code make it impossible, in most cases, to know which of two or more bases is the actual base in the third position of a given codon [*see illustration above*]. This ambiguity is removed, however, in two cases where the amino acid change directed by a mutation narrows down the assignment of probable codons. Thus at amino acid position 48 in the *A*-protein molecule, where a mutation changes the amino acid glutamic acid to valine, one can deduce from the many known changes at this position that of the two possible codons for glutamic acid, GAA and GAG, GAG is the correct one. In other words, GAG (specifying glutamic acid) is changed to GUG (specifying valine). The other position for which the codon assignment can be made definite in this way is No. 210. This position is affected by two different mutations: the amino acid glycine is replaced by arginine in one case and by glutamic acid in the other. Here one can infer from the observed amino acid changes that of the four possible codons for glycine, only one—GGA—can yield by a single base change either arginine (AGA) or glutamic acid (GAA).

Knowledge of the bases in the messenger RNA for the *A* protein can be translated, of course, into knowledge of the base pairs in the *A* gene, since each base pair in DNA corresponds to one of the bases in the RNA messenger. When the ambiguity in the third position of most of the codons is resolved, and when we can distinguish between two quite different sets of codons for arginine, leucine and serine, we shall be able to write down the complete base sequence of the *A* gene—the base sequence that specifies the sequence of the 267 amino acids in the *A* protein of the enzyme tryptophan synthetase.

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VISION AND TOUCH

It has been held that human beings must learn how to see, and that they are taught by the sense of touch. New experiments demonstrate, however, that vision completely dominates touch and even shapes it

by Irvin Rock and Charles S. Harris

A visual perception is not simply a copy of the image on the retina. The image has two dimensions, the perceived object three. The image is upside down, but the object is seen right-side up. An image of a given size can be projected on the retina either from a small object that is nearby or from a large object that is distant, and yet one usually perceives the actual size of the object quite accurately. The image is received by millions of separate light-sensitive cells in the retina, but one sees a unified object with a definite shape.

The striking differences between the retinal image and perception have led many philosophers and psychologists to assume that one must learn how to see. If the retinal image supplies only distorted and incomplete information, one must at first make use of some other source of information about the properties of objects. The most likely source has been considered the sense of touch. In the 18th century the philosopher George Berkeley proposed that an infant discovers by touching an object that it is a distinct, three-dimensional body of a certain size and shape in a certain location and orientation. Thus touch presumably educates vision, adding meaning to the initially meaningless jumble of retinal images.

We have investigated this assumption and have concluded on the basis of several experiments that it is wrong. The sense of touch does not educate vision; vision is totally dominant over touch. As an example, one of our experiments shows that if a subject looks at his hand through a prism, so that the hand appears to be several inches to the right of where it really is, he soon comes to believe the hand is where it appears to be, in spite of nerve messages to the contrary that must be traveling from the hand to his brain. Indeed, one can now turn the traditional argument around and suggest that vision shapes the sense of touch.

We should emphasize that in referring to the sense of touch we mean more than the sensations of contact with the skin that one experiences when touching an object. Touch includes several other components, of which the one most significant for this discussion is the position sense: the sense that enables us to know the position of our body parts when our eyes are closed. It is touch in this broad definition that has been so widely believed to educate vision.

The arguments for the belief rest not only on the recognition of the differences between a retinal image and a visual perception but also on observable evidence. For instance, people who gain sight after having been blind since birth seem at first to have trouble seeing correctly. The phenomenon has been interpreted as suggesting that they must learn to see on the basis of information from touch.

Similar implications have been drawn from experiments by a number of psychologists. A classic experiment was conducted in 1895 by George M. Stratton of the University of California. He spent several days wearing lenses that turned everything upside down. Ivo Kohler of the University of Innsbruck has conducted similar experiments and has also used prisms that reverse right and left. Experiments with prisms that displace the retinal image to one side were carried out in the 19th century by Hermann von Helmholtz and recently by Richard Held of the Massachusetts Institute of Technology [see "Plasticity in Sensory-Motor Systems," by Richard Held; SCIENTIFIC AMERICAN, November, 1965].

In these studies the subject at first saw the world upside down, reversed or displaced, and he acted accordingly. He tried to duck under objects he should have climbed over, he made wrong turns, he missed when he reached for things. After a while, however, he adapted: he behaved normally again, reacting appropriately in spite of the abnormal retinal image.

Such adaptations create the impression that they involve radical adjustments in vision so that the subject again sees the world as normal. Indeed, the adaptations would not be surprising if visual perception is derived from touch. If an infant must learn how to see, an adult could be expected to relearn how to see when his sense of touch tells him that his eyes are deceiving him.

Let us now, however, consider some arguments against the proposition that visual perception is based on touch. In the first place, the same reasoning that seems to rule out innate visual perception also argues against any innate sense of touch on which to build visual perception. Why should one assume that the separate tactile and position components of touch are innately organized into an impression of a solid object with a particular shape? Second, the sense of touch seems far too imprecise to be the source of the accurate perception of form and space that is achieved through vision.

Third, a considerable body of recent evidence suggests that vision is well developed at birth or very soon thereafter. Eleanor J. Gibson of Cornell University and Richard D. Walk of George Washington University found, for example, that babies, kittens and other infant animals have good depth perception before they have had any opportunity to learn it in any way [see "The 'Visual Cliff,'" by Eleanor J. Gibson and Richard D. Walk; Scientific American, April, 1960]. T. G. R. Bower of Harvard University found that human infants see the size and shape of things in the same way adults do [see "The Visual World of Infants," by T. G. R. Bower; Scientific American, December, 1966].

A fourth argument is provided by our own experiments. Even though we have worked separately and have used somewhat different techniques, we have both arrived at essentially the same conclusion, namely that when vision and touch provide contradictory information, perception is dominated by the information from vision. (Similar experiments by Charles R. Hamilton at the California Institute of Technology and by Julian Hochberg, John C. Hay and Herbert Pick, Jr., at Cornell have led them to similar conclusions.)

One of us (Rock) has been investigating perception of size and shape in collaboration with Jack Victor, a graduate student at Yeshiva University. By using a lens that reduces the size of an object's retinal image we can present a subject with contradictory information from vision and from touch [*see illustration at right*]. If he grasps an object while viewing it through the reducing lens, vision should tell him the object is a certain size and touch should tell him it is much larger.

We wanted to find out what the subject would experience under these conditions. Would he be aware that he was seeing an object of one size and feeling an object of another size? Or would he somehow reconcile the conflicting sensory information to achieve a unified perception or impression? If the latter were the case, which sense would have the most influence—vision or touch?

We considered it essential that the subject remain ignorant of the actual situation, otherwise the experiment might be reduced to a conscious decision about which sense to rely on. Because the subject would know that vision can be optically distorted but touch cannot, he would undoubtedly judge the size of the object in terms of what he felt. Accordingly we did not tell the subject that he was looking through a reducing lens. Moreover, we arranged matters so that he saw nothing through the lens except a one-inch white square made of hard plastic.

The subject grasped the square from below through a cloth so that he could not see his own hand; if he could have seen it, he might have deduced that he was looking through a reducing lens, since he would be familiar with the visual size of his hand. To be certain that the subject would not make measurements, such as laying off the side of the square against his finger, we did not ask him anything until after he had been exposed to the conflicting information for five seconds. Each subject was exposed to such a situation only once.

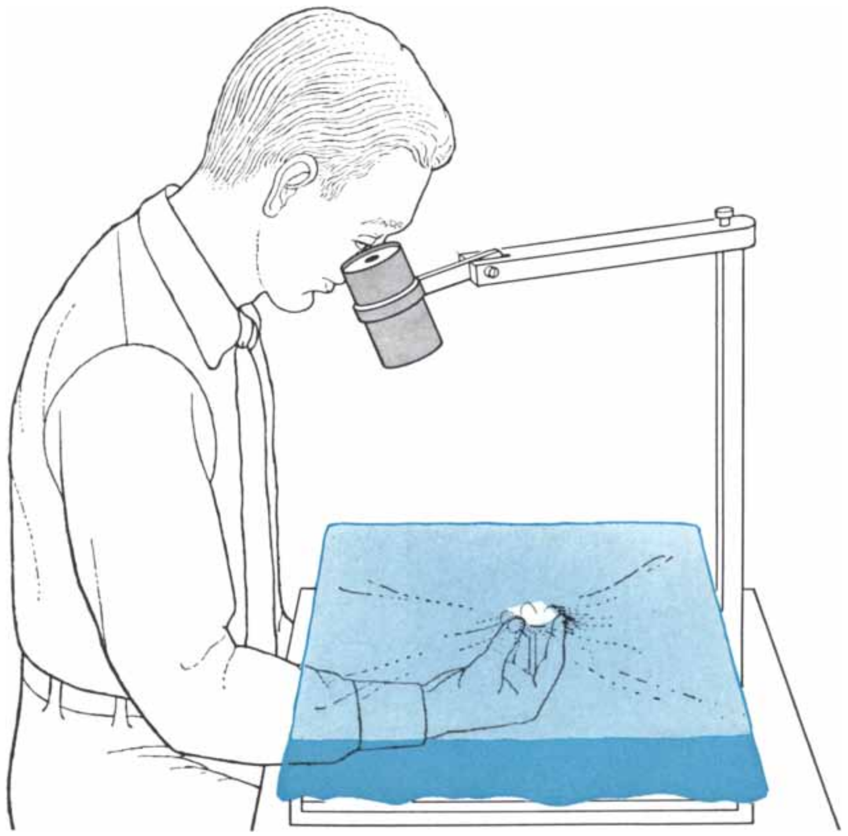
In assessing the subject's perception we could not ask him what was the size of the object he saw or what was the size of the object he felt; either question would prejudice the outcome. Instead we asked him to give his impression of the size of the square. We measured the impression in several ways [*see illustration on page 99*]. Some subjects were asked to draw the size of the square as accurately as they could; drawing involves both vision and touch. We asked others to pick out a matching square from a series of squares presented only visually. Still others were asked to choose a matching square from a series of squares that could be grasped but not seen.

The results of all the tests were clear. Most of the subjects were not even aware that they were receiving conflicting sensory information. This in itself is a most interesting fact. The subjects had a definite unitary experience of the size of the square, and the experience agreed closely with the illusory visual appearance of the square. The average size drawn or matched was about the same when the square was both seen and felt as when, in a control experiment, it was only seen. That size was consistently smaller than the size in another control experiment in which the square was only touched. Thus touch had almost no effect on the perceived size.

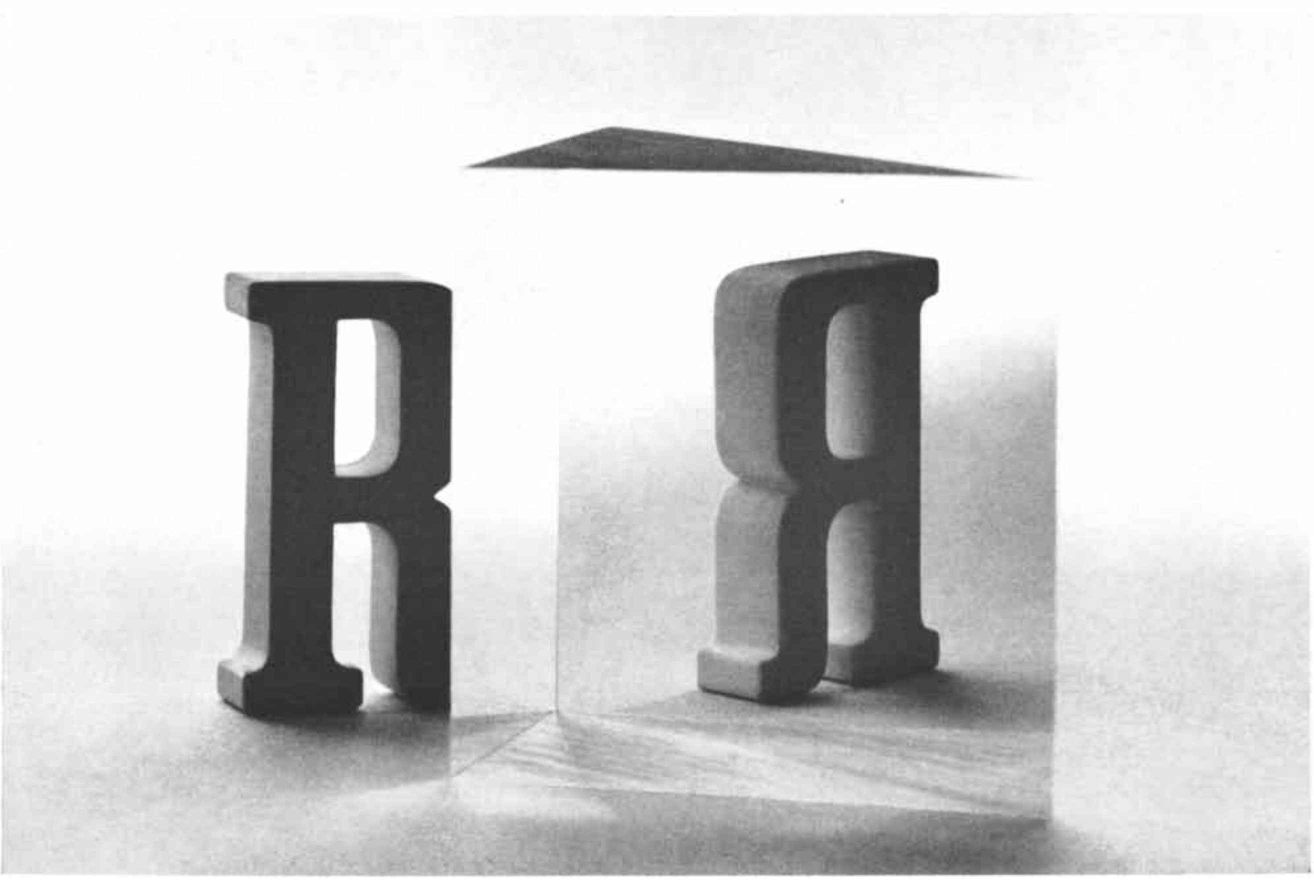
We then performed an experiment on the perception of shape. For this test we used a cylindrical optical device that made things seem narrower, so that a square looked like a rectangle with sides in the proportion of two to one. What would happen when the subject simultaneously saw and touched an object that looked like a rectangle but felt like a square?

The result was again quite clear. Vision was completely dominant. In fact, it was so dominant that most subjects said the square actually felt the way it looked. If subjects closed their eyes while grasping the object, they often thought they felt it changing its shape from a rectangle to a square.

A similar domination of touch by vision has been found by Hay, Pick and



EXPERIMENTAL ARRANGEMENT used to test the effect of a reducing lens on a subject's impression of size included the lens, a cloth over the subject's hand so that he would not deduce from the small appearance of his hand that he was looking through a reducing lens, and a square made of hard plastic. In this test he looked at square and simultaneously grasped it.



OPTICAL DEVICES were used in experiments to determine whether vision or touch would have the stronger effect on a subject to whom they were providing conflicting information. A reducing lens (*top*) made an object look half its actual size; a prism (*bottom*) reversed left and right. When subjects looked through such a lens or prism and also used touch, they received conflicting sensory data.

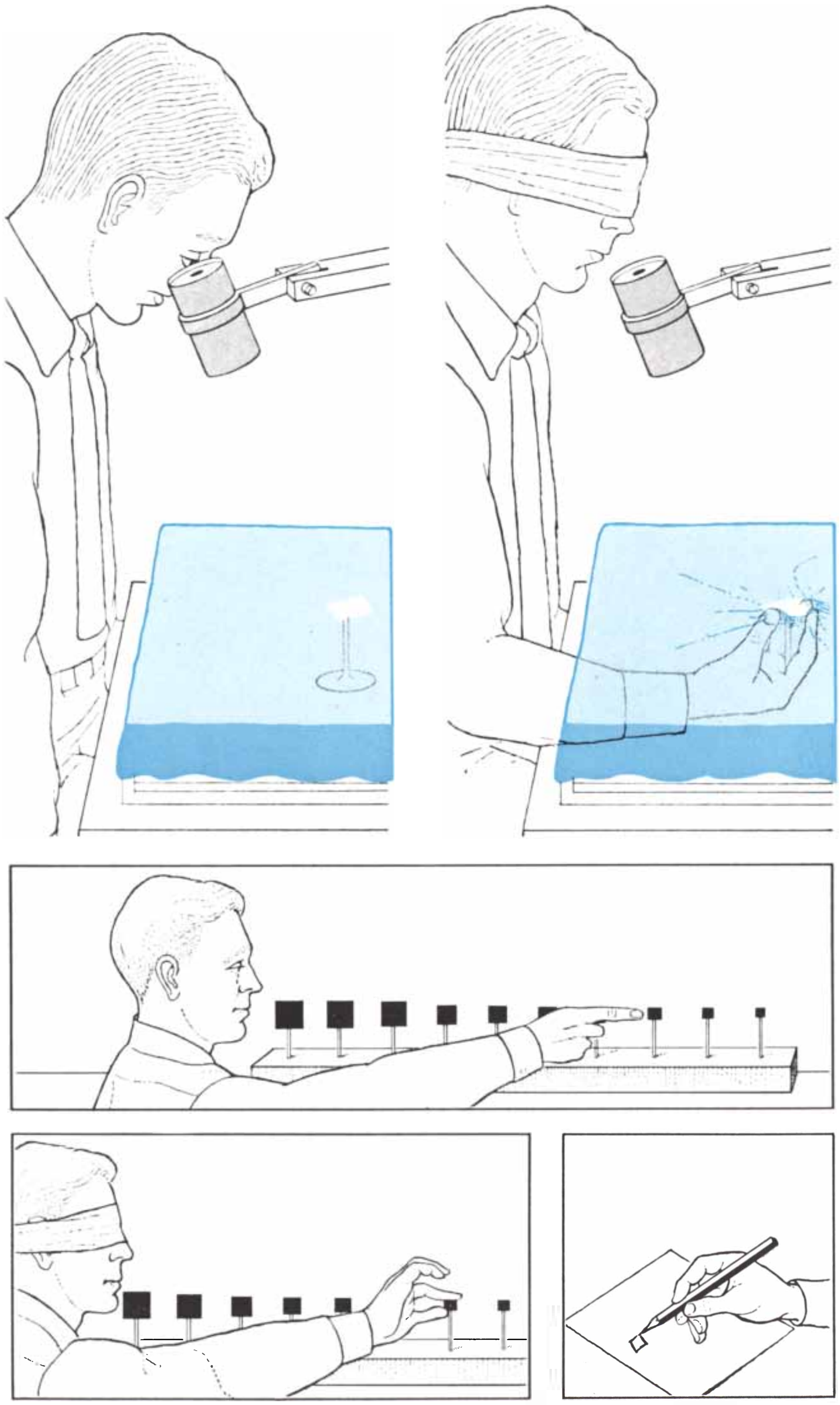
Karren Ikeda, working at Smith College. They had each subject rest one hand on a table and look at it through wedge prisms that displaced its visual image to one side. When the subject was asked to reach under the table and make a mark directly below the forefinger of his upper hand, a task he could perform quite accurately when blindfolded, he marked a location about as far from the finger's actual location as the prism-displaced image. Subjects did the same even when they were urged to rely entirely on where they felt the fingertip to be and to ignore its visual appearance. The investigators used for this effect of vision on touch the vivid term "visual capture."

Visual capture had also been observed 30 years earlier by James J. Gibson (then also at Smith but now at Cornell). He noted that when subjects ran their hand along a straight rod while looking through prisms that made the rod look curved, the rod felt curved. Torsten Nielsen of the University of Copenhagen recently demonstrated a similar form of visual capture without using any prisms. His subjects inserted one arm into a box and ran a pencil along a straight line while looking through a peephole. What they actually saw, however, was not their own hand but the experimenter's, reflected in a mirror so that it appeared to be in the same location as theirs. At first both the subject and the experimenter moved their hand back and forth along the line in time to a metronome. Then the experimenter started veering off the line. Strangely enough, few of Nielsen's subjects realized even then that the hand was not their own. They felt that their own hand was uncontrollably moving in a curve in spite of their efforts to stay on the line.

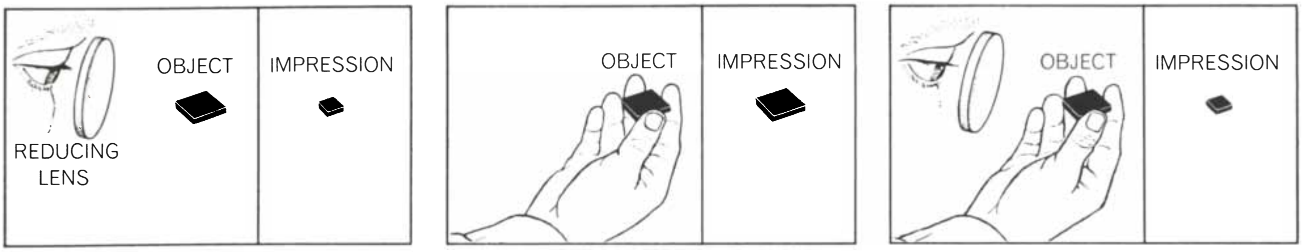
All these experiments show that when vision and touch provide conflicting information, the visual information dominates. Still, this is an immediate effect. Those who believe vision is originally educated by touch are thinking about the long-term result of continuous experience with the two senses. Perhaps, therefore, the experiments we have described are not crucial to the argument. A more pertinent question is: What happens after a period of exposure that is long enough to allow a genuine change in perception to take place?

In the experiments we have cited it could be that vision suppresses touch only temporarily, with the result that as soon as a person closes his eyes his touch perceptions return to normal. It could even be that although vision is at first dominant, it eventually changes to match touch. On the other hand, the converse could be true: with sufficient exposure the sense of touch may be altered so that misperceptions by touch persist even after vision is blocked. With this issue in mind, we shall now consider experiments in which changes in perception might be expected to occur because the exposure to the conflict is continued over a period of time.

Experiments by Helmholtz, Held and others using goggles fitted with sideways-displacing prisms do demonstrate



VARIETY OF TESTS determined what size a subject perceived a square to be when he was receiving conflicting data from vision and touch. In control tests he looked at the square without touching it (*top left*) and touched it without seeing it (*top right*). Then he matched it against squares shown only visually (*center*), matched it by touch alone (*bottom left*) and drew it (*bottom right*). In the tests the illusory visual size of the square predominated.



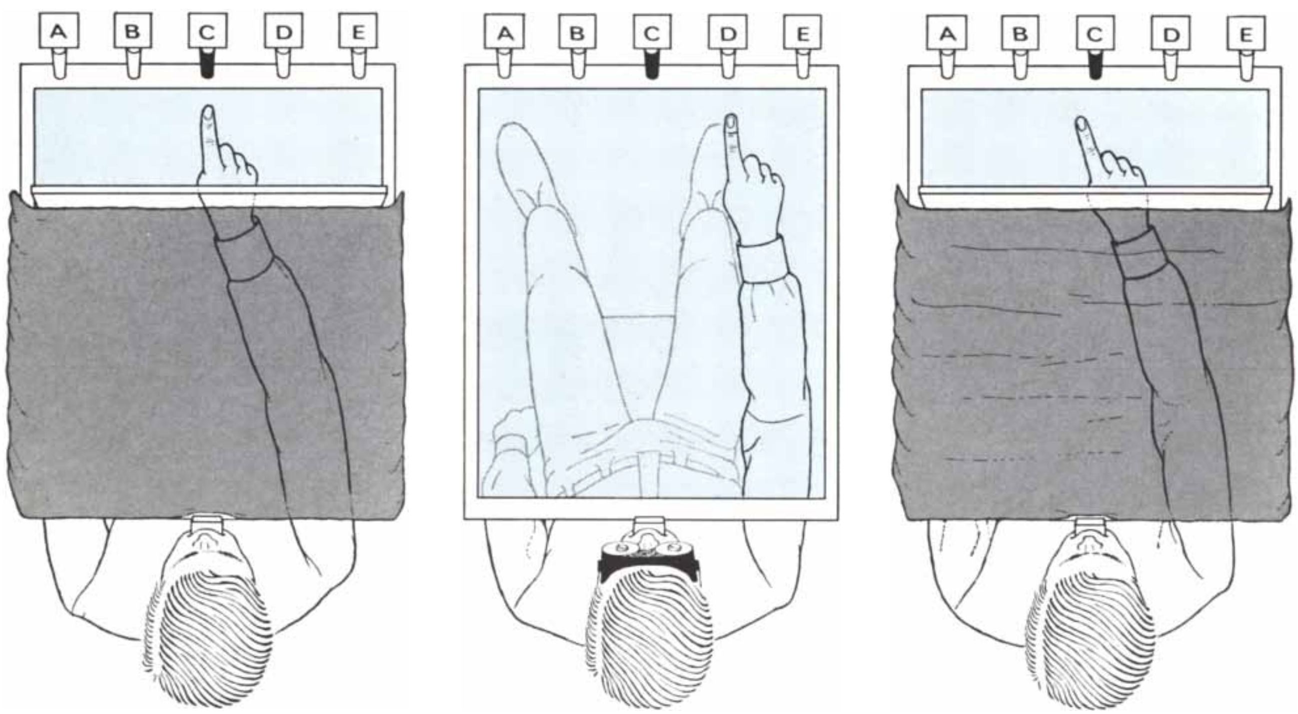
SUBJECT'S IMPRESSIONS in various experiments involving the reducing lens are indicated. In some cases (*left*) he merely saw an object through the lens; in some (*center*) he only felt the object, and in others (*right*) he simultaneously saw an object and felt it.

that appropriate exposure to a conflict between vision and touch produces aftereffects. When an observer first puts on the prisms and tries to point rapidly at an object, he misses. After several minutes of looking at his moving hand through the prisms, however, he points much more accurately even though his retinal images are still displaced. This adaptation is evident even if the subject's view of his hand is blocked during the pointing tests, thus preventing him from steering his seen hand to the seen target.

What does this adaptation show? It could be that the subject's visual perception has changed. He may be pointing more accurately because he is now seeing the object's location more accurately in spite of the displaced retinal image. If so, it could be contended that touch, which remained correct, had educated vision.

Conversely, it could just as well be that the subject is still seeing the object as displaced but now mistakenly feels that his hand is displaced when it is actually pointing straight ahead. This would mean that the adaptive change is in the sense of touch, specifically the sense of where one part of the body is with respect to the rest—the position sense. With continued exposure to the prisms the sensation of where the hand is may more closely approximate its observed location. The subject's misperception of his hand would compensate for his visual misperception of the object, enabling him to point fairly accurately.

To find out which explanation of the adaptation to sideways displacement is correct, one of us (Harris) carried out a series of experiments (some in collaboration with his wife, Judith R. Harris). The apparatus we used consisted of a glass surface that was just below the eye level of a seated subject and had as targets a row of lettered rods standing upright on the glass [*see illustration below*]. The experiments had three parts: pretest, adaptation and retest. In the pretest a black cloth was thrown over the glass surface so that the subject could see the targets but not his hand below the glass, and he was asked to



DISPLACED VISION was tested with this apparatus. First (*left*) the subject pointed at lettered rods without being able to see his hand; this pretest determined his normal responses. Then (*center*) he wore prism goggles that displaced his vision about four inches to one side, in this case to the right; while wearing them he was asked to point repeatedly at the center target with one hand. He usually missed at first because of the goggles. Finally (*right*) with the goggles off he was asked to point at various targets. Subjects typically showed an adaptation, or shift in pointing, with the hand used while wearing goggles but little or none with the other hand. Experiment suggested that his sense of the position of the adapted arm had changed. Biting device kept the subject's head steady.

point at various rods from below the glass. The pretest determined the subject's normal responses to the tests he would be given after adapting.

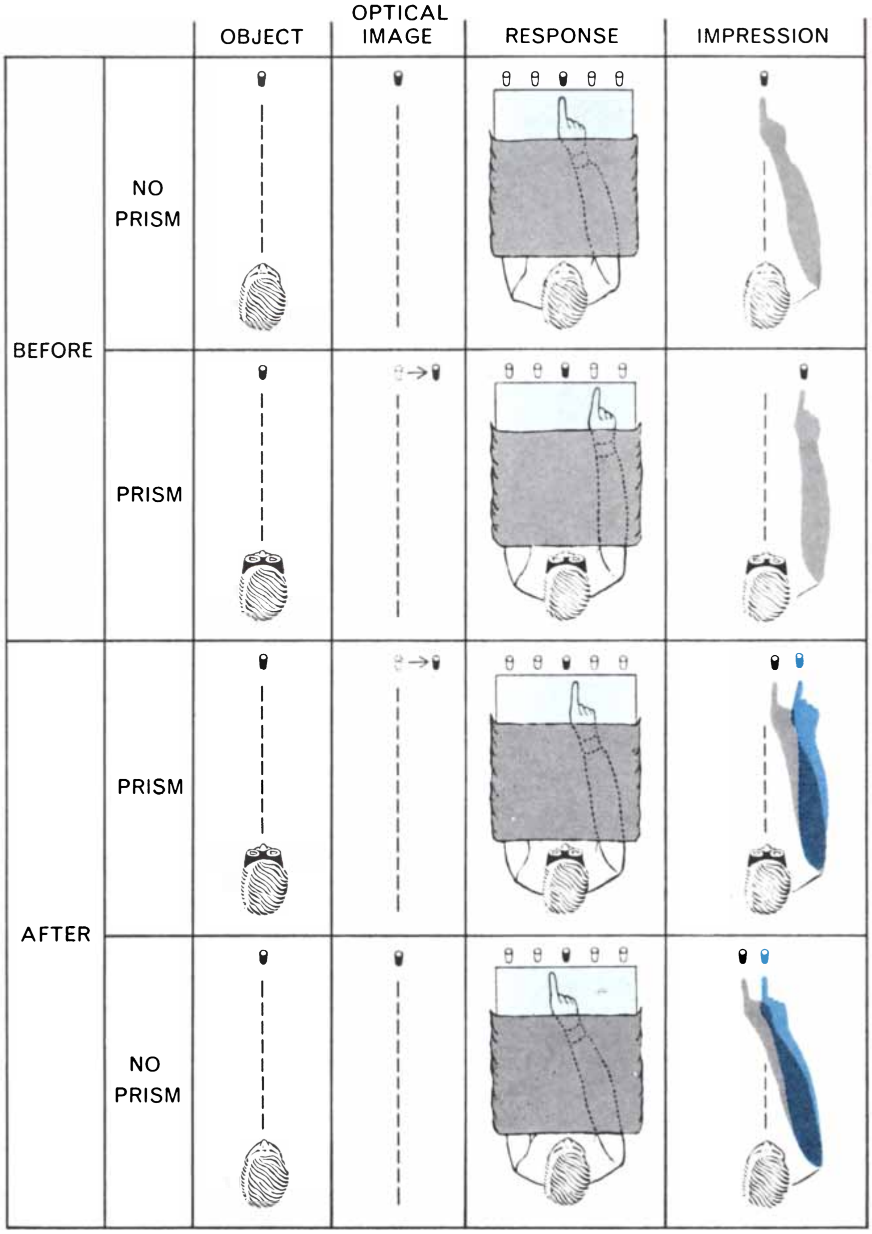
During adaptation the subject wore prism goggles for three minutes. The prisms shifted his visual field 11 degrees to the right or the left; the shift amounted to about four inches at arm's length. The subject's task was to point repeatedly with one hand at the center target. The cloth was removed during this phase so that the subject could see his hand through the glass. At first, because of the prisms, he tended to miss the target, but he quickly became more accurate.

For the retest we needed more than one kind of measurement in order to decide between the alternative explanations for the adaptive change in pointing by the subjects. The tests we chose were (1) pointing at visual targets seen without prisms, (2) pointing in the direction of sounds and (3) pointing in whatever direction the subject thought was straight ahead. During the nonvisual tests, of course, the subject kept his eyes closed.

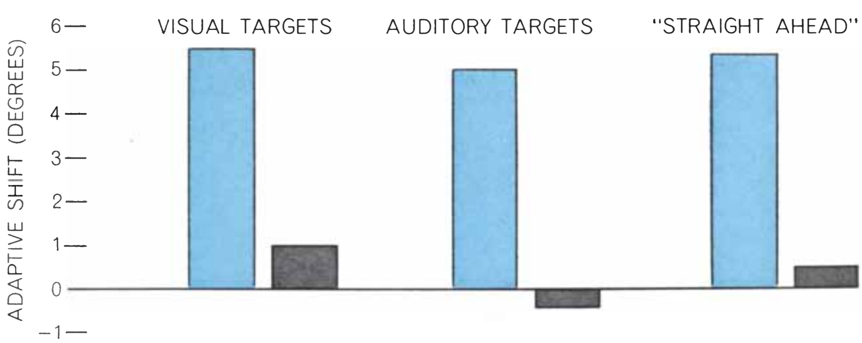
We found that the subjects showed a large shift in pointing with the adapted hand on all three retests [*see bottom illustration at right*]. In contrast, there was little or no adaptive shift when a subject pointed with his unadapted hand—the one he had not seen through prisms. Each of these results has been obtained in at least one other laboratory, although there are still some unanswered questions about the effects of changing certain details of the experimental procedure.

This pattern of results is consistent with the conclusion that the adaptation involved a change in the position sense of the adapted arm. If the adapted subject feels that he is pointing straight ahead when he is actually pointing about five degrees to one side, he will make the same error no matter what he is pointing at: a visual object, a sound source or the straight-ahead direction. With his unadapted hand, however, he will show no error in pointing.

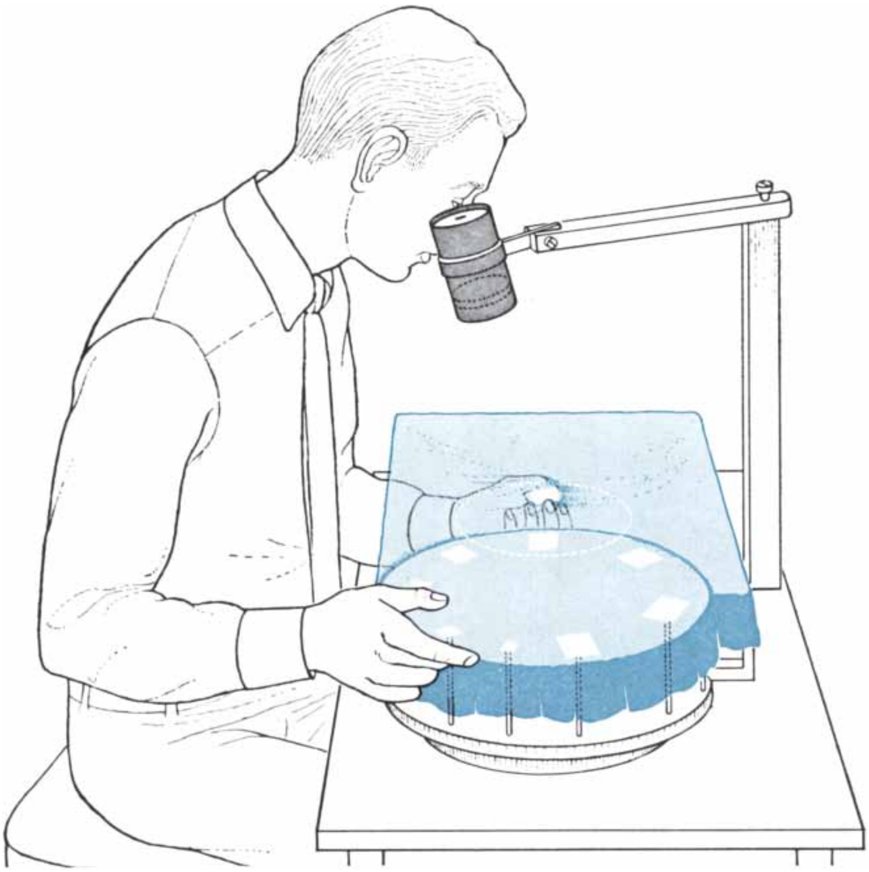
The findings clearly rule out the possibility that the adaptation is a change in visual perception. First, if the subject had learned to perceive the visual target in a new location, he should point at that new place with either hand. What actually happened was that when our subjects were asked to point at a target, they pointed in one direction with one hand and in a different direction with the other. Second, if adaptation were



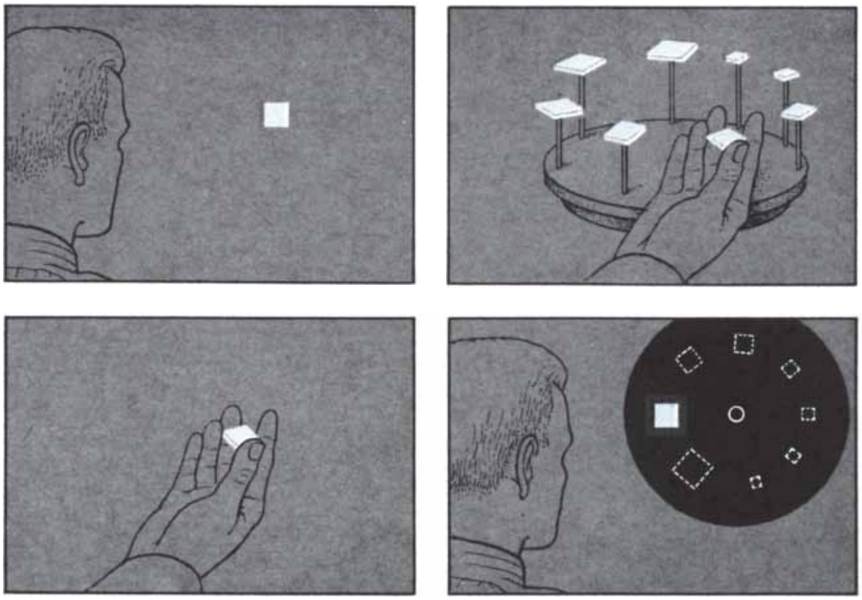
RESULTS OF TESTS with displacing prisms are charted before and after adaptation. "Object" column shows actual location of a target viewed by the subject; "image" column, how prisms displaced the target; "response," how the subject pointed. His impression of where the object was and where he was pointing is in last column. Experiment sought to find if pointing change after adaptation arose because he saw target differently (*gray*) or because he felt the position of his arm differently (*color*). Results showed that it was the latter.



SHIFT IN RESPONSE was made by eight subjects after they had pointed at an object with one hand while wearing prisms that displaced vision to the side. Their shifts in subsequent pointing without prisms are shown for adapted hand (*color*) and unadapted hand (*gray*).



PROLONGED EXPOSURE to conflicting data from vision and touch was achieved with this apparatus. The revolving wheel held squares of various sizes. For 30 minutes the subject looked through the reducing lens while grasping one square after another through a cloth that prevented him from seeing his hand. Tests were given before and after the 30-minute exposure. Aim of experiment was to find if visual perception or touch perception changed.



MATCHING TESTS given before and after 30-minute exposure to conflicting data included asking a subject to look at a square in a dark room (*top left*) and to match it by touch from a set of squares he could not see (*bottom left*). He was also asked to feel a square (*top right*) and to match it from a set displayed visually (*bottom right*). Use of reducing lens made subjects choose by touch a larger square than before as matching the visual standard; by vision they chose a smaller square than before as matching a square they had touched.

only a change in visual perception, it should have no effect on tests performed with the subject's eyes closed. Yet we found large adaptive shifts in pointing in the direction of a sound or in the straight-ahead direction—about as large as in pointing at visual targets. Third, if the adaptation is a change in visual perception, it should be revealed by tests of visual localization in which pointing is not involved, but no such effect has been found in that type of experiment.

A fourth potential explanation of adaptation to prisms (and it is a popular one among psychologists) is that adaptation is the learning of new motor responses: the subject simply learns to make movements appropriate to the altered visual stimulus. A person could correct his movements without any changes in perception. In fact, it may be that in some earlier experiments this is what happened. For example, it is quite clear that Stratton, who wore lenses that inverted the retinal image, did gradually learn to avoid the motor errors he initially made so often. The improvement does not, however, in itself demonstrate that he underwent any perceptual changes, such as learning to see normally through the inverting lenses. In our experiments too it could be that the adaptive shifts in pointing indicate only changes in motor response rather than in perception of where the arm is located.

To find out whether the change is in the subject's position sense or just in the movements he makes, we need a condition in which he judges the location of his hand without moving it. In one such test we had the subject estimate the distance between his hands while he was blindfolded. He made these judgments before and after one arm had been adapted. The adaptation procedure was the same as in the earlier experiment: the subject undertook to point repeatedly with his right hand at a visual target seen through prisms. During the pretest and retest, however, he was blindfolded and his right hand was moved by the experimenter to a predetermined location on the table in front of him. The subject was asked to place his unadapted left hand at a specified distance from his right hand. The right hand was then moved by the experimenter to a new location and the process was repeated.

We knew from the earlier results that the unadapted left hand had not been affected by the adaptation procedure, and during this test the adapted right hand was given no opportunity to execute any new responses it might have learned. Thus the subjects were forced to rely on their position sense in judging how far apart their hands felt. Their judgments indicated that after their right hand had been adapted to prisms that shifted the visual field to the right, the subjects felt that, at a given physical distance, their hands were farther apart than before. After adapting to a visual shift to the left, they felt that their hands were closer together. The results show that the subject's position sense had indeed been altered to the point that he misperceived the location of his adapted hand with respect to the location of his other hand.

The observations with the reducing lens mentioned earlier at first seem to contradict this finding. Although vision was dominant over touch when both senses were active, in that experiment touch returned to normal as soon as the subject closed his eyes. Would the change in touch outlast the conflict situation if the conflict situation were continued for a longer time? This question was investigated in experiments by one of us (Rock) in collaboration with Arien Mack, A. Lewis Hill and Laurence Adams. Over a 30-minute period the subject handled squares of various sizes while looking at them through a reducing lens [*see top illustration on opposite page*]. A cloth prevented the subject from seeing his hand during this time.

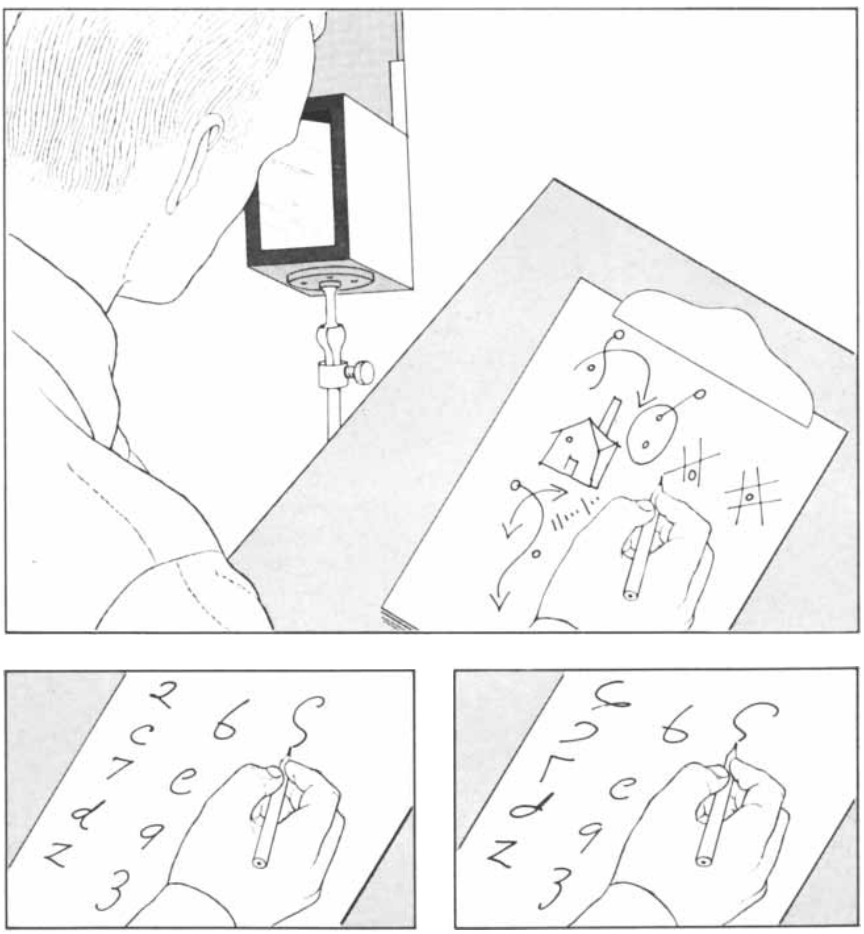
Two matching tests administered before and after the 30-minute period showed that the subject's perception of size had changed. In one test we showed him a standard square that he could see but not touch and asked him to select by touch a matching square from a set he could touch but not see. After the 30-minute period with the reducing lens subjects typically selected by touch a larger square than before as matching the visual standard. When they were given a standard square to touch without being able to see it, they typically chose a smaller matching square from a set that was displayed visually. (In both tests the squares were coated with luminous paint and presented in the dark so that there would be no familiar objects to which a square could be compared.)

Both results demonstrate that after exposure to the conflicting information the subject matches felt size with seen size differently than he did before. For a felt object and a seen object to seem equal to him the visual object has to be smaller than before. These results do not reveal, however, which sense has changed to yield the new match. Did the subject pick a smaller seen square because seen objects now looked larger or because felt objects now felt smaller? Although the immediate result of the conflict between vision and touch is a dominance of vision, the correct information provided by touch may still be having an effect, even if it does not enter the consciousness. In that case the square might look larger after adaptation, perhaps ultimately reaching its true size. If, on the other hand, the visual size of the square were to serve as the crucial information and the square were to come to feel smaller than it is, we would have an example consistent with all our other findings.

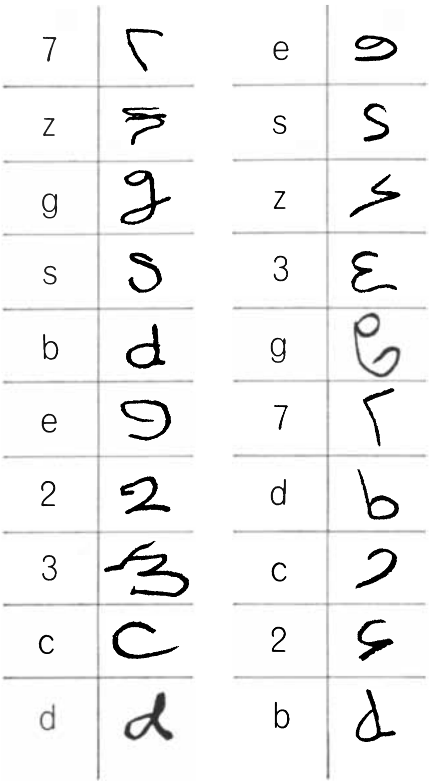
To determine whether it was vision or touch that had changed, we used a "remembered standard" test. In the test of visual size we first had the subject practice looking at a one-inch square and then matching it visually from immediate memory. Then, after the 30 minutes of looking through the reducing lens, we asked him to select visually a square the same size as he remembered the standard square to be. The selection was again done in the dark with luminous squares.

If visual size has undergone a change, the subject should now (without the reducing lens) select a smaller square as matching the standard one than he did before the exposure to the conflict situation; the smaller square should now look larger than it is. The result, however, was that the subject selected a square that was the same size on the average as the one he chose before exposure to the conflict situation. In other words, there was no change in the visual perception of size.

We used a similar procedure to find out if touch had changed. Before exposure to the conflict the subject practiced feeling the standard square and matching it by touch from immediate recollection. After exposure to the conflict situa-



REVERSING-PRISM EXPERIMENTS called for a subject to doodle (*top*) while looking through a prism that reversed right and left. Before exposure to the prisms every subject wrote numbers and letters as shown at bottom left; after use of the prisms the subjects often wrote as shown at bottom right. In many cases the subjects thought the letters they had written backward were normal and letters they had written normally were backward.



WRITING ABERRATIONS of two subjects after exposure to reversing prisms are represented. The letters and numbers they were asked to write are at left; what they wrote is at right. In the second sample only the *S* is normal; that was the only letter the subject thought she had written backward.

tion he selected by touch alone a square that he felt was the same size as the previously experienced one-inch square. The great majority of subjects chose a larger square as matching the standard than they had before. The larger square now felt smaller than it was.

What would happen if there were a more dramatic conflict between vision and touch, as in experiments on inversion or reversal of the retinal image? If a subject looks through reversing prisms, for example, while moving his hand from left to right, could he be misled into feeling it as moving right to left? An experiment undertaken by one of us (Harris) and Judith Harris showed that vision is powerful enough to accomplish even this radical a misperception.

We had the subject look through a right-angle prism, which acts like a mirror, reversing the visual field right for left [*see illustration on preceding page*]. The prism was attached to a rigid frame. The subject watched his hand through the prism, while drawing and doodling, for 15 minutes a day on four different days. For reasons that will soon become evident, he was not allowed to write or see any letters or numbers while looking through the prism.

For most subjects there was no immediate visual capture. When they felt their hand move in one direction, they saw it stubbornly going in the opposite direction. The felt hand and the seen hand seemed to be separate things.

Within a matter of minutes, however, visual capture took over. Most subjects no longer experienced any discrepancy between how they saw their hands move and how they felt them move. They no longer had trouble drawing or doodling or reaching for locations indicated by the experimenter.

In order to determine if there was an aftereffect of this visual capture, we hit on the following simple procedure. At the end of each prism period we slid a metal plate in front of the prism, blocking the subject's view. We then asked him to quickly write 10 letters and numbers as we dictated them. We had previously told the subjects that the adaptation procedure might make them write an occasional letter backward and that they must be sure to tell us whenever they thought they had done so.

Actually a subject could have two kinds of misperception. He could believe a letter was normal when it was really backward, and he could believe a letter was backward when it was really normal. We found that both kinds of misperception occurred; every one of our eight subjects made at least one such error. In fact, immediately after looking through the prism the subjects misperceived fully 30 percent of the letters and numbers they wrote. (In the pretests given before the use of the prism, of course, no subject ever misperceived what he was writing.) The results, some of which are shown in the illustration on this page, are particularly surprising in view of the fact that writing normal letters and numbers is such a highly practiced skill.

Our experiments all show, then, that when a subject's sense of touch conveys information that disagrees with what he is seeing, the visual information determines his perception. What happens during such a conflict to the information the sense of touch is providing? Is it blocked before it reaches the brain, is it ignored or is it transformed? After sufficient exposure to an intersensory disagreement there is a change in the sense of touch itself. Since the subject continues to misperceive by touch even with his eyes closed, he cannot be blocking or ignoring the information provided by touch. It is therefore a reasonable guess that the information is not blocked or ignored when his eyes are open either. Instead it must be transformed into new touch perceptions that are consistent with visual perception.

The further implications of our experiments are less clear, particularly for situations that are more normal than the restricted conditions under which our subjects worked. What kind of adaptation to altered retinal images takes place when a subject can move about freely and can see much more of his environment than our subjects saw? The experimental data are still fragmentary enough to allow us to disagree on this point.

One of us (Rock) believes visual perception can change if a person subjected to optical distortion has adequate visual information about the distortion. For example, the world might look upside down through reversing prisms, but if the subject can see his own body—the image of which would also be inverted—he realizes that the world is not upside down in relation to himself. Similarly, if a seated subject looks at a straight vertical line through prisms that at first make it appear curved and he then stands up, the appearance of the line will change in a way that would not be the case if the line were really curved. Hence he may come to see that the line is straight. This argument maintains that a change in visual perception can occur but acknowledges that information from touch alone is insufficient to cause such a change.

The other of us (Harris) thinks all substantial adaptation to optical distortions probably results from changes in the sense of the position of the limbs, the head or the eyes. If a person felt that his arms and legs were where he saw them through inverting or reversing prisms, he would make responses like those reported by Stratton and Kohler. If he felt that his eyes were pointing directly ahead or tracing a straight path when they were actually pointing somewhat to one side or tracing a curved path, he would show the kind of adaptation to displacement or curvature that is found in some other experiments.

Our disagreement does not affect the basic points demonstrated by our separate experiments. Those points are that there is no convincing evidence for the time-honored theory that touch educates vision and that there is strong evidence for the contrary theory. Further experiments along these lines can be expected to clarify the points that remain obscure.

SHOULD WE ALSO FLOOD THE SISTINE CHAPEL SO TOURISTS CAN GET NEARER THE CEILING?

EARTH began four billion years ago and Man two million. The Age of Technology, on the other hand, is hardly a hundred years old, and on our time chart we have been generous to give it even the little line we have.

It seems to us hasty, therefore, during this blip of time, for Man to think of directing his fascinating new tools toward altering irrevocably the forces which made him. Nonetheless, in these few brief years among four billion, wilderness has all but disappeared. And now these:

1) There are proposals *still* before Congress to "improve" Grand Canyon. If they succeed, two dams could back up artificial lakes into 93 miles of canyon gorge. This would benefit tourists in power boats, it is argued, who would enjoy viewing the canyon wall more closely. (See headline.) Submerged underneath the tourists would be part of the most revealing single page of earth's history. The lakes would be as deep as 600 feet (deeper for example, than all but a handful of New York buildings are high) but in a century, silting would have replaced the water with that much mud, wall to wall.

There is no part of the wild Colorado River, the Grand Canyon's sculptor, that would not be maimed.

Tourist recreation, as a reason for the dams, is in fact an afterthought. The Bureau of Reclamation, which has backed them, calls the dams "cash registers." It expects they'll make money by sale of commercial power.

They will not provide anyone with water.

2) In Northern California, during only the last 115 years, nearly *all* the private virgin redwood forests have been cut down.

Where nature's tallest living things have stood silently since the age of the dinosaurs, there is, incredibly, argument against a proposed park at Redwood Creek which would save a mere 2% of the virgin growth that was once there. For having cut so much and taken the rest for granted, the lumber companies are eager to get on with business. They see little reason why they should not.

The companies have said tourists want only enough roadside trees for the snapping of photos. They offered to spare trees for this purpose, and not much more. The result would remind you of the places on your face you missed while you were shaving.

3) And up the Hudson, there are plans for a power complex —a plant, transmission lines, and a reservoir near and on Storm King Mountain—effectively destroying one of the last wild and high and beautiful spots near New York City.

4) A proposal to flood a region in Alaska as large as Lake Erie would eliminate at once the breeding grounds of more wildlife than conservationists have preserved in history.

5) In San Francisco. real estate interests have for years been filling a bay that made the city famous, putting tract houses over the fill; and now there's a new idea—still more fill, enough for an air cargo terminal as big as Manhattan.

There exists today a mentality which can conceive such destruction, giving commerce as ample reason. For 74 years, the Sierra Club (now with 48,000 members) has opposed that mentality. But now, when even Grand Canyon is endangered, we are at a critical moment in time.

This generation will decide if something untrammelled and free remains, as testimony we had love for those who follow.

We have been taking ads, therefore, asking people to write their Congressmen and Senators; Secretary of the Interior Stewart Udall; The President; and to send us funds to continue the battle. Thousands *have* written, but meanwhile, Grand Canyon legislation *still* stands a chance of passage. More letters are needed and much more money, to help fight the notion that Man no longer needs nature.*

David Brower, Executive Director
Sierra Club
Mills Tower, San Francisco

- ☐ Please send me more details on how I may help.
- ☐ Here is a donation of $________ to continue your effort to keep the public informed.
- ☐ Send me "Time and the River Flowing," famous four color book which tells the complete story of Grand Canyon, and why T. Roosevelt said, "leave it as it is." ($25.00)
- ☐ Send me "The Last Redwoods" which tells the complete story of the opportunity as well as the destruction in the redwoods. ($17.50)
- ☐ I would like to be a member of the Sierra Club. Enclosed is $14.00 for entrance and first year's dues.

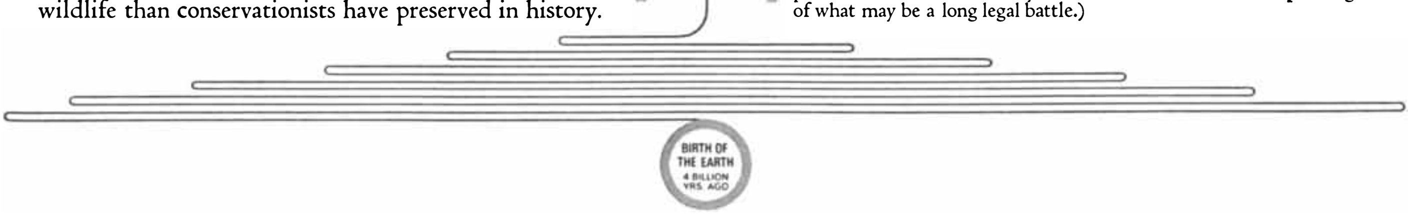
Name________________________________

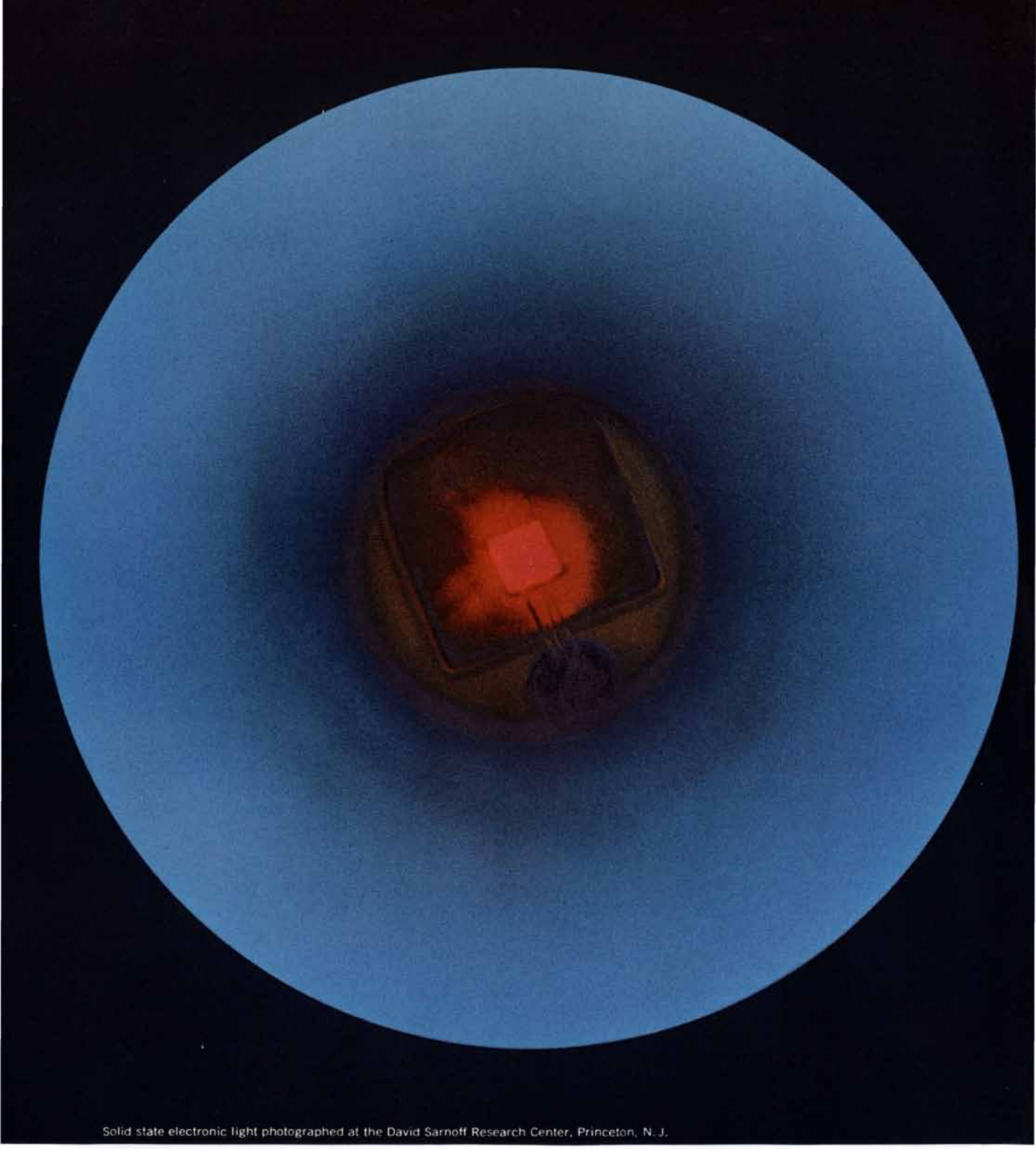
Address______________________________

City______________State__________Zip______

*The Sierra Club, founded in 1892 by John Muir, is nonprofit, supported by people who, like Thoreau, believe "In wildness is the preservation of the world." The club's program is nationwide, includes wilderness trips, books and films—as well as such efforts as this to protect the remnant of wilderness in the Americas. There are now twenty chapters, branch offices in New York (Biltmore Hotel), Washington (Dupont Circle Building), Los Angeles (Auditorium Building), Albuquerque, Seattle, and main office in San Francisco.

(Our previous ads, urging that readers exercise a constitutional right of petition to save Grand Canyon from two dams which would have flooded it, produced an unprecedented reaction by the Internal Revenue Service threatening our tax deductible status. IRS called the ads a "substantial" effort to "influence legislation." Undefined, these terms leave organizations like ours at the mercy of administrative whim. [The question has not been raised with organizations that favor Grand Canyon dams.] So we cannot now promise that contributions you send us are deductible—pending result of what may be a long legal battle.)



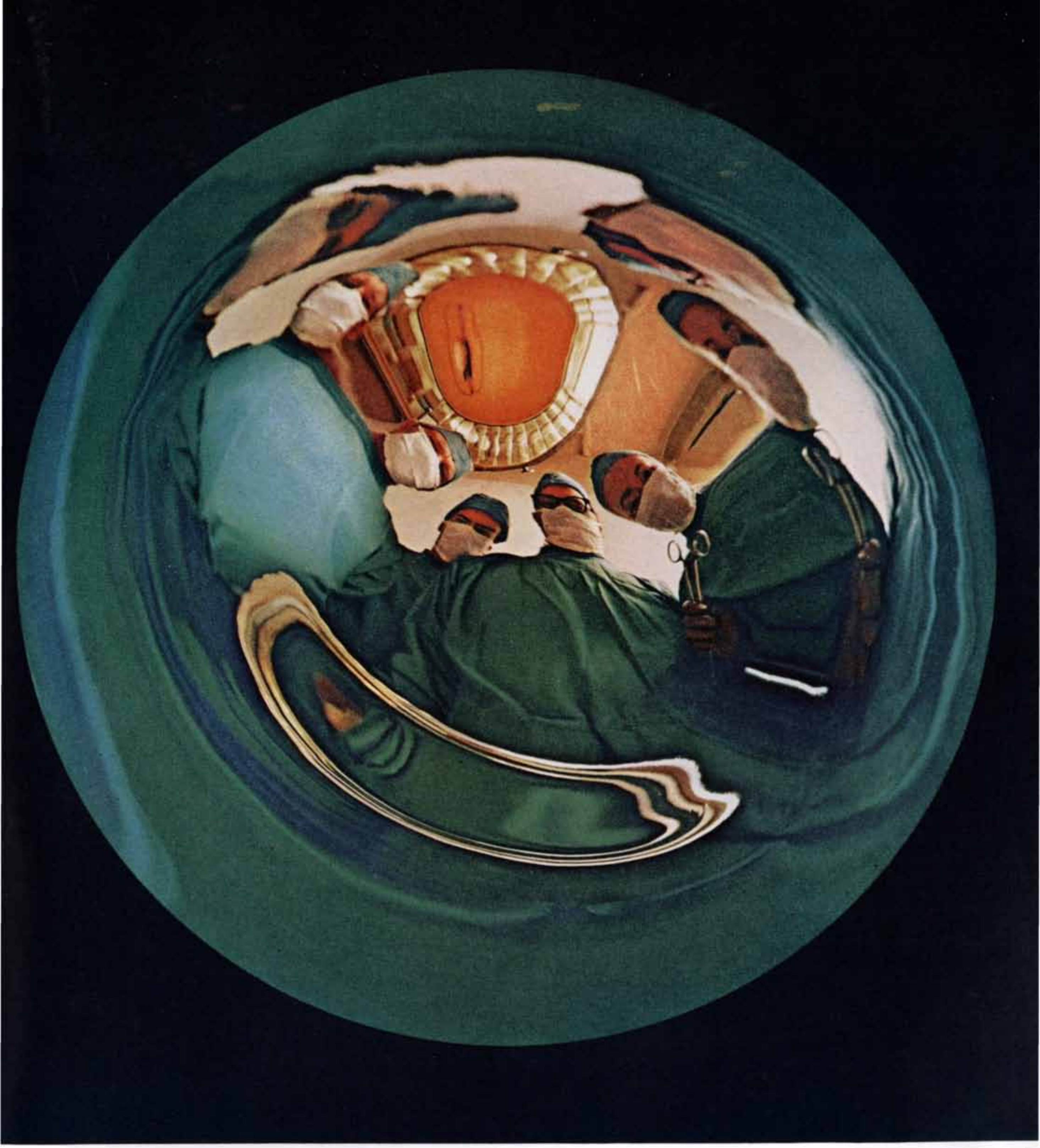


Solid state electronic light photographed at the David Sarnoff Research Center, Princeton, N. J.

RCA perfects a new source of light...and also

RCA scientists are working on a new kind of light that comes directly from a solid state device called an optical diode. There is *no* bulb. Initially, it will be used to "read" information from punched cards into a computer. But someday it may light your home—and it will never burn out.

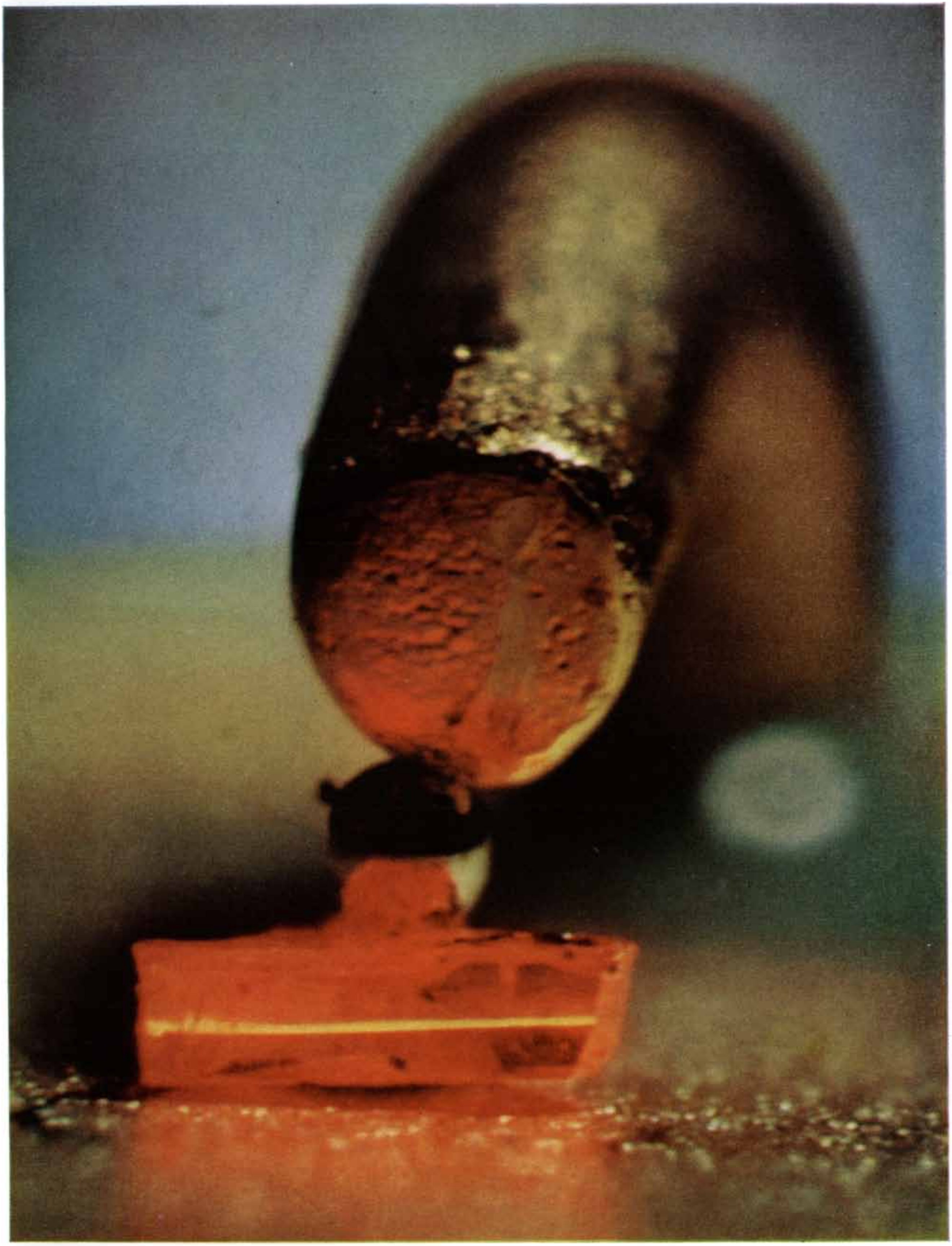
In another area of light, RCA scientists have added immeasurably to the lifespan of a new kind of gas laser. It will work for thousands of hours and can now be used to help save lives in surgery. Tomorrow this laser may be used to communicate with men on Mars.



helps light the way to medical breakthroughs.

RCA engineers are constantly pioneering better ways of doing things—electronically—from research in light to advanced Spectra 70 computers to worldwide satellite communication systems. And we can apply these skills to help your business grow.

RCA The Most Trusted Name in Electronics



CRYSTAL OF GALLIUM PHOSPHIDE emits red light when an external voltage is applied across it. The crystal is divided into two semiconducting regions, one consisting of *n*-type material (*top half*), in which electrons predominate, and the other consisting of *p*-type material (*bottom half*), in which electron "holes" predominate. The light is emitted as the result of the recombination of electrons and holes at the junction between the two regions. The junction appears yellow in the photograph because the light from it has overexposed the color film. The negative electrode (*top*) is a gold-plated wire about .02 inch in diameter. It is connected to the crystal by a ball of solder. The crystal diode is mounted on a gold-plated disk (*bottom*), which serves as the positive electrode.

LIGHT-EMITTING SEMICONDUCTORS

A variety of electron-exciting mechanisms can be used to induce luminescence in crystals of semiconducting compounds. Among the applications of this capability are efficient solid-state lasers

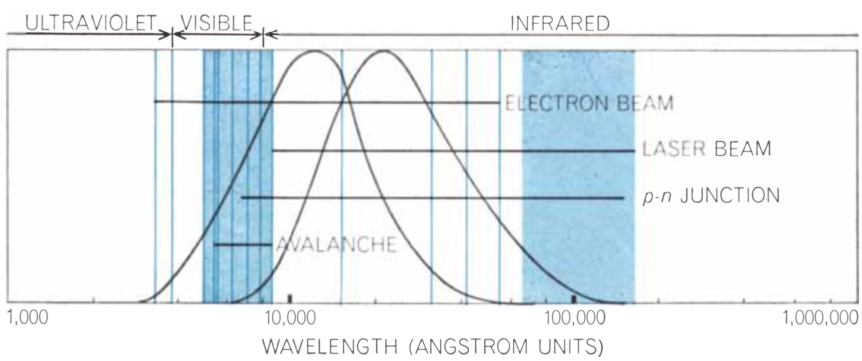
by Frederick F. Morehead, Jr.

Research aimed at developing an efficient solid-state source of visible radiation has undergone a major shift of emphasis since the late 1950's. At that time the most promising approach appeared to involve the Destriau effect, a property of certain phosphorescent powders discovered by the French physicist Georges Destriau in 1936. The most common technique for exploiting the Destriau effect was to spread a thin layer of phosphorescent powder (similar to the coating on the inside of a television picture tube) between the parallel plates of a transparent capacitor; by applying a high alternating voltage across the resulting "sandwich" the phosphors could be made to emit a steady glow [see "Electroluminescence," by Henry F. Ivey; SCIENTIFIC AMERICAN, August, 1957]. Owing to the high voltages and high frequencies required for this method to produce light that is bright enough for most purposes, however, such electroluminescent panels have not lived up to their early promise, and the state of the art is substantially what it was 10 years ago.

In the past five years the main focus of attention in the field of solid-state electroluminescence has centered on the study of single crystals of various semiconducting compounds. The trend in this direction received its greatest impetus in 1962 when workers at the Lincoln Laboratory of the Massachusetts Institute of Technology discovered that a simple junction diode consisting of a crystal of semiconducting gallium arsenide was an efficient emitter of infrared radiation. Later that year groups at the Lincoln Laboratory, the General Electric Company and the International Business Machines Corporation announced almost simultaneously that each had succeeded in obtaining laser light from gallium arsenide diodes.

Today semiconducting light sources are available in a wide range of wavelengths, extending from the near-ultraviolet region of the electromagnetic spectrum to the far-infrared region [*see illustration below*]. Many of the semiconducting compounds are suitable for service in lasers. Although difficulties remain, it seems likely that just as the transistor, with its quick response, high reliability, long life and small size, has replaced the vacuum tube for many purposes, so the light-emitting semiconductor will eventually, and for similar reasons, replace small incandescent lamps, particularly where such lamps are used in conjunction with predominantly transistorized devices—for example as circuit indicators or display devices in electronic computers. In addition, infrared-emitting diodes of gallium arsenide coupled with solid-state detectors of pure silicon may in the not too distant future replace the heavy cables that link one part of a large computer to another, thereby cutting costs and increasing the speed of data transmission. The impact of semiconductor light sources is likely to be less in general lighting, where large incandescent lamps, fluorescent lamps and various gas-discharge devices occupy an apparently unassailable position at present.

It is important at the outset to distinguish between the two principal mechanisms for generating visible light: incandescence and luminescence. Incandescence is the broad-band radiation emitted by matter as a consequence of the thermal motion of its constituent atoms. To obtain incandescence one simply pours energy into a piece of suitable material, say by passing an electric current through a tungsten wire. The electric energy is converted into thermal motion, which is measured in terms of temperature. The higher the temperature, the greater the total amount of radiation that is produced and the greater the fraction of the total that is in the form of high-energy photons, or light



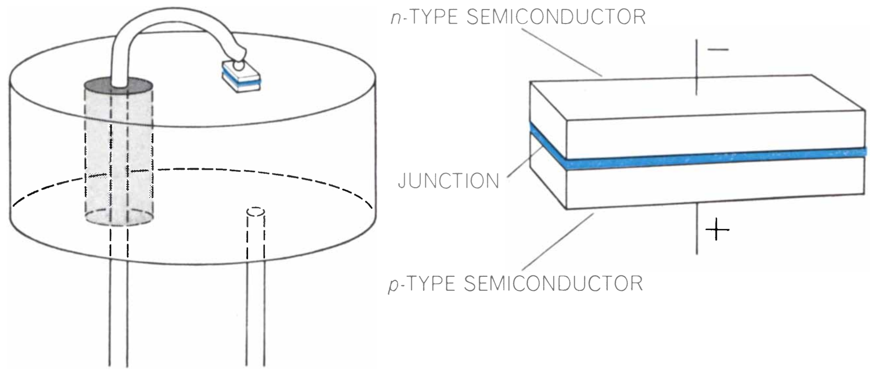
WAVELENGTHS SPANNED by currently available semiconductor light sources are indicated by color in this schematic representation of a portion of the electromagnetic spectrum. The broad-band emission spectra for two incandescent lamps (*gray curves*) are shown for comparison; the maximum filament temperatures of the lamps are 3,100 degrees centigrade (*left*) and 1,400 degrees C. (*right*). The black horizontal lines show the ranges covered by four different methods used to excite luminescence in semiconducting crystals.

I	II	III	IV	V	VI	VII
3 LITHIUM Li	4 BERYLLIUM Be	5 BORON B	6 CARBON C	7 NITROGEN N	8 OXYGEN O	9 FLUORINE F
11 SODIUM Na	12 MAGNESIUM Mg	13 ALUMINUM Al	14 SILICON Si	15 PHOSPHORUS P	16 SULFUR S	17 CHLORINE Cl
29 COPPER Cu	30 ZINC Zn	31 GALLIUM Ga	32 GERMANIUM Ge	33 ARSENIC As	34 SELENIUM Se	35 BROMINE Br
47 SILVER Ag	48 CADMIUM Cd	49 INDIUM In	50 TIN Sn	51 ANTIMONY Sb	52 TELLURIUM Te	53 IODINE I
79 GOLD Au	80 MERCURY Hg	81 THALLIUM Tl	82 LEAD Pb	83 BISMUTH Bi	84 POLONIUM Po	85 ASTATINE At

SHORT FORM of the periodic table contains all the elements that combine in pairs to form semiconducting binary compounds suitable for use as light sources. The elements that so combine are in identically colored columns. The best light-emitters are compounds from Group II and Group VI (sometimes called II–VI compounds) and those from Group III and Group V (III–V compounds). Each element is accompanied by its atomic number: the number of protons in its nucleus or the number of electrons bound by them.

WAVELENGTH (ANGSTROM UNITS)	SEMICONDUCTING COMPOUND	SYMBOL	TYPE	METHOD OF EXCITATION	EFFICIENCY (PERCENT)
3,300	ZINC SULFIDE	Zn S	II–VI	ELECTRON BEAM	6
4,900	CADMIUM SULFIDE	Cd S	II–VI	ELECTRON BEAM	25
3,800	ZINC OXIDE	Zn O	II–VI	ELECTRON BEAM	?
4,900 – 6,800	CADMIUM SULFIDE-SELENIDE	Cd $S_x Se_{1-x}$	II–VI	ELECTRON BEAM	6
5,400	ZINC TELLURIDE	Zn Te	II–VI	AVALANCHE	1
5,500 , 7,000	GALLIUM PHOSPHIDE	Ga P	III–V	*p-n* JUNCTION	.01 , 1
6,200	ZINC SELENIDE-TELLURIDE	Zn $Se_x Te_{1-x}$	II–VI	PHOTO-*p-n* JUNCTION	18
6,300 – 8,500	GALLIUM ARSENIDE-PHOSPHIDE	Ga $As_x P_{1-x}$	III–V	*p-n* JUNCTION	20
7,000 – 8,500	ZINC-CADMIUM TELLURIDE	$Zn_x Cd_{1-x}$ Te	II–VI	*p-n* JUNCTION	6
7,800	CADMIUM SELENIDE	Cd Se	II–VI	ELECTRON BEAM	6
8,500	CADMIUM TELLURIDE	Cd Te	II–VI	*p-n* JUNCTION ELECTRON BEAM	12
8,500	GALLIUM ARSENIDE	Ga As	III–V	*p-n* JUNCTION ELECTRON BEAM AVALANCHE LASER BEAM	80
15,000	GALLIUM ANTIMONIDE	Ga Sb	III–V	*p-n* JUNCTION ELECTRON BEAM	?
31,000	INDIUM ARSENIDE	In As	III–V	*p-n* JUNCTION ELECTRON BEAM LASER BEAM	?
41,000	MERCURY-CADMIUM TELLURIDE	$Hg_x Cd_{1-x}$ Te	II–VI	LASER BEAM	?
54,000	INDIUM ANTIMONIDE	In Sb	III–V	*p-n* JUNCTION ELECTRON BEAM LASER BEAM	?
65,000 – 165,000	LEAD-TIN TELLURIDE	$Pb_x Sn_{1-x}$ Te	IV–VI	LASER BEAM *p-n* JUNCTION	?
65,000 – 165,000	LEAD-TIN SELENIDE	$Pb_x Sn_{1-x}$ Se	IV–VI	LASER BEAM *p-n* JUNCTION	?

MOST EFFICIENT light-emitting semiconductors are listed in this table, along with the characteristic wavelength at which they radiate, the groups they represent and the methods used to promote their electrons to excited states. The efficiency of each source is equal to the ratio of the energy of the light emission (output) to the energy of excitation (input). All the emissions listed were obtained at 77 degrees Kelvin (degrees centigrade above absolute zero) except the red band of gallium phosphide at 7,000 angstrom units, which was obtained at room temperature (300 degrees K.). The emissions that are suitable for use in lasers are shown in color.



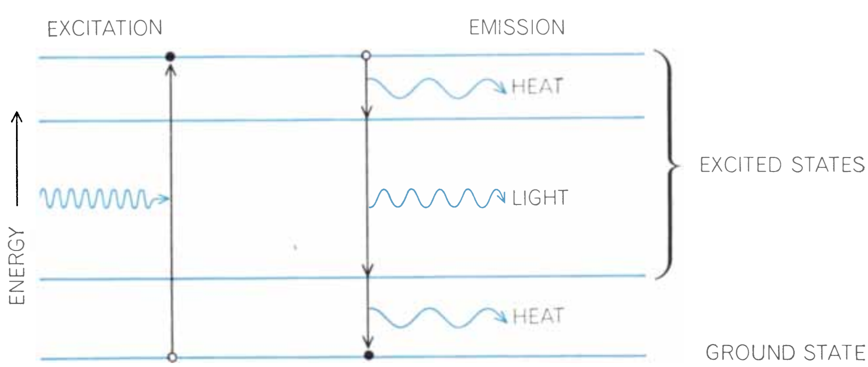
P-N-JUNCTION DIODE of the same general type as the one in the photograph on page 108 is shown in its mounting at left and greatly enlarged at right. The diode is said to have a forward bias, that is, the effect of the external voltage is to increase the rate at which electrons diffuse into the positive (*p*) side of the junction and holes into the negative (*n*) side. Light is generated in the plane of the junction (*color*) by the recombination of these "minority" charge-carriers. An actual diode crystal is about a third of a millimeter on a side.

quanta. The lifetime of an incandescent lamp is normally determined by the rate of evaporation of atoms from the heated filament. A typical household lamp with a rated life of 500 hours and a maximum filament temperature of 2,600 degrees centigrade converts about 80 percent of its input electrical power to radiation; most of the output is in the infrared and only about 9 percent is visible to the human eye. An incandescent indicator lamp designed to run directly from transistor circuits and to last about 10,000 hours burns at 1,400 degrees C. and produces visible radiation with an efficiency of .5 percent.

Luminescence, on the other hand, is the narrow-band radiation emitted by matter as a result of a change in energy states (usually of electrons) when the sample is excited by an external source of energy that does not significantly change the temperature of the sample. The luminescent system may be isolated atoms in a gas that has been excited by an electric discharge, or it may consist of impurity atoms in a solid that has been excited by high-energy photons or electrons. High-pressure mercury-discharge lamps, fluorescent lamps and television picture tubes are among the practical embodiments of luminescence. In each case some of the input energy causes electrons to occupy excited energy states [*see bottom illustration on this page*]. The electrons involved in luminescence are either the orbital electrons of isolated atoms in a gas or a solid, or the binding electrons in a solid. The spontaneous return of the excited electron to a lower energy state can be accompanied by the emission of a photon, which carries away the difference in energy between the upper and the lower energy state. This energy difference is proportional to the frequency of the emitted light. If a large enough number of the excitable electrons can be "pumped" into the excited states, a photon produced by the return of one such electron to its ground state will stimulate the return of others and a "standing" wave of intense electromagnetic radiation will be produced within the walls of the solid. It is this stimulated emission of radiation that is basic to the operation of any laser. The light waves that emerge from such a laser will be extremely monochromatic (all at the same wavelength) and coherent (all in step). I shall return to the topic of semiconductor lasers after first discussing the relation between luminescence and the electrical properties of semiconducting solids.

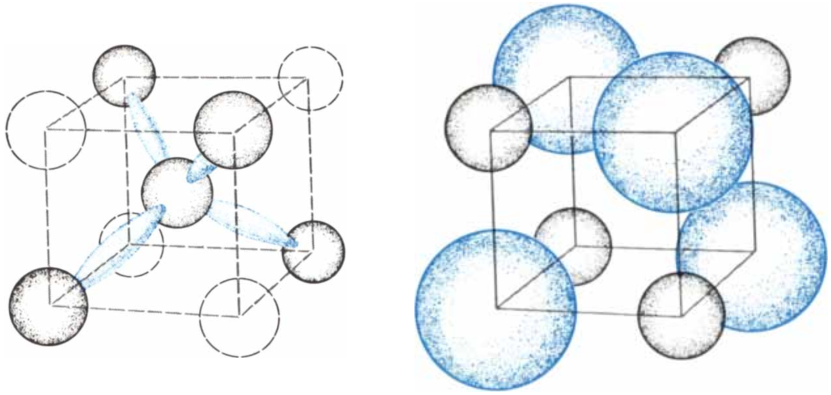
The forces that bind atoms to one another in a solid to form the three-dimensional array called a crystal lattice are intimately related to electrons. The particular electrons involved are those that would occupy the outermost energy orbits if the atoms were isolated. In the case of an elementary solid, such as the semiconducting element germanium, these electrons, four to a germanium atom, form negatively charged clouds around and between the positively charged cores of the atoms [*see illustration on next page*]. The electrostatic attraction between the negative electron clouds and the positive atomic cores is called a covalent bond; it is the glue that holds the system together. The energy levels of the inner electrons are essentially the same as they are in isolated atoms, whereas those levels available to the binding electrons spread into almost continuous bands of levels associated with the entire solid (which can be regarded as a giant molecule) rather than with individual atoms. The number of allowed states for these binding electrons in any band divided by the number of atoms in the solid is usually two. This rule means that at low temperatures a band is either completely filled, half-filled or empty. If the highest energy band is completely filled and the next highest allowed band is completely empty, and if the two bands are separated by an energy gap of finite width, then the solid is an insulator at low temperatures. There can be no net displacement of charge in either a completely filled band or a completely empty one. If the highest occupied band is half-filled, or if it overlaps in energy the next highest allowed band, the electrons can move in the solid in the presence of an electric field; the solid is then called a metal.

In the case of compound solids there is a net positive or negative charge on



ENERGY-LEVEL DIAGRAM of an electron in an isolated atom (for example, in a gas) illustrates the general mechanism of luminescence. An external excitation, which can be a high-energy photon, or light quantum (*left*), promotes the electron from its ground state to a higher energy state. When the excited electron returns spontaneously to a lower energy state (*right*), the energy difference between the two states can be carried away in the form of another photon. Relaxation processes following both excitation and emission produce heat, so that the energy of exciting photon is always greater than that of emitted photon.

techniques: by injecting electrons into a material in which holes predominate (a positive, or *p*-type, semiconductor), by injecting holes into a material in which electrons predominate (a negative, or *n*-type, semiconductor) or by injecting both holes and electrons into an insulating region. If this injection of "minority" carriers into the efficient recombination zone occurs as the result of passing current through the structure, one is then dealing with the direct conversion of electrical energy into light, or electroluminescence.



ELECTRONS INVOLVED in luminescence in most semiconducting solids are the binding electrons that hold the crystal lattice together. In a solid with covalent bonds, typified here by germanium (*left*), these binding electrons form negatively charged clouds (*color*) between the positively charged cores of the atoms (*black*). In a solid with ionic bonds, typified here by sodium chloride (*right*), the binding electrons are outermost electrons of both the positively charged sodium ions (*black*) and the negatively charged chlorine ions (*color*).

The most effective system for injecting minority carriers into a semiconducting material is the *p-n* junction. As the name implies, one side of the junction (the *n* side) is conducting by means of electrons contributed to the conduction band by donor impurities, whereas the other side (the *p* side) is conducting by means of holes contributed to the valence band by acceptor impurities. The shape of the bands at the junction and the occupancy of the donor and acceptor states is shown in the lower illustration on the opposite page. The origin of the potential barrier at the junction can be explained briefly as follows: In order to establish equilibrium between the two sides of the junction, electrons will diffuse from the *n* side to the *p* side, whereas holes will diffuse from the *p* side to the *n* side. The vacated donors on the *n* side form a positively charged region; the empty acceptors form a corresponding negatively charged region on the *p* side. The electric field produced by this separation of charge opposes the diffusion process, and at equilibrium no further net change occurs. An external voltage applied to the junction to lower the potential barrier increases the rate at which electrons diffuse into the *p* side and holes into the *n* side. Such a junction is said to have a forward bias. Recombination of the injected minority carriers (electrons on the *p* side, holes on the *n* side) occurs with a loss in energy roughly equal to the energy of the band gap.

This energy loss can be radiative, in which case a photon is emitted, or nonradiative, in which case a large number of vibrational quanta, called phonons, appear in the crystal. The current is driven by the thermal motion of the "majority" carriers (electrons on the *n* side, holes on the *p* side). The applied voltage determines the height of the barrier and hence the rate at which it will be surmounted by the holes and electrons. If every injected hole or electron leads to the emission of a photon

the cores of the atoms of the two different elements. In this case the electrostatic attraction between the cores themselves also contributes to the forces that hold the solid together. All the outer electrons for both ions are more or less tightly held so that the electron cloud between the ions is very thin; almost all the binding force is ionic rather than covalent. Both types of bonding are present in all compound solids, ranging from almost completely ionic for a compound of elements from Group I and Group VII in the periodic table to almost completely covalent for a compound of two elements both of which are in Group IV [*see top illustration on page 110*].

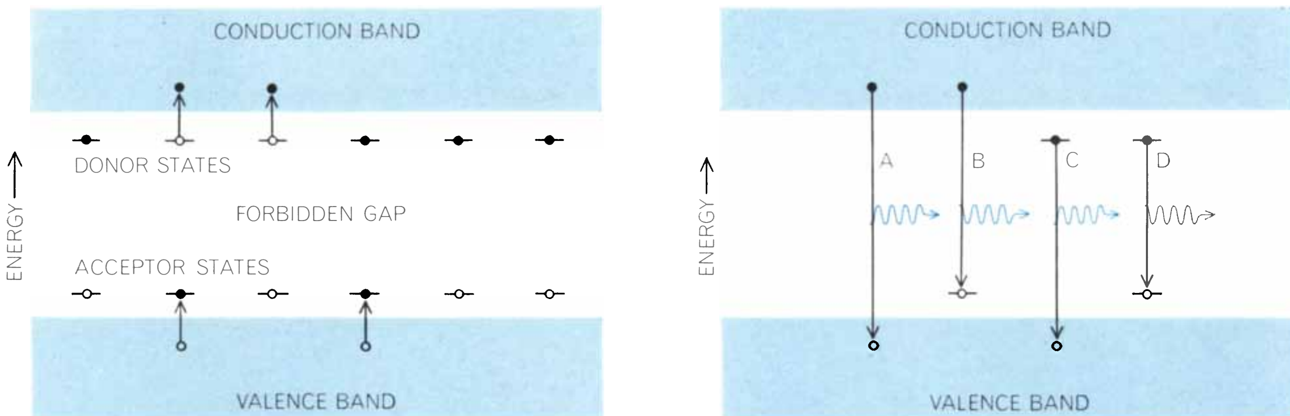
Semiconductors without impurities are insulators with a narrow "forbidden" gap, so that at room temperature a significant number of the binding electrons have been thermally promoted from the highest normally filled band (the valence band) into the normally empty band (the conduction band). At this temperature the conduction-band electrons can carry a current through the solid. The "holes," or empty states, in the valence band also conduct, moving in an electric field as positive charge carriers in a direction opposite to that of the electrons. Insulators with wider gaps require the presence of impurities to become semiconducting at normal temperatures [*see upper illustration on opposite page*]. A donor impurity is one that has more valence electrons than the host atom for which it substitutes; it can donate these excess electrons to the conduction band. In general the ground, or lowest, state of the extra electrons will lie within the forbidden gap, usually close to the conduction band. If the energy difference is not too great, some of the electrons will be in the conduction band at normal temperatures and contribute to the conductivity of the solid.

An acceptor impurity has fewer electrons than the atom for which it substitutes in the host lattice; it can accept the missing electrons to complete its bonding requirements from the valence band, leaving holes behind. The excited state to which the valence electrons must be promoted (or the ground state from which the hole must be freed) also lies in the forbidden gap, usually close to the valence band. If the semiconductor contains both donor and acceptor impurities, the system can lower its energy either when a free electron falls into an acceptor level occupied by a hole or when a free hole recombines with an electron in a filled donor site. In either case the donor has compensated the effect of the acceptor and the solid will be an insulator at room temperature for exactly equal numbers of added donors and acceptors.

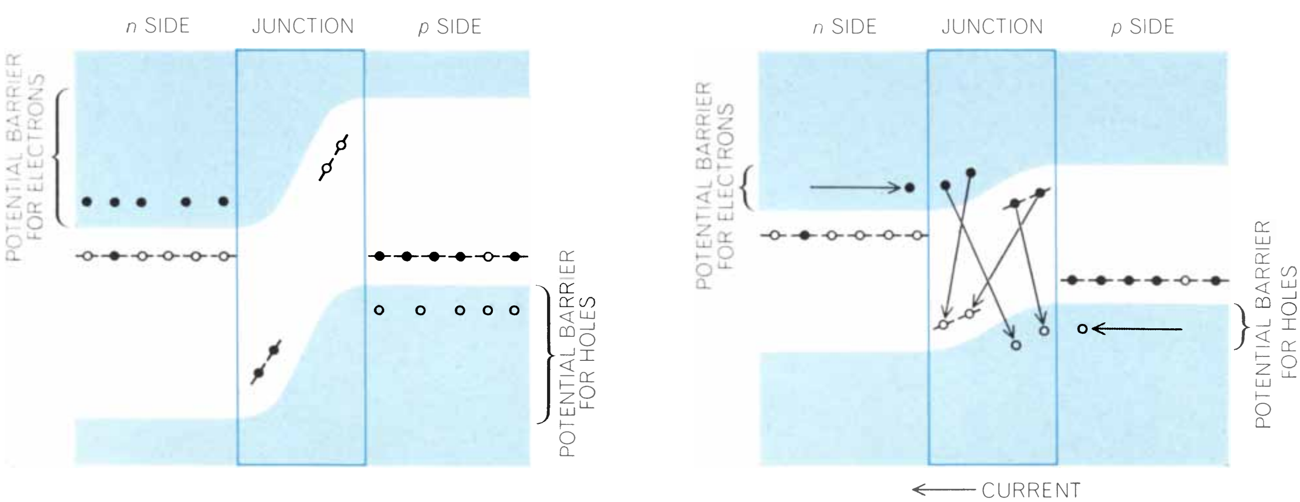
The recombination of an electron and a hole in a semiconductor, either directly across the gap or at a donor or acceptor impurity site, can be accompanied by the emission of a photon. The energy lost by the electron is acquired by the photon. It is this type of luminescent process that takes place in a light-emitting semiconductor. An efficient semiconductor light source combines (1) a fast, radiative recombination path for the holes and the electrons and (2) a suitable structure for introducing electrons into excited states. One can accomplish these ends by three different whose energy is that of the band gap, then for applied voltages less than the band-gap energy in electron volts (eV) the radiative output exceeds the electrical input. Like a heat pump, the forward-biased *p-n* junction removes thermal energy from the crystal lattice and ultimately gives up this energy in the form of radiation. The radiative output can exceed the electrical input to the extent that the device refrigerates its surroundings.

Ideally the efficiency of a *p-n* junction is limited only by the first and second laws of thermodynamics. In practice, however, electrical energy losses (usually at the contacts) and the reabsorption of the light before it escapes the crystal reduce, to about 20 percent or less at low currents, the efficiency with which even the best of such junctions convert their electrical input to an external optical output. The applied voltage often is significantly less than the energy of the photon in electron volts, particularly at low currents. A major problem is extracting the internally generated light without reabsorption. One solution (which unfortunately is not always available) is to cause the onset of stimulated emission in the junction.

P-n-junction injection electroluminescence in some semiconductors is extraordinarily efficient, with every injected minority carrier resulting in the internal emission of a photon. Such semiconductors, which are compounds from Group III and Group V of the periodic table with gaps of less than 1.8 eV, are characterized by "direct" recombination transitions. This means that an electron at the bottom of the lowest conduction band and a hole at the top of the highest filled valence band have the same momentum. A transition of the conduction electron to the hole in the valence band can occur directly with the emission of a photon, conserving both the



ENERGY-BAND DIAGRAMS of a typical semiconducting solid illustrate the role of impurities in promoting the conduction of an electric current. The current can be carried either by electrons in the normally empty conduction band or by electron holes in the normally filled valence band (*left*). "Donor" impurities with energy levels in the "forbidden" gap between the two bands give electrons to the conduction band, whereas "acceptor" impurities in the forbidden gap give holes to the valence band. An *n*-type semiconductor has more donors than acceptors; a *p*-type semiconductor has more acceptors than donors. Radiative recombination (*right*) can occur between a free electron in the conduction band and a free hole in the valence band (*A*), between a free electron and a hole at an acceptor (*B*), between a free hole and an electron at a donor (*C*) or between an electron at a donor and a hole at an acceptor (*D*).



ENERGY BANDS ARE BENT at the junction between an *n*-type semiconductor and a *p*-type semiconductor. In an unbiased *p-n* junction (*left*) the resulting potential barriers prevent the diffusion of electrons into the *p* side and holes into the *n* side. The application of a forward bias in the form of an external voltage lowers these potential barriers (*right*), greatly increasing the current. Recombination of the injected minority carriers (electrons on the *p* side, holes on the *n* side) can occur with the emission of photons.

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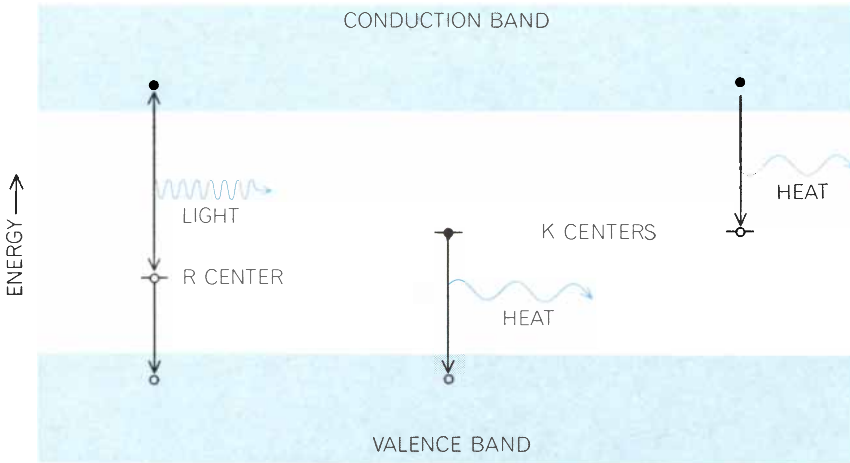


THERMAL QUENCHING in a semiconductor is the decrease in the ratio of radiative to nonradiative recombination with increasing temperature. In this case radiative recombination occurs between a free electron from the conduction band and a hole trapped at an acceptor impurity (*R*) just above the valence band. Competing with this route is a nonradiative, heat-emitting route through a "killer" impurity (*K*) near mid-gap. High temperatures favor the recombination of minority carriers (holes in this case) at *K* with no emission of photons; low temperatures favor recombination at *R* with emission of photons.

energy and the momentum of the entire system. If the lowest-energy conduction electron has a value of momentum different from that of the hole in the valence band, the emission of a phonon is required to conserve momentum. The latter process, called an indirect transition, is much less likely than the direct transition, and in indirect semiconductors, such as germanium, a radiative recombination occurs far less frequently than a nonradiative one.

Nature has generously given all real crystals an abundance of impurities and native defects that provide fast, nonradiative paths for the recombination of minority carriers. The presence of an impurity provides the momentum change required in direct-transition crystals, and hence the recombination energy can produce a photon, although it is more often dissipated in the successive emission of a large number of phonons. To obtain efficient radiative recombination from indirect-transition materials, carefully selected impurities that provide a radiative path must be added in sufficient numbers to overwhelm the nonradiative routes. This selection has been reasonably successful with gallium phosphide (GaP) but not with silicon carbide (SiC), which yields blue or yellow light at no more than one photon for every 10,000 injected charge-carriers.

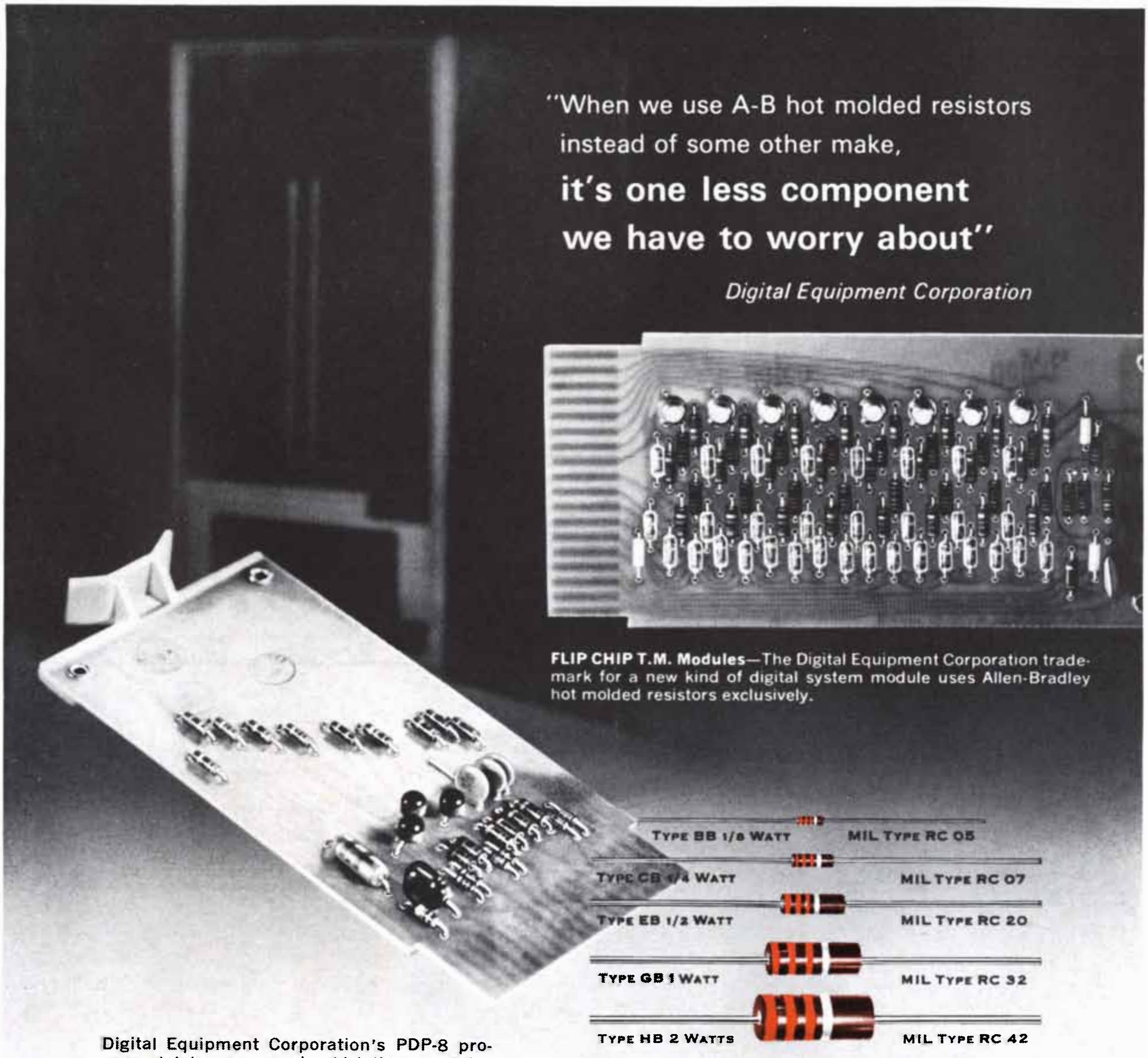
The efficiency with which heavily "doped" *p-n* junctions in the direct-gap Group III and Group V semiconductors (for example gallium arsenide) convert injected carriers into photons is almost 100 percent at high currents. If the emission is spontaneous (that is, not stimulated), the number of photons that escape the crystal diode is greatly reduced by their reabsorption in inactive parts of the diode. Radiation striking the flat interface between the crystal and the air is totally reflected internally if it deviates from the perpendicular to the interface by more than a specific angle that is determined by the index of refraction between the crystal and the air. For all but a few percent of the spontaneously emitted radiation the light path through the crystal will be very long as a result of multiple internal reflections, and the loss by absorption will be almost complete. If the diode itself is spherical or if it is encapsulated in a hemisphere of a transparent material that tends to match the index of refraction of the semiconductor in air, absorption of the radiation can be greatly reduced.

The onset of stimulated emission, or laser action, at high currents is the most efficient means of collecting externally nearly all the internally generated photons. All the emerging radiation is contained in a narrow beam in the plane of the junction. Two ends of the diode perpendicular to the junction plane are usually polished or cleaved to form an efficient, constructively interfering, resonant cavity, and it is from these surfaces that the laser beam escapes. External quantum efficiencies as high as 80 percent have been observed from "lasing" gallium arsenide diodes at low temperatures.

Gallium arsenide has a band gap such that the emission is in the infrared region of the spectrum, at a wavelength of about 9,000 angstrom units at room temperature and at one of 8,400 angstroms at 77 degrees Kelvin (degrees centigrade above absolute zero), the temperature of liquid nitrogen. Gallium phosphide, another compound in the Group III–Group V series, is a semiconductor with an indirect gap of 2.3 eV and a wavelength of about 5,400 angstroms. With appropriately chosen impurities respectable quantum efficiencies can be achieved with gallium phosphide, both for green light at very low temperatures and for red light at room temperature [*see illustration on page 108*]. Coherent stimulated emission in indirect material is considered unlikely. In a solid solution of gallium arsenide and gallium phosphide ($GaAs_xP_{1-x}$), however, injection lasers have been achieved only for an *x* of more than .5. At this composition the band-to-band transition is still direct, whereas for values of *x* less than .5 it is indirect. The emission occurs at wavelengths greater than about 6,300 angstroms at low temperatures, which is currently the lower limit of the wavelengths obtainable from *p-n* junction lasers.

The series of semiconducting compounds with direct gaps large enough to accommodate visible emission are from Group II and Group VI of the periodic table. These compounds are well known for their luminescence. Zinc sulfide (ZnS), for example, has a band gap of 3.7 eV in the near ultraviolet. Visible emission from zinc sulfide arises from recombination at impurities with energy levels within the forbidden band. Zinc sulfide phosphors are usually in the form of a microcrystalline powder. Efficient excitation of these powders to give visible emission can be achieved with near-ultraviolet radiation, electron beams and even high-frequency alternating electric fields (the Destriau effect). In the case of ultraviolet excitation as many as half of the absorbed ultraviolet photons are converted to visible photons. The rough, irregular shape of the microcrystals enables the internally generated photons to escape without much of the absorption loss that afflicts *p-n* junctions.

The problem one immediately encounters with these otherwise promising Group II–Group VI compounds is that the wider-gap members cannot be made both *n* type and *p* type. Zinc selenide (ZnSe), for example, with a gap of 2.7 eV, can be made usefully only *n* type; zinc telluride (ZnTe), with a 2.3-eV gap, can be made highly conducting *p* type, but in *n* type its resistance is too high. Zinc sulfide can be made *n* type only with difficulty and *p* type not at all. The



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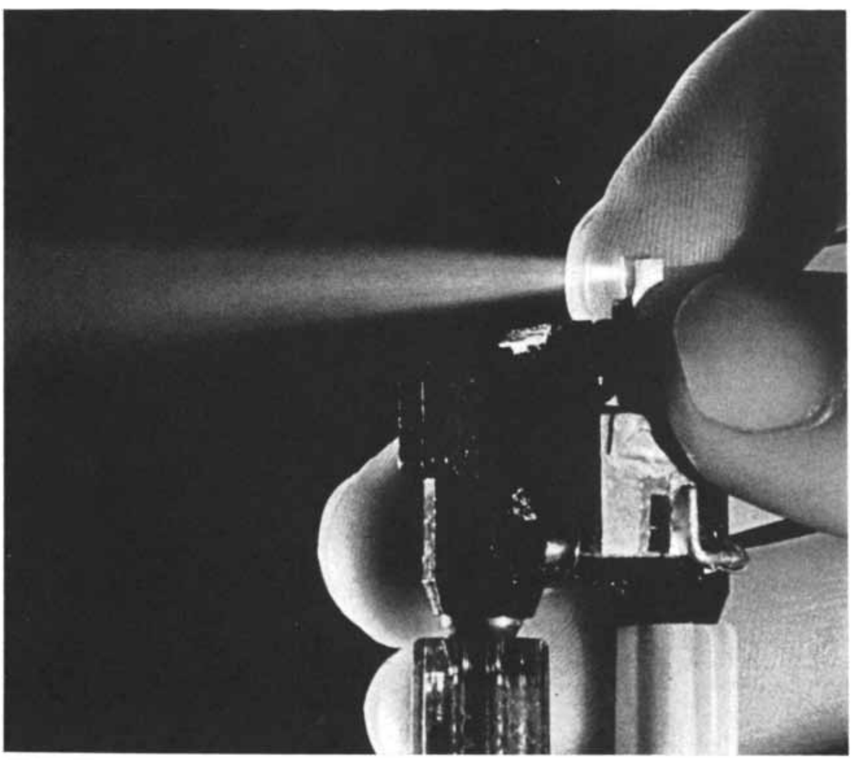
complete explanation for this recalcitrant behavior is complex, but a primary cause is a phenomenon called self-compensation. Just as one can compensate, or neutralize, the electrical effect of added donors by adding an equal concentration of acceptors, so there is the possibility that at sufficiently high temperatures the material itself can generate defects, such as vacancies (missing atoms), to produce the same effect. Either type of compensation lowers the energy of the system by an amount equal to the energy lost by the electron in going from the donor to the acceptor. Whether or not a given material will compensate itself at the temperature at which the impurities are introduced depends on a delicate energy balance. If the energy cost to generate a compensating vacancy, for example, is less than the energy of the band gap, then the equilibrium state of the material at a given temperature will correspond to a state with a high concentration of such compensating vacancies. High-band-gap ionic solids, such as sodium chloride, are completely self-compensated and are always insulating. Elements from Group IV, such as silicon and germanium, and Group III–Group V compounds have much stronger covalent bonds and hence exhibit virtually no self-compensation; as a result they can be made in highly conducting forms with either donors or acceptors. The Group II–Group VI compounds are intermediate cases and generally exhibit only one type of strong conductivity.

Cadmium telluride (CdTe) is the only Group II–Group VI compound of moderate gap (1.5 eV) that can be doped to have both a useful *n*-type and a useful *p*-type conductivity. In 1964 workers at IBM prepared *p-n* junctions in crystals of this compound that showed quantum efficiencies of about 10 percent in an emission band a little lower than the band-gap energy at 77 degrees K. At room temperature the efficiency was less by a factor of 100. Even in this case self-compensation and other factors operate to limit the number of majority carriers one can obtain on each side of the junction to about 10^{16} per cubic centimeter. This concentration is less by a factor of 1,000 than the concentration characteristic of a good gallium arsenide injection laser. Accordingly the maximum density of recombining electrons and holes that one can obtain at high currents is too low to achieve laser action at low temperatures and too low to give rise to efficient radiative recombination at room temperature. Introducing zinc into the cadmium telluride lattice produces solid-solution crystals of the composition $Zn_xCd_{1-x}Te$ with a larger band gap. *P-n* junctions for an x of less than .4 have been prepared in this system (also at IBM in 1964) with efficient electroluminescence at 77 degrees K. in the deep red region of the spectrum at 7,000 angstroms. For values of x greater than .4 the system can no longer be made *n* type.

The decrease in the ratio of radiative to nonradiative recombination with increasing temperature is often called thermal quenching. This term applies only to recombination at an impurity. For example, consider the radiative recombination of a free electron with a hole trapped at an acceptor impurity just above the valence band [*see illustration on page 116*]. Competing with this radiative transition at the center (R) is a nonradiative route through a "killer" center (K) near mid-gap. At low temperatures a hole captured by R will stay put until recombination with a conduction electron occurs. At higher temperatures more and more of the holes will escape to the valence band as a result of lattice vibrations and suffer the chance of capture at K. Increasing the temperature, therefore, decreases the relative number of radiative transitions and the overall luminescence efficiency of the system. At any temperature, however, it is theoretically possible to introduce holes into this region at a sufficient rate to saturate recombination through K and increase the relative number of radiative recombinations at R to achieve high recombination efficiency. Whether or not this can be done in practice depends on the effectiveness of the injecting structure.

Another Group II–Group VI solid solution that should yield efficient *p-n* junctions is zinc selenide–zinc telluride ($ZnSe_xTe_{1-x}$). Since zinc telluride can be made highly conducting in *p*-type form and zinc selenide in *n*-type form, there should be a range of x within which both types are possible. Workers at General Electric have prepared devices of this composition that, under forward bias at 70 degrees K., emit at 6,200 angstroms with quantum efficiencies as high as 18 percent. Careful examination of this device has shown that both sides of the junction are quite insulating in the dark. The absorption of light—external light at first and later internally generated light—produces the electrons on the *n* side of the junction and the holes on the *p* side. At room temperature the quantum efficiency of this device decreases by a factor of 10,000.

There are a number of techniques for



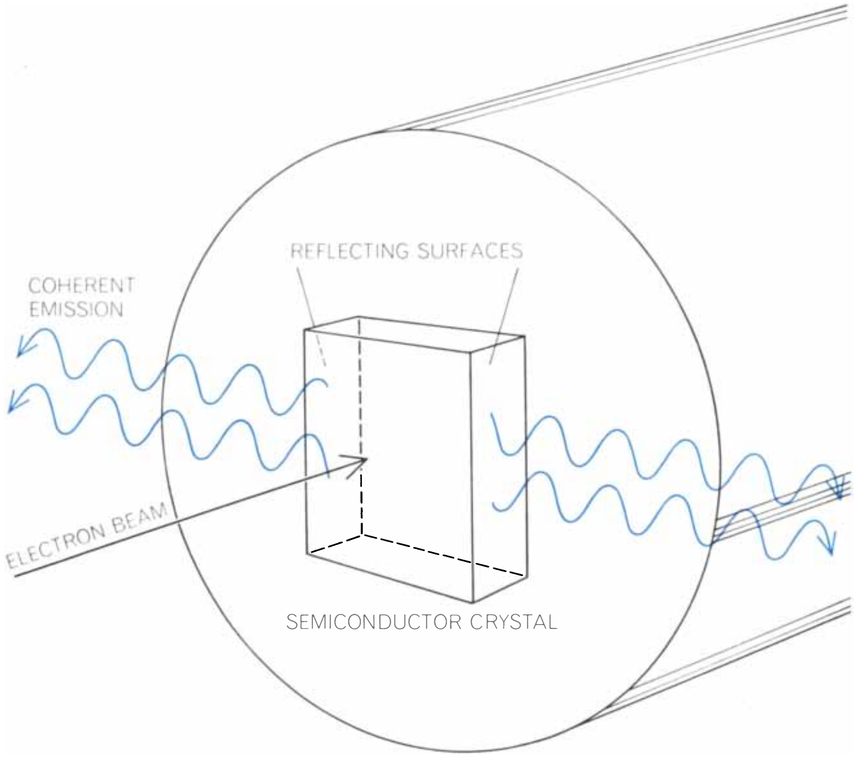
***P-N*-JUNCTION INJECTION LASER** **consisting of a single tiny crystal of gallium arsenide was made by researchers at the International Business Machines Corporation. It emits pulses of infrared light with a wavelength of about 9,000 angstroms and a power of about 10 watts at room temperature. The crystal is inside the metal mount between the fingers.**

injecting minority carriers other than that of a forward-biased *p-n* junction. For example, a metal with a high work function (a measure of the energy of the metal's electrons) can be used to make contact with an *n*-type semiconductor. Holes can be injected from such a contact into the valence band of the semiconductor. A much larger number of electrons is usually extracted from the conduction band of the *n*-type semiconductor, however, resulting in poor injection efficiency. A heterojunction, as the name implies, is a junction in which the *n* side is one compound and the *p* side another.

Another injection technique utilizes a quantum-mechanical process called tunneling. Electrons can "tunnel" through the potential barrier presented by a narrow film of a wide-band-gap insulator into a luminescent *p*-type semiconductor. The probability of tunneling increases with an increase of electric field across the insulator barrier. Electroluminescence of this type in Group II–Group VI compounds has been reported by workers at the Ford Motor Company and the Radio Corporation of America.

All these techniques unfortunately yield only very low efficiencies, even at very low temperatures. A single exception to this rule has been found by our group at IBM. Contact injection from indium alloys on *p*-type zinc telluride has given quantum efficiencies up to 1 percent at 77 degrees K., but only at current densities in excess of 10,000 amperes per square centimeter. Even if one can arrange one of these systems to give good injection efficiency, they all involve an interface between two different solids at the point of the injection of minority carriers. Such interfaces always contain a high density of recombination states that are invariably fast and nonradiative. Cathode-ray-tube phosphors, for example, always have a "dead" layer on the surface. The electrons in the exciting beam must be accelerated to high enough energies to penetrate well below this surface to obtain efficient cathodoluminescence.

Perhaps the most promising alternative to *p-n*-junction injection is avalanche injection. This technique of injecting minority carriers requires a thin layer of insulating semiconductor sandwiched between either two conducting regions of the same crystal or a conducting region and a metal contact. When the field in the insulating region is high enough, a small number of "primary" current-carriers are accelerated to sufficient ki-

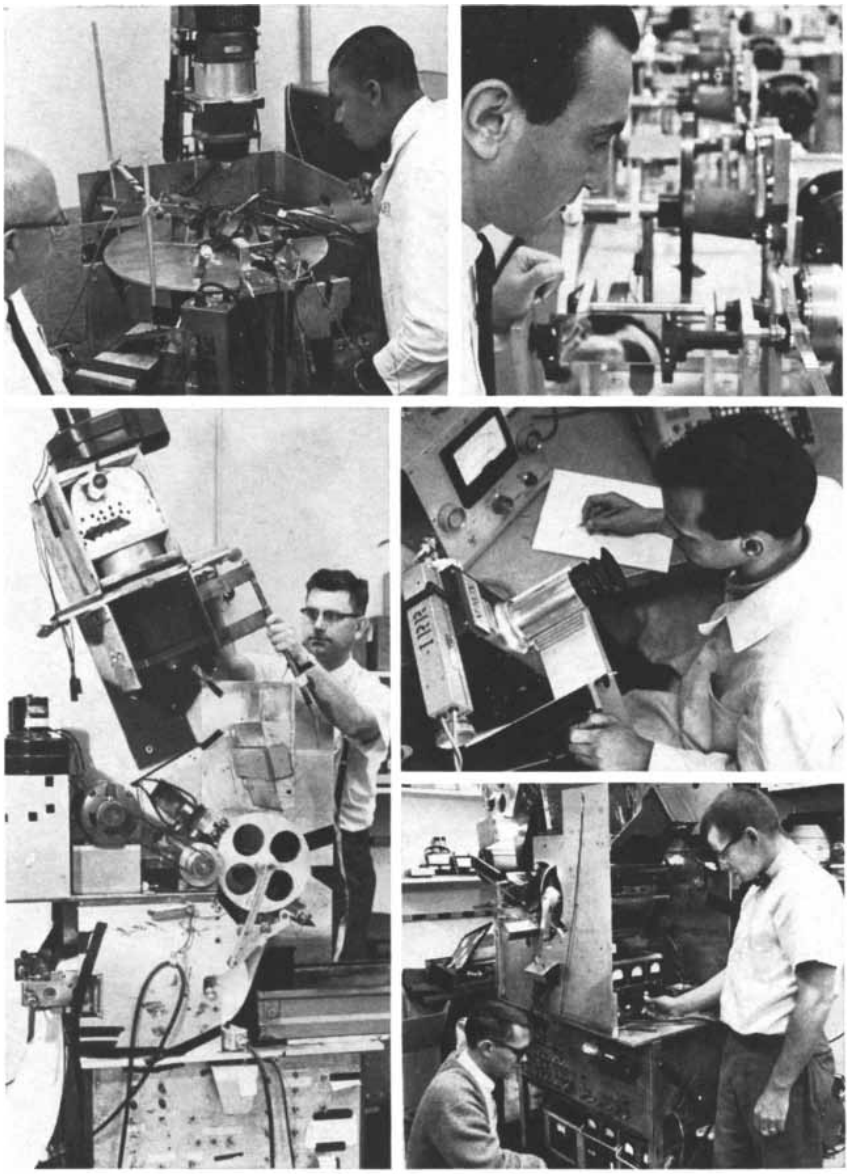


ELECTRON BEAM can also be used as the exciting mechanism in a semiconductor laser. How far the excited region extends into the semiconducting crystal depends on the energy of the electrons in the beam (usually greater than 50,000 volts). Two reflecting surfaces on the sides of the crystal form an optical cavity in which stimulated emission is produced.

netic energies to produce electrons and holes from the lattice atoms by inelastic impact. These impact-ionized carriers are in turn accelerated and impact-ionize more carriers; the insulating region breaks down in what is picturesquely but accurately referred to as an avalanche. Since after breakdown most of the carriers will have been produced by impact, and half of them will be minority carriers, one should be able to approach an internal quantum efficiency of 50 percent in such a system. The minority carriers will be swept by the field into a region in which efficient recombination is possible. Efficient avalanche injection was first demonstrated in gallium arsenide at IBM in 1965.

Avalanche injection would appear to be a very good technique to apply to the wider-gap Group II–Group VI compounds, since it requires only a single type of conductivity. The avalanche-injection structure does not involve an interface between two different solids, so that the deleterious interface states are avoided. IBM researchers have reported efficient avalanche injection in *p*-type zinc telluride structures. Quantum efficiencies as high as 2 percent have been observed at 77 degrees K. with green and yellow emission. The operation of the device is complicated by photoconductive effects, and room-temperature operation has been disappointing. There is good reason to hope, however, that better avalanche structures can be made in zinc telluride and other related compounds, which can achieve the high recombination densities necessary for the efficient emission of visible light at room temperature.

If the objective is a semiconductor laser emitting at visible wavelengths and shorter ones, one possibility is to introduce the excitation externally. High-energy electron beams are an obvious choice for such external excitation. With up to 150,000 eV of accelerating potential available, such beams can deliver, in pulses or continuously, 100 watts of power to a region less than a millimeter in diameter. A further advantage of the electron beam is that for accelerating potentials greater than 20,000 eV most of the excitation energy is dissipated from the surface, avoiding nonradiative recombination at the dead surface states. The minority carriers necessary for radiative recombination are generated in the same way as in the avalanche-breakdown process, by ionizing carriers from the lattice ions by impact. Because of



electrons backscattered at the surface and internal energy losses, one is limited to an internal energy efficiency of much less than 100 percent, perhaps no more than 30 percent.

Thin, relatively pure platelets of several Group II–Group VI compounds have been "pumped" in this way with high-energy electron beams. Pulsed operation at low temperatures at the Lincoln Laboratory has produced coherent emission from zinc sulfide, cadmium sulfide and cadmium selenide, with peak outputs as high as 350 watts and energy efficiencies of about 25 percent. Less efficient high-power outputs have been reported in zinc oxide by workers at RCA and in cadmium telluride by workers in the U.S.S.R. High efficiencies and high powers have been obtained with the solid-solution system cadmium sulfide–cadmium selenide ($CdSe_xS_{1-x}$). If, as expected, the zinc sulfide–cadmium sulfide system ($Zn_xCd_{1-x}S$) also yields good results, one can then obtain coherent radiation from semiconductor lasers all the way from 3,300 angstroms in the ultraviolet to nearly 50 times this wavelength in the infrared.

There are, or course, many uses for small light-emitters in which the human eye is the detector—the numerous indicator lamps mounted on computers are a typical example. These needs are now filled primarily by incandescent lamps. It is quite likely that solid-state devices will meet these requirements in the future, particularly where long operating life and reliability are of paramount importance. Even where the eye is not the detector, as in the case of light-sensitive paper for an optical printer, sensitivity is greater in the visible region. Here too visible emitters such as gallium phosphide or some Group II–Group VI device may find application in the future.

The most highly developed semiconductor light source is of course gallium arsenide. High efficiency (10 percent) but incoherent continuous output at room temperature is possible with specially doped *p-n* junctions that avoid much absorption loss. Laser operation, in pulses of much less than a millionth of a second, is possible at room temperature, and continuous coherent output at a temperature of 77 degrees K. and below has been achieved. The most important potential application of the *p-n*-junction laser is in communications. The ultimate goal is to take advantage of the tremendously broad band of frequencies associated with a coherent output at infrared wavelengths (approximately 400 million megacycles per second). As an optical communication link the *p-n*-junction laser possesses advantages in both directionality and high efficiency. A large number of voice channels and a single television signal (with bandwidths on the order of a million cycles per second) have been transmitted with gallium arsenide injection lasers over a distance of several miles.

The quenching and amplifying effects of one *p-n*-junction laser on the operation of another *p-n*-junction laser can also be used to perform logical operations in a computer. In addition the use of *p-n*-junction lasers to couple computer circuits by means of light rather than electricity provides the maximum in electrical isolation when there is no signal, a major design advantage. The detectors in such circuits can also be *p-n* junctions (usually silicon) to provide the best possible response time. Delays as small as a few billionths of a second are possible.

Proposed applications of semiconductor lasers pumped by an electron beam include various scanning devices. Electron beams are easily deflected by electrostatic or magnetic fields. If the semiconductor is a centimeter or so long, several millimeters wide and about 10 micrometers thick, there will be perhaps as many as 1,000 points along the centimeter dimension that can be made to emit coherent radiation, depending on where the electron beam is made to impinge. Two-dimensional scanning could be accomplished by arranging a number of such crystals like steps on a stairway. A thousand steps would be required to achieve the million points characteristic of cathode-ray-tube displays, which is probably too many steps to be practical. If the electron-beam lasers emit in the same direction as the electron beam (rather than perpendicularly to it), a much simpler scanning configuration is possible that would be completely analogous to a television picture tube. The phosphor screen is merely replaced by a continuous sheet with optically flat sides of the desired laser material.

Light-emitting semiconductors are clearly a prominent part of the current scientific and technological scene. Pumped with electron beams, with other lasers or with forward-biased *p-n* junctions, they represent an important source of intense, coherent radiation in many regions of the spectrum. The investigation of their fascinating properties has led to an increased understanding of the nature of the solid state and should continue to aid the rapid expansion of this vigorous young branch of physics.

ORDINARY MATTER

The extraordinary particles created in accelerators are important clues to the nature of matter. They obscure the fact, however, that the matter of ordinary experience consists of only three particles

by Gerald Feinberg

Thales of Miletus, the first philosopher, is said to have asked, "How, and of what, is the world made?" and many men have since tried to answer him. In my opinion current physical theory provides an adequate answer to the question, so that physics has solved Thales' problem and has thereby repaid its debt to him and indirectly to philosophy for inspiration.

Physics deals with one problem and with many problems. In the widest sense physics is the study of all phenomena that occur in nature, and its problem is to understand them. But at any given stage in the development of physics we are aware only of some fraction of the phenomena that will be known at a later stage. Furthermore, because of historical accident, cultural variation and other incidental reasons the physicists of different times have often concentrated on particular phenomena or particular aspects of phenomena in their investigations, disregarding others for the time being.

There is, however, one problem that has remained close to the center of interest for physicists for almost 2,500 years. The first explicit statement of the problem is the question attributed to Thales. Less poetically, we can say that the question concerns the structure and composition of bulk matter, by which is meant the objects and substances we find around us.

In the asking of this question there is implicit the assumption of a simplicity underlying the complexities of bulk matter. Starting with the Ionian philosophers, of whom Thales was one, physicists have proceeded on this assumption, with the result that by the middle of the 20th century we have found a comprehensive explanation of the properties of bulk matter. I refer of course to the description in which matter is taken to be composed of nuclei and electrons, and these objects follow the laws of quantum mechanics.

With this theory I believe we have essentially answered Thales' question, at least in the sense in which it was originally posed. The answer is that many aspects of the world around us can be understood by supposing that matter is composed of atoms. Most of the remainder are understood by analyzing the atoms into electrons and nuclei. A very small number of everyday phenomena, such as the shining of the sun, require for their understanding a further analysis of the nuclei into neutrons and protons, together with the introduction of the neutrino, a particle that seems to play no role in natural phenomena other than in certain decay processes.

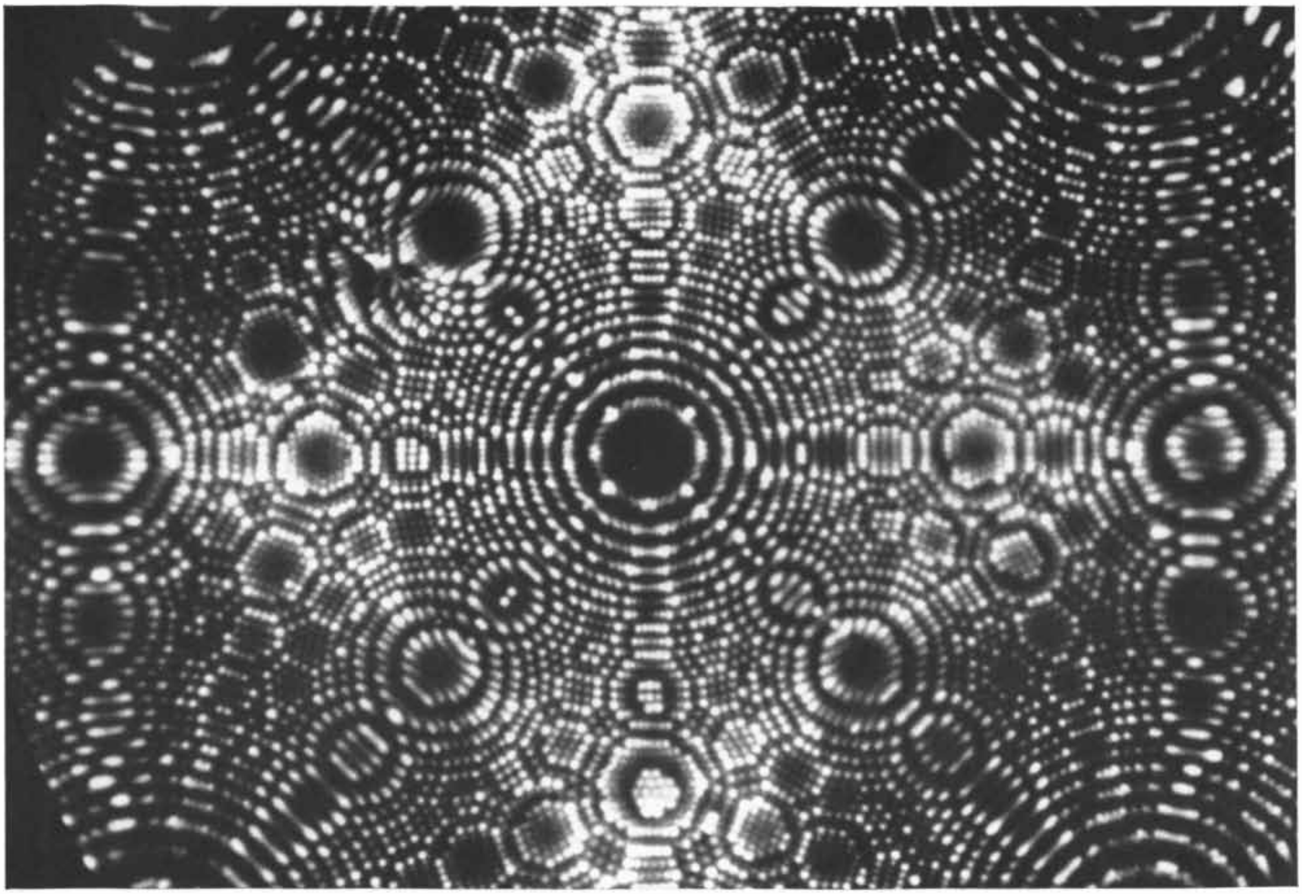
The multitude of "elementary particles" that have been discovered in high-energy physics in the past 30 years appear to play a negligible role in phenomena outside the laboratory, except perhaps on the cosmic scale. Because of this "irrelevance" of the elementary particles for most natural phenomena, it seems inappropriate to include the study of them in Thales' problem. This is not to say that such study is unimportant. Indeed, elementary-particle physics is one of the frontiers of human inquiry, and very subtle intellectual questions are involved in it that we are far from answering. Nevertheless, I think it is a mistake to let the unsolved problems of particle physics obscure the progress we have made in understanding matter. Even though matter, in the deepest sense we know, is composed of particles such as neutrons and protons that we do not wholly understand, none of the phenomena we generally encounter seems to depend on those aspects of particle physics that are still mysterious. It is in this sense that I believe we have solved Thales' problem, and now understand how and of what the world is made.

In order to document this thesis I shall first briefly discuss some of the historical stages in our understanding of matter. In particular I shall mention four approaches to the structure of matter. These are the views of the Greeks before Democritus, the atomic theory of Democritus, the atomic-molecular theory of the 19th century and the contemporary view. By comparing these views we shall see how physics has gradually come to understand everyday phenomena in terms of objects very different from everyday ones. Next I shall analyze more carefully the notion that most of elementary-particle physics is irrelevant to the structure of matter. I shall finish by outlining some questions that may occupy physicists in the future, as Thales' problem has in the past.

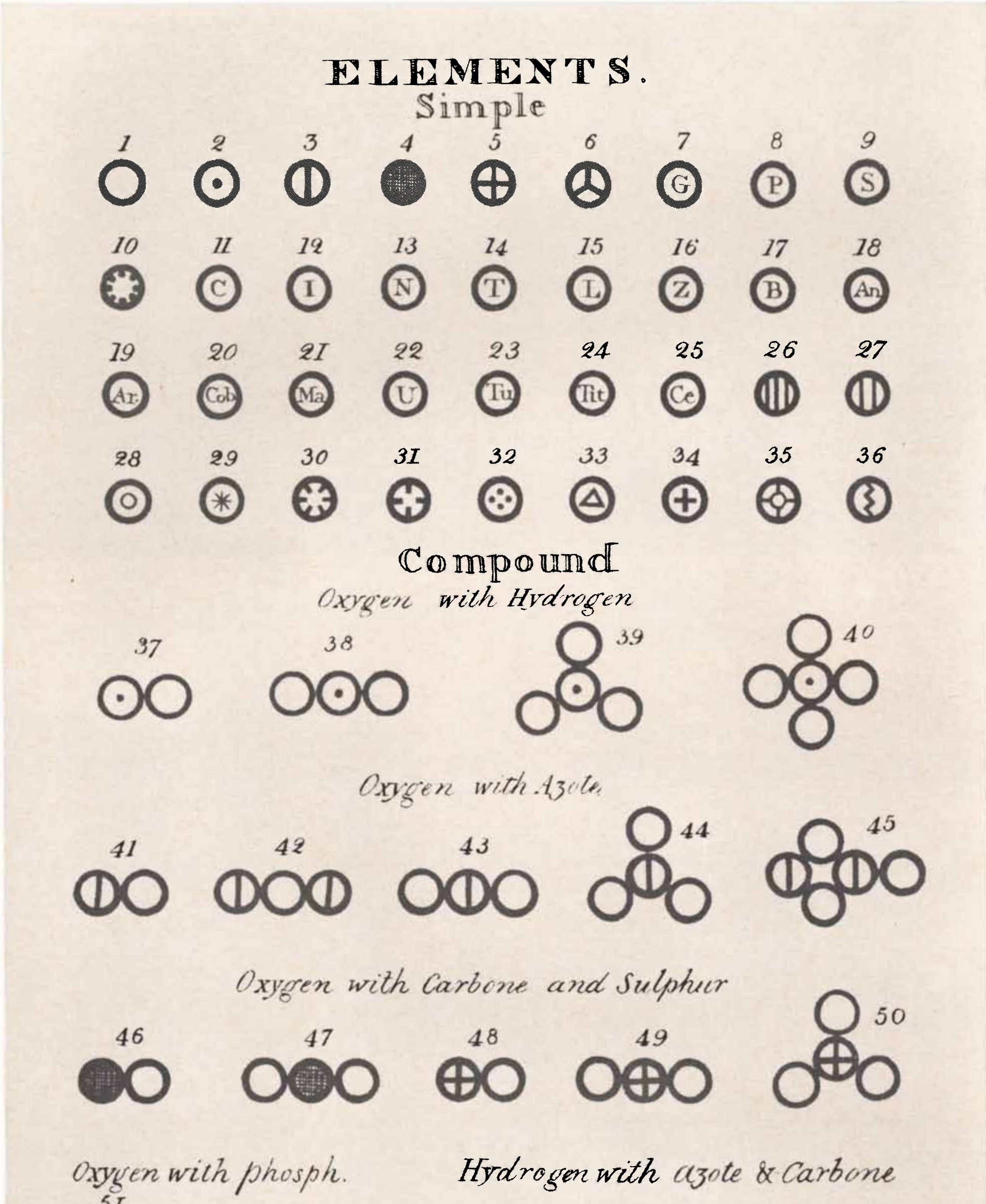
The earliest recorded speculations about the structure of matter, which date back to 600 B.C., are based on the idea that the different forms of matter observed are composed of a single "primal" constituent or a few such constituents. Thales said that this primal substance was water; Heraclitus, that it was fire. At a later stage the combination of earth, air, fire and water was introduced by Empedocles. At a distance of 25 centuries these attempts may seem hopelessly naïve. It is well to note that they were among the first efforts to find a simplicity behind the complexities of natural phenomena and, as such, are the direct ancestors of our own theories of matter.

An important feature of the Ionian speculations is that the primal substance was always taken as one or more of the forms of matter apparent to the senses. To the Ionians it seemed very reasonable that the ultimate stuff of which the uni-

EXTRAORDINARY MATTER is represented by the particles that made the tracks in this bubble-chamber photograph. This particular photograph was the one on which the omega-minus particle was discovered. The track made by the omega-minus is a short one at an angle to the roughly parallel tracks at the far left. The spiral tracks were left by less energetic particles moving in a magnetic field.



ORDINARY MATTER is represented by the atoms that made the luminous spots in this field-ion micrograph of an iridium crystal. Each spot corresponds to a single atom. Micrograph was made by Erwin W. Müller and O. Nishikawa of Pennsylvania State University.



ATOMS VISUALIZED BY JOHN DALTON were the ultimate particles comprising the chemical elements. He proposed 36 kinds of atoms, one for each of the elements known at that time (*top*). These atoms, he believed, combined to form the molecules of compounds (*bottom*). This illustration is reproduced from Part II of Dalton's *A New System of Chemical Philosophy*, published in 1810.

verse is made should be a familiar substance, with familiar properties. The feeling was essentially that the underlying reality should already be apparent on the surface of things. Such an attitude has indeed persisted among some of the greatest physicists through the 19th and 20th centuries. Examples that come easily to mind are the desire of James Clerk Maxwell for a mechanical model of the electromagnetic field and of Albert Einstein for a deterministic substratum of quantum phenomena. It would have been comforting if the physicist's job were made easier in this way. Unfortunately the world is not so simple, and the proper understanding of matter requires the imagination to invent entities not apparent in everyday phenomena. It is the enduring miracle of creative thought that the mind is equal to this task.

This next step was already taken by some of the Greeks, in the atomic theory of Leucippus and Democritus. In this theory the sensorially apparent forms of matter and their properties are regarded as secondary, and the ultimate realities—the components of matter—are the indestructible atoms, moving about in the vacuum. Democritus himself makes this point very clearly, in his celebrated statement: "Color is by convention, sweetness is by convention, bitterness is by convention, in reality there is nothing but atoms and the void."

The remarkable thing about the Greek atomic theory is not that it anticipated the atomic theory of the 19th century. There were, after all, no phenomena known to Democritus that required atoms for their explanation, and he does not seem to have predicted any new phenomena with his theory. What is remarkable is that he was willing to make the intellectual leap of assuming the existence of unobserved objects quite different from those found in ordinary matter, and to account for everyday objects in terms of them. It is in this sense that Democritus is a forerunner of modern physics, in which the properties of bulk matter are accounted for in terms of atoms and their component particles, which themselves behave very differently from the way bulk matter does. Of course, Democritus was not able to give such an explanation himself, since neither the relevant dynamics nor the relevant observations yet existed.

Yet so tempting was the Democritean theory that Isaac Newton more or less adopted it in his own theory of matter, as he outlined it in the famous Question 31 of his *Opticks*. The atoms were now given inert mass, and endowed with gravitation and other forces to describe their interaction. Newton used this model to explain some of the chemical and physical properties of matter, those we would now classify under solid-state physics. There were still no quantitative results, and hence Newton's atomism was not given the attention bestowed on his dynamics.

In the 19th century the atomic theory was revived by John Dalton and others, who used it to explain the fact that in chemistry different elements always entered into compounds in amounts that were the ratios of small integers. The Daltonian atoms differ from those of Democritus mainly in that distinct elements have different kinds of atoms associated with them. As yet there is no hint of atomic structure or dynamics.

The other triumph of the atomic theory in the 19th century was the kinetic theory of gases. This was essentially an application of the Newtonian model. By assuming that gases are composed of atoms that obey Newton's laws of motion it was possible to explain many properties of gases. Again, this step did not require any detailed knowledge of atomic structure at first, except the assumption that the atoms were perfectly elastic. It was possible to go somewhat further, and by examining the deviations from the ideal-gas laws J. D. Van der Waals and Maxwell were able to determine the number of atoms per unit volume in a gas, or Avogadro's number, to an accuracy of about 50 percent. With this number it was finally possible to estimate the size of atoms, which made the atoms seem somewhat more real.

Still, some of the sharpest thinkers among 19th-century physicists completely rejected the atomic theory. Ernst Mach, for example, went so far as to call it meaningless or useless. The main reason for this rejection seems to have been that throughout the 19th century the atom remained hypothetical in that there was no direct evidence for its existence. More important, it was not even clear how such evidence could be obtained in principle. In the 20th century, by means of techniques such as X-ray diffraction, direct evidence was finally obtained. At the same time that this direct evidence of the existence of atoms became available, it was also discovered that atoms are not really indivisible but rather can be analyzed into components: nuclei and electrons. Thus, somewhat paradoxically, most physicists were convinced of the existence of atoms only after the discovery that the atoms are not the ultimate constituents of nature.

The discovery that atoms have a structure and contain charged particles was made late in the 19th century and early in the 20th by J. J. Thomson and Ernest Rutherford. This discovery by itself was sufficient to solve some of the remaining problems in the structure of matter, such as how bodies can be electrified and magnetized. The next step was rather unexpected. It soon became clear that the components of atoms could not be adequately described by the dynamical laws describing large-scale objects, that is, Newton's laws of motion. This was quite shocking to physicists, who thought that the "system of the world" had long since been discovered. Nevertheless, it did not take very long (some 25 years) for them to invent a new description of nature—quantum mechanics—for dealing with atoms and their constituents.

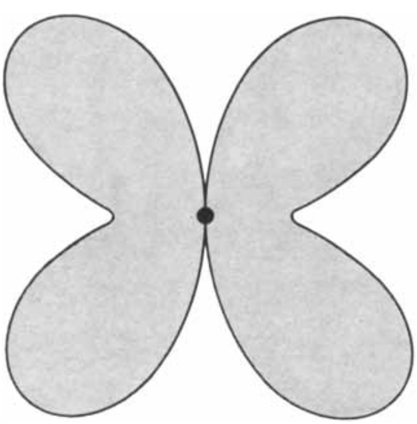
Perhaps in retrospect the fact that some of the laws governing atoms are different from those apparently governing bulk matter should not have been so surprising as it was. As we have seen, Democritus already realized that the components of matter were substances different from matter itself. We might have expected that the laws describing atoms might contain new features quantitatively unimportant for large objects. This may, however, be one of the arguments that can only be made from hindsight.

The nuclear atom of Rutherford and Niels Bohr, as described by quantum theory, proved sufficient, as it has been said, to account for all of chemistry and most of physics. This is not to say that there are no more problems left in solid-state physics or in other branches of the subject not dealing with elementary particles. The point is rather that we are almost sure that there are no new laws of physics to be discovered in these areas. I would make an exception in this statement for cosmology, or the study of the universe as a whole. Most physicists would agree that the properties of solids, liquids, gases, atoms and even nuclei are contained in known physical laws and that the remaining problems in those fields require only that we find the correct way of applying these principles. Of course, saying this makes the problems no easier to solve.

The process of solving Thales' problem involved a double triumph of the imagination. On the one hand, we have been able to account for the multitude of diverse properties of bulk matter—such as hardness, color, superconductivity and even life—on the basis of rather simple properties of electrons and nuclei. On the other hand, by experiments with bulk matter we have been able to discover its elementary constituents, even though these are many orders of magnitude smaller than the objects with which we deal and display quite different behavior. For the most part the reasoning has been indirect, although in the last stages of the search there have been discovered effects on a macroscopic scale, such as superconductivity, in which the quantum properties of electrons and nuclei play an essential role.

The fact that it is possible to understand bulk matter by using only simple properties of electrons and nuclei does not mean that the latter are themselves simple. On the contrary, the physics of the past 30 years has been largely concerned with the study of those objects and others associated with them. Along the way it has been found that these "elementary particles" have some rather unexpected properties of their own. It can indeed be that the physics of elementary particles is as rich a field as the physics of bulk matter has been. Nevertheless, it appears that the two fields are almost distinct.

In the past 30 years liberal amounts of time, thought and the taxpayers' money have been invested in the study of what are called elementary particles. For the present purpose we can take as an elementary particle anything apart from a hydrogen atom with a definite angular momentum and a mass less than that of a deuterium nucleus. From this study have come many remarkable experimental results, a few glimpses of theoretical understanding and much confusion. Perhaps the salient feature of the elementary particles discovered so far is that there are a large number of distinct varieties of particles (some 200 at present) and that, when enough energy is available, they change into one another freely without regard to number and kind, except insofar as they are constrained by certain conservation laws. This has led some physicists to doubt that any particle is more fundamental than any other and to state that the proton is no more nor less a composite than the uranium nucleus. I do not intend to enter into this interesting question here. I should, however, like to remark that, of the properties displayed by the particles in high-energy experiments, only a small number are relevant to determining the structure of bulk matter. Indeed, only a small number of the particles seem relevant to this problem.



MODERN ATOM consists of a nucleus (*black dot*) surrounded by an electron cloud. In this representation the cloud is the butterfly-shaped configuration of the hydrogen atom in one of its higher energy states. Shape of the cloud represents the region in which the electron is likely to be found.

Let us see how one is led to this view. In order to recognize that atoms are composed of electrons and nuclei it is sufficient to do experiments at very low energy. (The kinetic energy of the atoms can be on the order of a few electron volts.) With experiments at such low energy, say with slow neutrons striking the nuclei of uranium 235, one can even show that nuclei are composite objects. The particles that are found by disintegrating atoms in this way are neutrons, protons and electrons. The particles of these kinds that come from a particular atom were not created in the process of disintegration but in some sense were there all the time. It is difficult to make this notion of preexistence precise for a quantum-mechanical system, but at least two important criteria are satisfied. One is that properties of the atom such as charge and mass are very nearly equal to the sums of these quantities for the particles that are found in this way. The other is that the number of neutrons, protons and electrons obtained from a given atom is the same even if we use different low-energy probes to examine the atom. On this basis it seems reasonable to conclude that these particles are not created in the process of analyzing the atom but were there all along.

It seems, furthermore, to be the case that ordinary matter contains only these three particles. The sense of this is that, if we analyze matter with probes whose kinetic energy is well below the threshold for creating one of the other known particles, none of these other particles will be found. An apparent exception comes if we use probes made of antimatter, such as antiprotons. In this case, even if the antiprotons have a very low kinetic energy, they can still annihilate with the protons and neutrons in matter, producing many of the unstable particles. I do not think this vitiates the analysis, since it does not seem useful to consider the annihilation products as preexistent in the proton and antiproton. Instead one must, as in other instances in particle physics, allow for the creation of particles that were not there before. Thus if we restrict our considerations to that domain of physics where the average kinetic energy per particle is small compared with the muon rest energy, which is the smallest energy necessary to create one of the unstable particles, the only particles that appear in real form are electrons, protons and neutrons. In addition to these there are the particle-like photons, which compose light beams, whose properties are well understood, and the neutrinos, which interact so weakly with matter that they are unimportant for Thales' problem.

Now, in most of the universe the average energy per particle is very small compared with the rest energy of the muon. For example, at a temperature of 1.2×10^{10} degrees centigrade—hotter than the center of any known star—the average kinetic energy per particle is only 1 percent of the muon rest energy. Hence only one particle in 10^{40} will have an energy equal to the muon rest energy. As far as we know, only in cosmic rays and in man-made accelerators are energies high enough to create the other unstable particles.

It follows that any effect of these other particles on the properties of ordinary matter can come only through their occurrence in "virtual" states. That is to say, it is possible to create the other particles for a very short time, in which case, on the basis of the uncertainty principle, energy conservation need not apply.

There are of course effects of such short-time creation and annihilation of particles. For example, the creation and destruction of pions is mainly responsible for the nuclear forces. It would be misleading, however, to conclude from this that we must understand the pion and the other unstable particles in great detail before we can understand "how the nucleus holds together." Insofar as we are willing to treat the nuclear force phenomenologically, we can learn about it from a study of nuclei themselves, without reference to where the force comes from. Even if we wish to derive the nuclear force from the theory of pions, what is mainly relevant is the existence of particles with a certain mass and angular momentum, not the details of high-energy-scattering cross section or the other phenomena of interest to particle physi-

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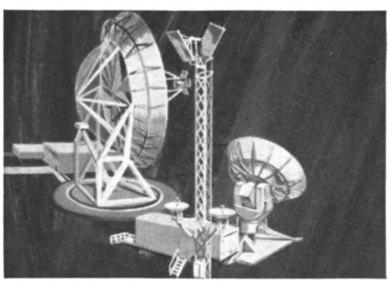

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	CHARGE	MASS
ELECTRON	⊖	1
PROTON	⊕	1836.1
NEUTRON	○	1838.6

THE THREE PARTICLES of ordinary matter are listed. The masses of the two nuclear particles, the proton and the neutron, are given in terms of the mass of the electron.

cists. It therefore seems to me unlikely that further discoveries concerning the elementary particles or the addition of new members to that family will shed any real light on the properties of nuclei. The still unsolved problems of detail in that field are more likely to be understood through the discovery of subsystems of nuclei, such as the shell structure of nuclei, in terms of which simple approximations can be made.

I expect that it is even less likely that the details of elementary-particle physics are relevant to phenomena not involving nuclear transformations. Most of the phenomena that take place on the earth and in the outer layers of stars are in this category. Unless our present ideas are wholly misleading, a knowledge of electromagnetic and gravitational forces, together with a knowledge of the existence of nuclei and electrons, is sufficient for the understanding of these phenomena.

I have said that the details of particle physics are irrelevant to the structure of bulk matter. The unsolved problems regarding the structure of matter remain because we are applying the known principles to complicated systems. A question one might still raise about the Thales problem is the possibility that the application of these principles might at some stage fail to explain either some known phenomenon or some yet undiscovered phenomenon involving bulk matter. Both such failures occurred late in the 19th century and early in the 20th, the former with regard to optical spectra and the latter with regard to radioactivity. In this connection some physicists have argued that the laws of quantum mechanics are insufficient to explain living phenomena (Walter Elsasser) or mental phenomena (Eugene Wigner). I think that it is premature to draw these conclusions, since the detailed study of living phenomena with the full use of physics and chemistry is rather recent, and its spectacular progress is such that predictions of impotence may soon be falsified.

One cannot rule out on a priori grounds the possible discovery of new macroscopic phenomena inexplicable by the atomic theory, but I am inclined to await their discovery skeptically. I think that the parallel with the situation in the late 19th century is not really valid. At that time there were many phenomena known for which not even an order-of-magnitude explanation was available, such as spectra. On the contrary, at present I would say that all macroscopic physical phenomena are understood at least qualitatively. Moreover, in the late 19th century atoms were still rather mysterious and no idea of their internal structure existed. It might have been anticipated that new effects would be discovered involving this internal structure. Although it may involve a lack of vision on my part, I cannot see any such unknown regions on our present map of nature. Accordingly it seems to me that we now have a model of the structure of bulk matter that is fairly complete and unlikely to change in its essential aspects. Only perhaps on a cosmic scale are we likely to find new laws of nature in the behavior of large bodies.

In conclusion I shall briefly discuss some problems with which I think physics will deal in the future and that I think have some possibility of being fundamental ones. The list is not meant to be exhaustive, and I shall confine myself to two areas, one involving very small objects, the other the universe at large.

The first of the future problems might be succinctly phrased: "Are particles elementary?" By this I do not mean the questions I mentioned earlier about whether certain of the known particles are to be considered composites of others. Rather, the question is whether particles are the simplest structures that appear in nature or whether the particles we observe are somehow manifestations of an underlying structure we have not yet detected. This might be expressed poetically by saying that particles are like ripples on a still unfathomed ocean. Of course, there is no evidence whatever for this point of view. It is not even obvious how to go about testing it. Yet there seems to me something suggestive about the idea. As I said earlier, one of the most striking characteristics of particles is that at high energies they are easily created and destroyed or transformed

into one another. It seems strange to me that this would occur if particles were really fundamental. In the transformations that occur when particles interact, however, some things remain constant. These are the conserved quantities, such as electric charge and energy. Other quantities change very slowly, such as parity. There is, furthermore, the mysterious fact that the electric charge of apparently unrelated particles such as the proton and the positron are equal. If indeed there is a substratum underlying particle physics, these quantities must be properties of the underlying stuff. Perhaps when we understand the conservation laws better we shall get some hint of whether or not the substratum really exists.

Another problem I think physics will have to deal with is the interrelation of the universe in the large with the behavior of objects in the laboratory. This problem is sometimes referred to as Mach's principle, because Mach raised the issue in connection with the inertial properties of matter. At first sight this problem would seem contrary to the history of physics since the time of Galileo. In our period physics has been fairly successful in accounting for laboratory phenomena while taking into account only the effects of nearby objects. Many physicists would regard any contrary assumption as a form of astrology. But Mach in the past century and Einstein in this one pointed out that the assumption that physical laws in a universe containing only a few objects would be the same as they are in our universe may lead to difficulties. For example, Einstein pointed out that if the earth were alone in the universe and Newton's laws were still valid, it would be possible for an observer on the earth to determine whether or not the earth was rotating by measuring the flattening of the poles. This conclusion seems counterintuitive, since one is inclined to ask: Rotating relative to what?

One possible way out of this problem is the one suggested by Einstein, who said that the inertial properties of matter arise when a body is accelerated relative to the average distribution of matter in the universe. According to this view, the inertial effects come from the gravitational force exerted on a body in the laboratory by the remaining bodies in the universe. This force depends, among other things, on the relative acceleration of two bodies. It also appears that the main contribution to the force on a given body comes from the distant background of galaxies. It is not yet clear whether or not the gravitational force of these galaxies is quantitatively sufficient to account for the inertia.

If this is indeed the correct explanation of inertia, a new problem arises. In order to know that the laws used to calculate the inertial effects are correct, we would have to know how all physical laws, including the law of gravitation, depend on the distribution of matter in the universe. That is, we would have to know the laws of physics for all conceivable distributions of matter, from an empty universe to one filled with matter in arbitrary motion. The orthodox view would be that the fundamental laws are independent of the distribution of matter. This leads to problems such as the one of the solitary rotating earth that I have cited. It may be possible to find the laws of motion for any distribution of matter, although to do so it will be necessary to assume that some laws do not change with the distribution. If this can be done, we might be in a position to understand some apparently accidental features of our world, such as the fact that space has three dimensions. However, the distribution of matter would still have to be prescribed arbitrarily.

There is another possible approach to the connection between the distribution of matter and the laws of motion. This has been emphasized by Dennis Sciama in his brilliant book *The Unity of the Universe*. According to Sciama, it may be that the connection between the laws of motion and the distribution of matter is so rigid that there are only one possible set of laws and one possible distribution of matter, those of the universe we inhabit. This is an extension of the view of Leibniz, who argued that, out of logical necessity, the universe could only be the way it actually is. Similar views have been expressed in the context of particle physics by Geoffrey Chew and his "bootstrap" school.

Clearly this approach also has its problems. In particular it seems easy to imagine logically consistent universes, very different from ours, such as a world with no bodies in it at all or a world with particles permanently fixed. Perhaps, in order to rule out these worlds, it is necessary to supplement the requirement of logical consistency with the requirement that there be an observer to make measurements.

In any case, it seems that the problem of the relation between the universe and the laboratory will be a knotty one to unravel, and perhaps it may replace the Thales problem as the central question in physics. One may hope that it will take us less than 2,500 years to solve it.

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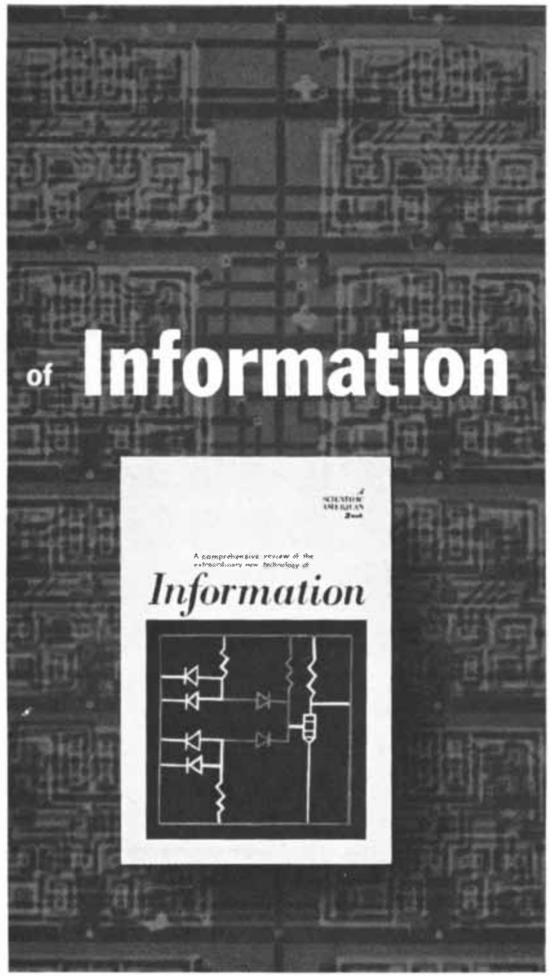

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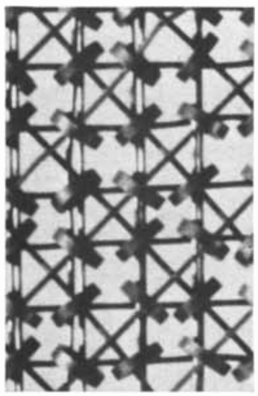

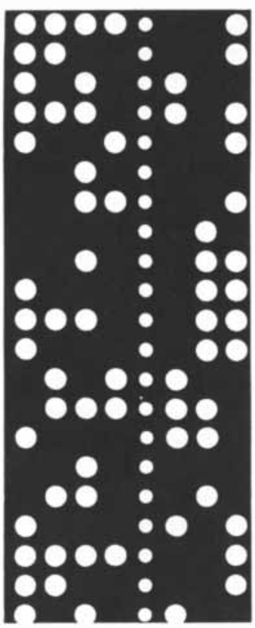

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MATHEMATICAL GAMES

Cube-root extraction and the calendar trick, or how to cheat in mathematics

by Martin Gardner

Even the greatest of the lightning calculators discussed in last month's department regularly included in their stage acts such feats as cube-root extraction and the calendar trick, which appear enormously difficult but actually are not, and many lesser calculators were not above introducing feats that operate almost entirely by trickery. Some of these tricks are so easily learned that the reader who wishes to amaze and confound his friends can master them with a minimum of practice and only the most elementary of calculating skills.

Consider, for example, the following multiplication trick, surprisingly little known even though it goes back to an Italian book of 1747, *I giochi numerici: fatti arcani* (*Numerical Games: Arcane Facts*), by G. A. Alberti. The trick works with numbers of any length, but it is best to limit it to three-digit numbers unless a desk calculator is handy for checking results.

Ask for any number with three digits. Suppose you are given 567. Write it twice on the blackboard or on a sheet of paper:

567 567

Ask for another three-digit number. Write it under the 567 on the left. Now you need a different three-digit number as a multiplier on the right. It has to be (although your audience must not know this) the "9 complement" of the multiplier on the left; that is, corresponding digits of the two multipliers must add to 9. Assume that the left multiplier is 382. The right multiplier must be 617:

567	567
382	617

If you do the trick for a group, you can arrange beforehand for a friend to act as a secret confederate and suggest the correct second multiplier. Otherwise simply write it yourself as though you were putting down a number at random. Announce that you now intend to perform the two multiplications in your head, add the two products and then, as a final fillip, double the result. Obtain the sum of the two products instantly by subtracting 1 from the multiplicand and then appending the 9 complement. In this case 567 minus 1 is 566, the 9 complement of 566 is 433 and so the sum of the two products is 566,433. If you wrote this down, however, someone might notice that it began with the same two digits as the multiplicand, which would look suspicious, so you conceal the fact by doubling the number. This is not hard to do mentally, writing the digits from right to left as you perform the necessary doublings in your mind. If you prefer, you can mentally add a zero to 566,433 and divide by 5 (since multiplying by 10 and dividing by 5 is the same as multiplying by 2), in which case you write the final answer from left to right.

Why does the trick work? The sum of the two products is the same as the product of 567 and 999, which in turn is the same as multiplying 567 by 1,000 and subtracting 567. Do this on paper and you will see at once why the result has to be 566 followed by its 9 complement.

A subtler principle underlies a variety of lightning-multiplication tricks involving certain curious numbers that seem innocent enough but actually can be multiplied quickly by any number of equal or shorter length. Suppose the stage calculator asks for a nine-digit number and a confederate in the audience calls out 142,857,143. Another nine-digit number is requested and given legitimately. The performer multiplies the two numbers in his head, writing the mammoth product slowly from *left to right*. The secret is absurdly simple. Merely divide the second number through twice by 7. If there is a remainder after the first division, carry it back to the front of the first digit, then divide through a second time. Suppose the second number is 123,456,789. In effect, you divide 7 into 123,456,789,-123,456,789. The result, 17,636,684,-160,493,827, is the answer. The division must come out even; otherwise you know you have made a mistake.

The magic number 142,857,143 is just as easily multiplied by a number of shorter length. Merely add enough zeros at the end to make it a nine-digit number when you do the first mental division by 7. Thus if the multiplier were 123,456, you would, in your mind, divide 123,456,000,123,456 by 7. While you are writing the answer you are of course secretly looking at the multiplier and performing the mental division.

The number 142,857,143 was well known to the great stage calculators. One of the last of them to give vaudeville performances in the U.S. was Arthur F. Griffith, who died in 1911 at the age of 31. He billed himself as "Marvelous Griffith" and had the reputation of being able to multiply two nine-digit numbers in less than half a minute. When I first read that, I became suspicious. Some digging at the library turned up an eyewitness account of his performance in 1904 before a group of students and faculty members at the University of Indiana. Griffith, the account says, wrote the number 142,857,143 on the blackboard. A professor was asked to

	CUBES	FIFTH POWERS
1	1	100 THOUSANDS
2	8	3 MILLIONS
3	27	24 MILLIONS
4	64	100 MILLIONS
5	125	300 MILLIONS
6	216	777 MILLIONS
7	343	1 BILLION, 500 MILLIONS
8	512	3 BILLIONS
9	729	6 BILLIONS
10	1,000	10 BILLIONS

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1805

JAN	1	THE **FIRST** MONTH.
FEB	4	A **C-O-L-D** (FOUR-LETTER) MONTH.
MAR	4	THE **K-I-T-E** MONTH.
APR	0	ON APRIL FOOLS' DAY I FOOLED **NO**BODY.
MAY	2	"MAY DAY" IS **TWO** WORDS.
JUN	5	THE **B-R-I-D-E** MONTH.
JUL	0	ON JULY 4 I SHOT **NO** FIRECRACKERS.
AUG	3	THE **H-O-T** MONTH.
SEP	6	START OF **A-U-T-U-M-N**.
OCT	1	A WITCH RIDES **ONE** BROOM.
NOV	4	A **C-O-O-L** MONTH.
DEC	6	BIRTH OF **C-H-R-I-S-T**.

Keys and mnemonic aids for calendar trick

put a nine-digit multiplier below it. As soon as he started to write it, from left to right, Marvelous Griffith began to write the product from left to right. "The student audience," the account continues, "rose with a shout." Griffith wrote a small book about his methods, *The Easy and Speedy Reckoner* (published in Goshen, Ind., in 1901), but it says nothing about 142,857,143.

There is one danger in using 142,857,143. If the multiplier happens to be evenly divisible by 7, the product "stutters"; that is, a series of numbers will be repeated in the answer and that will arouse suspicion. To avoid a stutter, Wallace Lee, a magician who has invented many excellent mathematical tricks, devised the magic number 2,857,143. (It is the other number with its first two digits removed.) Ask for a seven-digit multiplier in which each digit is not less than 5. This, you explain, is to make the problem more difficult; actually it simplifies the procedure. The method is the same as before except that the entire multiplier must be doubled before you make the first division by 7. If all the digits are greater than 4, the doubling can be done in your head as you go along, digit by digit, in the following manner.

Assume that the multiplier is 8,965,797. Double the first digit, 8, and add 1, making 17. Seven goes into 17 twice, so you write 2 as the first digit of the answer, keeping the remainder, 3, in mind. Double the next number, 9, and add 1, making 19. Discard the first digit and substitute the 3 that was the previous remainder, making 39. Seven goes into 39 five times, so write 5 as the second digit of the answer, keeping the remainder, 4, in mind. Double the next number, 6, and add 1, making 13. Substitute 4 for the 1, making 43. Seven goes into 43 six times, so write 6 as the third digit of the answer and keep the remainder, 1, in mind. Double the next digit, 5, and add 1, making 11. Substituting 1 for 1 leaves the same number, 11, so you divide 11 by 7, getting 1 as the fourth digit of the answer and a remainder of 4 to keep in mind. Continue in this way until you reach the end of 8,965,797. When you double the last digit, 7, do *not* add 1. The 2 that is the final remainder is carried back to the beginning to go in front of the 8. Now divide 8,965,797 by 7 in the ordinary manner, without doubling. The final result, 25,616,564,137,971, is the desired product.

The doubling procedure used for the first division is not difficult to master. The product is guaranteed not to stutter and the trick's *modus operandi* is much harder for the uninitiated to discover. Like the previous magic number, this one can be multiplied by smaller numbers if you mentally add zeros to the multiplier.

Both tricks have such gargantuan products that unless an adequate desk calculator is available it is hard to get quick confirmation of your results. There are many smaller magic numbers, however, that work essentially the same way. For example, the product of 143 and *abc* is obtained by dividing *abc* through twice by 7 and hoping that the quotient does not stutter. The product of 1,667 and *abc* is obtained by adding a zero to *abc* and dividing through by 6, halving the remainder, if any (the remainder will be either 0, 2 or 4), carrying it back to the beginning and dividing *abc* by 3. This is very easy to do in your head, the result will not stutter and spectators can check the answer without a machine—all of which makes it a capital impromptu trick to perform for friends.

The only reference I know to magic numbers of this type is in a privately printed work by Wallace Lee called *Math Miracles,* a book that contains many entertaining feats of lightning calculation. (The book can be obtained by sending $3 to the author at 505 Elizabeth Street, Durham, N.C. 27701.) As a pleasant exercise in number theory the reader is asked to determine, before the answers appear next month, how the four magic numbers I have given were obtained and why they work the way they do.

In another impressive lightning-calculation feat you ask someone to cube any number from 1 to 100 and give you the result; you quickly name the cube root. To perform this trick it is necessary to memorize only the cubes of numbers 1 through 10 [*see illustration on page 136*]. Note that each cube ends in a different digit. (This is not true of squares, which explains why cube-root extraction is much easier for a calculator than square-root extraction.) The final digit matches the cube root in every case except 2, 3, 7 and 8. Those four exceptions are easily recalled because in each case the cube root and the final digit of the cube add to 10.

Suppose someone calls out the cube 658,503. Discard in your mind the last three digits and consider only what is left, 658. It lies between the cubes of 8 and 9. Pick the *lower* of the two, 8, and call out 8 as the first digit of the answer. The terminal digit of 658,503 is 3, so you know immediately that the second digit of the cube root is 7. Call out 7. The cube root is 87.

Stage calculators often followed this

trick by asking for fifth powers of numbers. This seems even harder than giving cube roots but in fact is both easier and faster. The reason is that the last digit of any fifth power of an integer always matches the last digit of the integer. Again, it is necessary to memorize a table [*see illustration on page 136*]. Suppose someone calls out 8,587,-340,257. As soon as you hear "eight billion" you know that it lies between the ninth and the 10th number on the chart. Pick the lower number, 9. Ignore everything he says until he reaches the last digit, 7, at which point you instantly say 97. It is wise not to repeat this more than two or three times because it soon becomes obvious that final digits always match. The professional calculators worked with cubes and fifth powers of much larger numbers, by extensions of the systems given here, but I am limiting the explanation to the simpler two-digit roots.

The calendar trick—naming the day of the week for any date called out—was also featured by most of the great stage calculators. To perform it one must commit to memory the table shown on the opposite page, in which a digit is associated with each month. Initial memorization can be aided by the mnemonic cues on the right, proposed by Wallace Lee in his book.

To calculate the day of the week in your head the following four-step procedure is used:

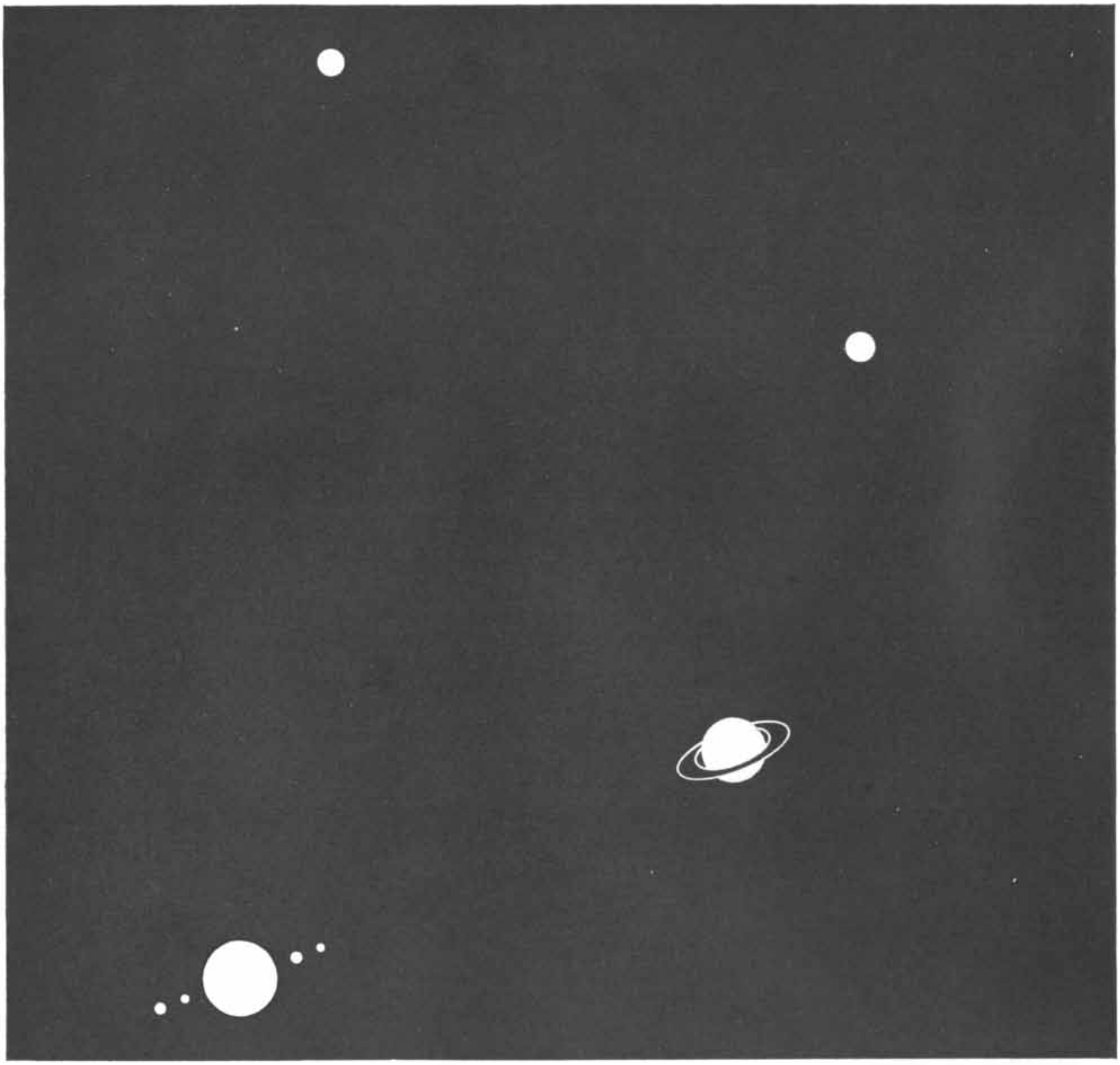
1. Consider the last two digits of the year as a single number. Divide it mentally by 12 and keep the remainder in mind. You now must add three small numbers: the number of dozens, the remainder and the number of times 4 goes into the remainder. Example: 1910. Twelve goes into 10 no times, with a remainder of 10. Four goes into this remainder two times. $0 + 10 + 2 = 12$. If the final result is equal to or greater than 7, divide by 7 and remember only what is left. In the example given here, 12 divided by 7 has a remainder of 5, so only 5 is retained in the mind. Henceforth this procedure will be called "casting out 7's." (A mathematician would say he was using "modulo 7" arithmetic.)

2. To the result of the preceding step add the month's key number. If possible, cast out 7's.

3. To the preceding result add the day of the month. Cast out 7's if possible. The resulting digit gives the day of the week, counting Saturday as 0, Sunday as 1, Monday as 2 and so on to Friday as 6.

4. If the year is a leap year and the

We're going to give Jupiter, Saturn, Uranus and Neptune the run-around



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month is January or February, go back one day from the final result.

The first step automatically alerts you to leap years. Leap years are multiples of 4 and any number is a multiple of 4 if its last two digits are. Therefore if there is no remainder when you divide by 12, or none when you make the division by 4, you know it is a leap year. (Bear in mind, however, that in the present Gregorian calendar system 1800 and 1900, although multiples of 4, are *not* leap years, whereas 2000 *is*. The reason is that the Gregorian calendar provides that a year ending in two zeros is a leap year only if it is evenly divisible by 400.)

The procedure just explained is restricted to dates in the 1900's, but only trivial final adjustments need to be made for dates in other centuries. For the 1800's go two days forward in the week. For the 2000's go one day back. It is best not to allow dates earlier than the 1800's because of confusion involving the shift that took place in England and the American colonies on September 14, 1752, from the Julian to the Gregorian calendar. Julius Caesar had used a year of 365.25 days, with a day added in February every fourth year to compensate for that excess fraction of one-fourth. Unfortunately the year has only 365.2422+ days, so with the passage of centuries the leap years overcompensated and a sizable error of excess days accumulated. To prevent February from overtaking Easter (which depends on the vernal equinox) Pope Gregory XIII authorized the dropping of 10 days and the adoption of a calendar with fewer leap years. This was done throughout most of Europe in 1582, but in the English-speaking world the change was not made until 1752. The day after September 2 was called September 14, which explains why George Washington's birthday is now celebrated on February 22 instead of February 11, the actual date (Old Style) on which he was born. For dates in the 1700's, after the 1752 changeover, go forward four days in the week.

An example will make the procedure clear. Suppose you are informed that someone in the audience was born on July 28, 1929. What was the day of the week? Your mental calculations are as follows:

1. The 29 of 1929 contains two 12's, with a remainder of 5. Four goes once into 5. $2 + 5 + 1 = 8$. Casting out 7's reduces this to 1.

2. The key for July is 0, so nothing is added. The 1 is kept in mind.

3. The day of the month, 28, is added to 1. Cast out 7's from 29. The remainder is 1. Your subject was born on Sunday. (In actual practice this last step can be simplified by recognizing that 28 equals zero, modulo 7, so that there is nothing to add to the previous 1.)

The fourth step is omitted because 1929 is not a leap year. Even if it were, the step would still be left out because the month is not January or February, the only months for which leap year adjustments must be made.

From time to time "idiot savants" get into the news by exhibiting an ability to perform this trick. A recent case of calendar-calculating twins with I.Q.'s in the 60-to-80 range was studied by psychiatrists and reported in *Scientific American* [see "Science and the Citizen," August, 1965]. It seems unlikely that any mysterious ability is operating in such cases. If the idiot savant takes a long time to give the day, he has probably memorized the first days of each year, over a wide range, and is simply counting forward in his mind from those key days to the given date. If he gives the day rapidly, he has probably been taught a method similar to the one I have described, or has come across it in a book or magazine.

Many methods for calculating the day of the week mentally were published late in the 19th century, but I have found none earlier than a method invented by Lewis Carroll and explained by him in *Nature* (Vol. 35, March 31, 1887, page 517). The method is essentially the same as the one described here. "I am not a rapid computer myself," Carroll wrote, "and as I find my average time for doing any such question is about 20 seconds, I have little doubt that a rapid computer would not need 15."

The 10-soldier puzzle in the March collection of short problems prompted many interesting letters from readers. (It was this puzzle, incidentally, that I had in mind when I wrote that the "last" problem was a combinatorial one and the most difficult of the lot. A rearrangement in the order of the eight problems made it the last but one.) For generalizations and extensions of the problem see two articles: "Monotonic Subsequences," by J. B. Kruskal, Jr., in *Proceedings of the American Mathematical Society*, Vol. 4 (1953), pages 264–274, and "Longest Increasing and Decreasing Subsequences," by Craige Schensted, in *Canadian Journal of Mathematics*, Vol. 13 (1961), pages 179–191.

THE AMATEUR SCIENTIST

How to study learning in the sow bug and photograph tiny live crustaceans

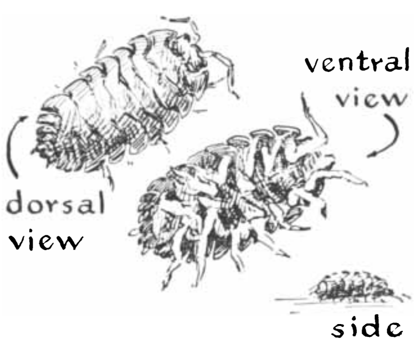
Conducted by C. L. Stong

Investigations of animal behavior have shown that dogs are easier to train than pigeons and pigeons easier than frogs. Similarly, frogs exhibit more intelligence than fish. How far down the evolutionary ladder can one go before the line thins out between intelligent behavior, judged by an animal's capacity to learn from experience, and instinctive reaction?

Several experiments have been devised for investigating this question. One that amateurs can perform easily is designed to measure the learning response of invertebrates. The procedure is described by John Frost, a graduate student at California State College at Fullerton, as follows:

"An interesting specimen to use for observing learning behavior in invertebrates is the common sow bug, *Porcellio laevia*. These organisms live in moist places almost everywhere. The adult is about half an inch long. The body consists of seven free segments, each of which bears a pair of legs.

"The animal has no effective biological mechanism for preventing the evaporation of water from its body. In order to survive it must avoid the drying effect of direct sunlight. Hence it has learned to shun light. The experimenter can take advantage of this characteristic to train the bugs, causing each to run a simple maze in a direction contrary to the path preferred by the bug before training.



Views of a sow bug

"Sow bugs can be found under rocks and logs. The insects may be scarce in winter and when the weather is hot and dry. In cities they tend to congregate during all seasons in the damp cellars of apartment buildings under wooden boxes and the like. If search is unsuccessful, try making a trap by hollowing out a potato and placing it under a tree or shrub. Cover the potato with a few leaves and come back after 48 hours. The trap will usually contain several lively specimens. I do not recommend the potato trap for indoor use because it may attract some less desirable organisms. Sow bugs run when they are frightened, which is exactly what one wants them to do in the maze. They may faint when severely frightened, but they soon recover and scurry off.

"Captured sow bugs can be maintained indefinitely in a culture chamber improvised from a one-pound coffee can or a similar container [*see illustration on opposite page*]. Half-fill the can with a mixture consisting of one part of sand by volume to two parts of leaf mold. On this surface place a peeled raw potato and a damp sponge of about the same size. Replace the potato and moisten the sponge every two or three days. The container should be closed by a perforated cover.

"Specimens must be kept in individual chambers during training. These chambers can consist of test tubes half-filled with peat moss or leaf mold covered with a piece of paper toweling [*see top illustration on page 144*]. A sliver of fresh potato is placed on the toweling along with the bug. The containers are loosely plugged with tufts of damp absorbent cotton and labeled so that the bug can be distinguished from others. Replace the potato as necessary and keep the cotton moist.

"The maze in which the bugs are trained consists of a simple *T*, made by cementing cardboard partitions in a box of clear plastic [*see bottom illustration on page 144*]. The box should be about three inches wide, 4½ inches long and 5/8 inch deep. The passages should be made about 3/8 inch wide. Rectangular openings that match the cross-sectional area of the passages are cut in the walls of the box at the base of the *T* and at each end of the crossarm. Two blocks of wood that make a loose fit with the openings must be provided for closing either or both openings of the crossarm.

"The experiment is divided into two phases. First, determine and record the natural turning preference of each bug. Most sow bugs will take a preferred path through the maze. Having crawled up the leg of the *T*, some will habitually turn into the right portion of the crossarm and others into the left. Some will show no preference. During the second phase of the experiment the bugs are trained to turn in the direction contrary to their natural preference.

"Begin the experiment by transferring five or six specimens from the culture chamber to labeled individual chambers. Then remove a bug from a selected container and, holding it lightly between your thumb and forefinger, let it crawl from your fingertip into the base of the *T*. Record the direction of the turn, right or left. The bugs can tolerate only about 10 runs a day without suffering ill effects. For this reason the 20 runs needed to establish a reliable estimate of turning preference should span two days.

"Training is then accomplished by running each specimen through the course and punishing 'wrong' behavior. Each time a bug makes a turn in the direction it naturally prefers, immediately plug all exits with wood blocks and hold a 100-watt incandescent light close to the top of the passageway for about 20 seconds. When the bug turns in the direction opposite to its natural preference, plug the exit of the runway for 20 seconds but do not expose the animal to the punishing light.

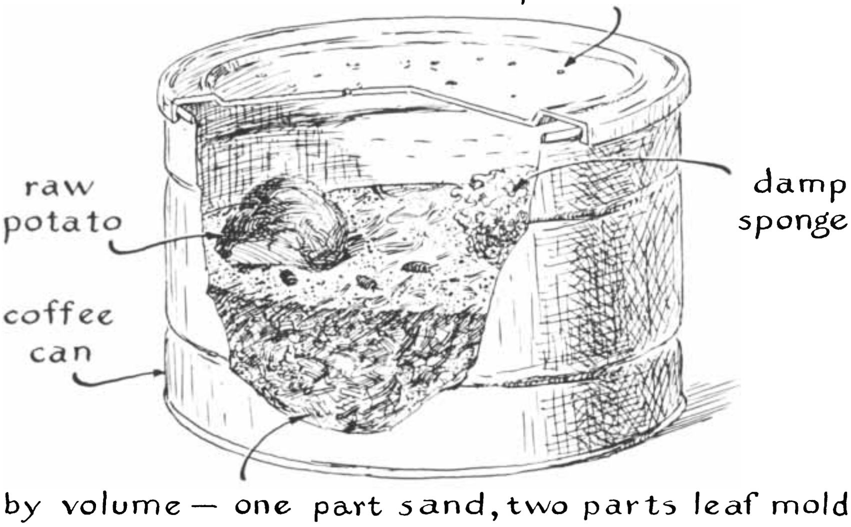
"The training runs must be spaced at

least five minutes apart. Between runs return the subjects to their individual quarters to 'think it over.' The experimenter can conserve his time by training a number of animals sequentially. This practice also tends to increase the reliability of the experimental results and to minimize the statistical effect of the occasional specimen that does not survive the training experience.

"The training period should normally take three to 10 days, depending on how quickly the individual learns. The bugs should be subjected to no more than 10 training runs a day. At the conclusion of the training phase nine consecutive correct turns can be taken as evidence that the bug has learned. A correct turn is defined as one made in the direction opposite to the bug's natural preference as determined by the first phase of the experiment. Statistically it can be shown that nine consecutive correct turns will occur by chance only once in 100 runs.

"The procedure can be varied. For example, the omission of the bright light following a correct turn can be considered a reward. The leg of the *T* is lighted brightly until the bug reaches the crossarm; the light is removed if a correct turn is made. The desired behavior can be further reinforced by darkening the passage when the correct turn has been made.

"Much serious work has been done in recent years on the turning behavior of sow bugs as well as on the learning ability of cockroaches and box-elder bugs. The objective has been to clarify the role of reward and punishment in training procedures. I am certain that amateurs who repeat and extend the experiments will be surprised to find evidence of intelligent behavior so low on the scale of evolution. They will also have the satisfaction of exploring animal behavior by means of experimental procedures that do not injure the organism."



John Frost's container for maintaining the bugs

Pete Rowe of Los Altos, Calif., is another amateur who enjoys working with small animals. His interest is in freshwater crustaceans and particularly in the physiology of the organisms, including their mechanisms of locomotion. These features are not easy to observe even under a microscope because most such crustaceans are largely transparent and their appendages move too fast to be seen by eye. For this reason Rowe worked out a procedure for recording the anatomical details of live crustaceans by high-speed photomicrography. The equipment he uses is available at prices most amateurs will find reasonable.

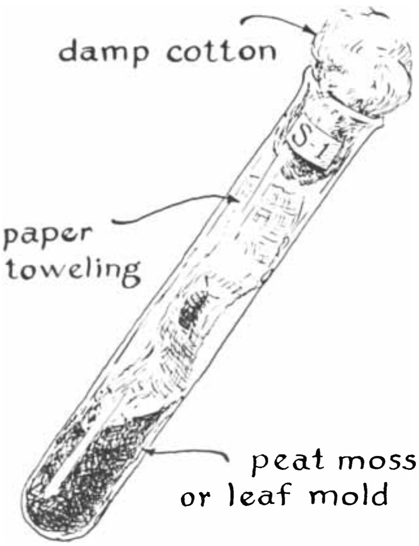
"In principle," Rowe writes, "the procedure of making a clear black-and-white photograph through the microscope differs only in detail from that of making a picture with a conventional camera. The subject should be clean, posed against an uncluttered background and properly lighted. The photographic emulsion should be capable of recording the full scale of gray tones present in the subject without displaying a grainy texture. The exposure should be sufficiently short to record an unblurred image.

"It is possible to make reasonably good photomicrographs with a fixed-focus camera, such as the inexpensive box type, if the subject is adequately lighted and the camera is supported rigidly above the eyepiece of the microscope. The front surface of the camera lens should be placed at, or very near, the point at which the rays from the eyepiece of the microscope converge. That point is called the eyepoint or the Ramsden disk. It can be located by focusing the microscope on an object, placing a screen of ground glass or white tissue paper over the eyepiece and moving the screen up and down until the disk of light that appears on the screen reaches minimum diameter. In eyepieces of conventional design the position of the Ramsden disk varies between 1/4 inch and 1/2 inch above the top surface of the upper lens.

"To make the photomicrograph place the specimen on the stage of the instrument. With live crustaceans I make the transfer by means of a pipette. Adjust the light for comfortable viewing and bring the specimen to sharp focus by eye. Center the camera over the eyepiece. Place the front surface of the camera lens at the eyepoint, darken the room and make the exposure. The correct interval of exposure must be determined experimentally. The magnification of the finished photograph, with respect to the diameter of the specimen, is equal to the visual magnification of the microscope multiplied by the amount by which the negative is enlarged during the printing process and multiplied again by the focal length of the camera lens (in millimeters) divided by 250. The accompanying photomicrograph of a female cyclops, which happened to be carrying two sacs of eggs, was made by this procedure [*see top illustration on page 147*].

"My first photomicrographs, including the one of the cyclops, were made with an old Leitz monocular microscope equipped with a condensing lens for directing light through the specimen. The light source was a photoflood bulb. The exposure interval was controlled by the shutter of the camera. The film was Eastman Kodak Plus-X. Although the 35-millimeter camera I was using was equipped with a lens-focusing mount, I adjusted it for universal focus and so it functioned like a box camera. The speed of the shutter had to be kept below 1/100 second because of the limited amount of light available from the photoflood bulb.

"During the brief exposure interval of the cyclops photograph the animal moved enough to blur the image. The intestine appears as a fuzzy dark patch and the image of one swimming appendage fades into the gray background. The gray areas of the original print have a granular texture. The area immediate-



Individual container

ly surrounding the organism also appears gritty. The shallow depth of field makes the image appear out of focus.

"Granular texture can be caused by excessive enlargement of the negative, a small change in the temperature of the solutions used for developing the negative or both. The shallow depth of field was the result of admitting light to the full aperture of the substage condensing lens. The depth of the field can be increased by closing the substage iris, thereby reducing the angle of the cone of rays that strikes the specimen. This expedient, however, would reduce the amount of light available for exposing the film, necessitating an even longer exposure and so aggravating the loss of detail occasioned by the movement of the specimen. The gritty appearance of the area adjacent to the specimen turned out to be a valid image: the organism was dirty.

"In spite of these defects the photograph disclosed several interesting details. Approximately 50 eggs can be counted in the sides of the egg sacs that face the camera. The total was perhaps twice that number. The segmented structure of the swimming appendages at the rear of the animal is clearly visible, as is the branching structure of the large antennae in front.

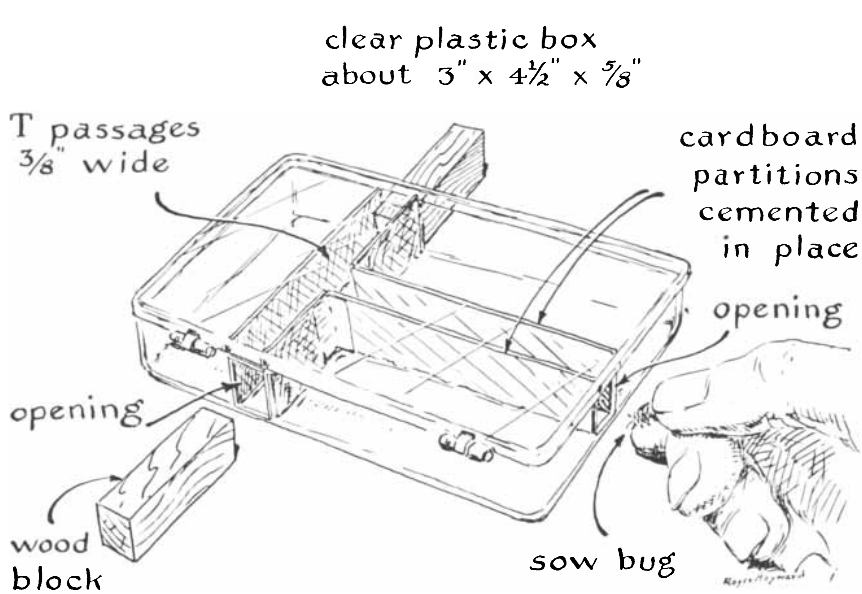
"It was apparent that a light source of more intensity would be required for improving the depth of field and reducing the exposure interval. I therefore bought an electronic flash lamp that developed a light output of 150,000 candlepower during a flash interval of 1/2,000 second. The flash tube was placed seven inches from the mirror of the microscope and covered with two sheets of white tissue paper. A green filter was also inserted in the substage to reduce the intensity of the light somewhat. The diaphragm of the camera was set at *f*/8 to minimize light reflection within the camera. (The setting of the diaphragm has no effect on the exposure because all light enters the camera through the minute Ramsden disk located on the optical axis of the lens.) The shutter was adjusted for an interval of 1/500 second. To prevent room light from reaching the film I coupled the lens barrel of the camera to the eyepiece with an adapter ring. In addition I switched to a camera fitted with an adapter for using four-inch by five-inch film (Polaroid type 55 P/N film packets). These packets deliver both a positive print and a negative that is capable of recording exceptionally fine detail.

"The results were most gratifying. Resolution was substantially improved. The problem of movement was solved by the high-speed exposure, as is evident in the accompanying photograph of a *Daphnia, Simocephalus expinosus* [*see top illustration on page 148*]. Observe in particular the fine structural features of the antennae.

"By the time I made this photograph I was using a microscope of better optical quality than the one used initially. Most of the improvement evident in the photographic print, however, resulted from the increased light, the shortened exposure and the use of the fine-grain photographic emulsion. With luck I finally succeeded in making a photograph of a daughter hydra breaking away from its parent [*see bottom illustration on page 147*]. Observe the cellular structure of the processes and the clear line of cleavage between the parent and the offspring.

"My most recent experiment consisted in adding a 101-millimeter, *f*/4.5 Graflex Optar lens, complete with diaphragm and shutter, to the standard condenser lens of the microscope and thoroughly washing the specimen before making the picture. In addition I used Eastman Panatomic-X film for the 35-millimeter camera in place of Plus-X; the former is slower and finer grained. The new condenser improved the depth of field about tenfold and also increased the contrast substantially. The cleaning procedure eliminated the foreign matter in the vicinity of the organism that not only imparted a granular texture to the surrounding fluid but also distorted the fine details of the specimen. Previously organisms had been transferred directly from the culture to the slide of the microscope by means of a pipette, which also transfers a drop of culture fluid containing bacteria and decaying matter in suspension.

"To clean the specimens I used a microculture slide in the form of a glass plate containing 12 depressions, each approximately one centimeter wide and four millimeters deep. The depressions were filled with distilled water at the same temperature as the culture solution. The organism to be cleaned was transferred to one of the depressions and allowed to swim freely for about 20 seconds. It was then transferred by means of a clean pipette to another of the depressions for 20 seconds and so on through the series of 12 baths. My next procedure was to transfer the specimen to a clean microscope slide, which I then



Apparatus for training bugs

Mike Kausch keeps busy managing conceptual studies on a variety of reentry vehicle programs. One recent day he chaired a data review session, worked up a plan for spending allocated funds, asked a technical support group to study a potential trouble spot, and read through contractors' reports to prepare for a mutual meeting. Mike has all the problems that technical managers have everywhere: he must make tough decisions, reconcile opposing viewpoints, fight the calendar, race the clock. But he also has his reward: he has a direct influence on the technical advancement of some of our most urgent defense programs. He's a Member of the Technical Staff at Aerospace.

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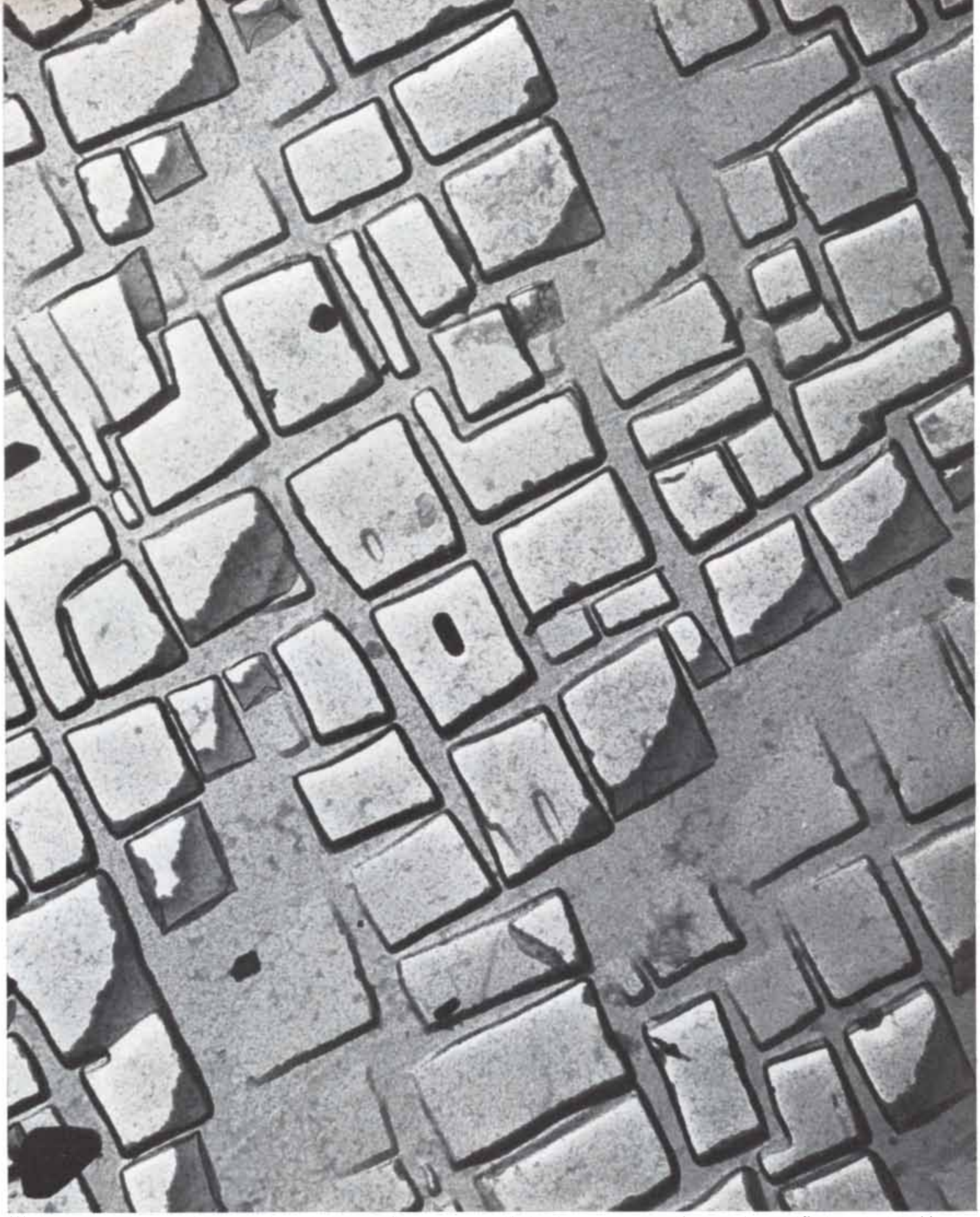
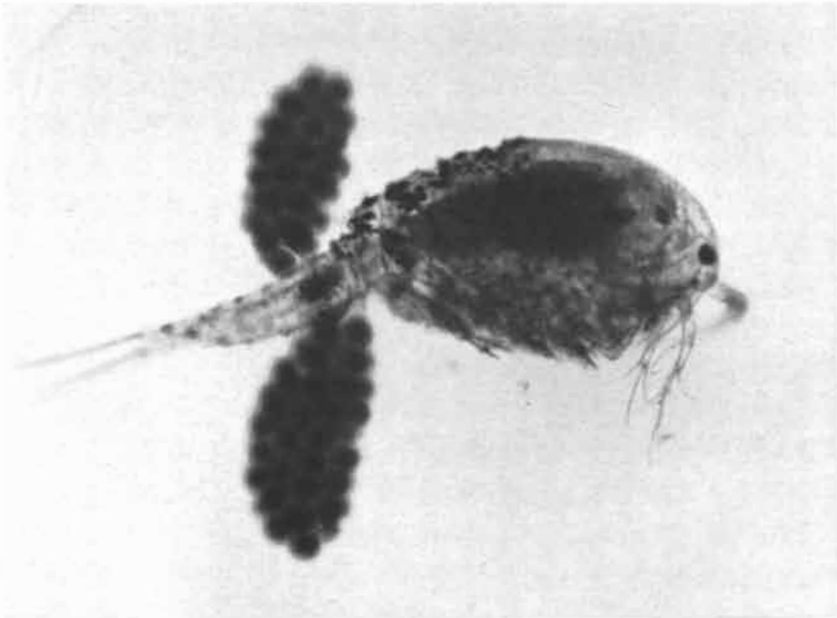


This electron micrograph shows the fine structure of the high-temperature alloy INCONEL at a magnification of 24,000 diameters. Paul D. Merica Laboratory of The International Nickel Company.

Announcing an issue of SCIENTIFIC AMERICAN devoted to the topic of

MATERIALS

To be published in September, 1967



Photomicrograph by Pete Rowe of cyclops with egg sacs

put in position on the stage of the microscope.

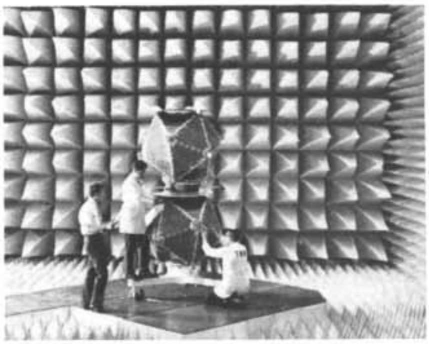
"This procedure appeared to eliminate about 95 percent of the foreign matter. The accompanying photomicrograph [*bottom of next page*] of a *Daphnia* so cleaned reveals many details not previously recorded. For example, observe the bubbles that surround the compound eye, the upper intestine, the bristle-like processes on the second branches of the antennae, the body cilia, the thoracic leg stopped on its outward stroke and, most interesting of all, the texture of the shell of the body.

"I do not want to give the impression that careful techniques can compensate for a microscope of inferior optical quality. The quality of the recorded image can be no better than that of the objective lens. Good objective lenses as well as eyepieces are now available at reasonable prices. They can be made to work almost as well on an inexpensive instrument as on one costing hundreds of dollars. The quality of the camera lens, on the other hand, is not so critical. It takes a better eye than mine to distinguish between a photomicrograph recorded by a camera priced at $35 and one by a camera that sells for $350.

"Where does the amateur who is interested in small crustaceans get specimens and how are they preserved? I collect mine from a nearby creek. A pint jar dipped anywhere along the stream contains numerous algae, hydroids, free-living copepods, ostracods and *Daphnia*. Similar organisms will be found in most freshwater brooks and pools of the U.S., particularly in late spring.

"Cultures can be maintained for some time merely by placing a bit of mud from the brook or pool in the bottom of a five-liter flask, filling the flask with water from the brook or pool and main-

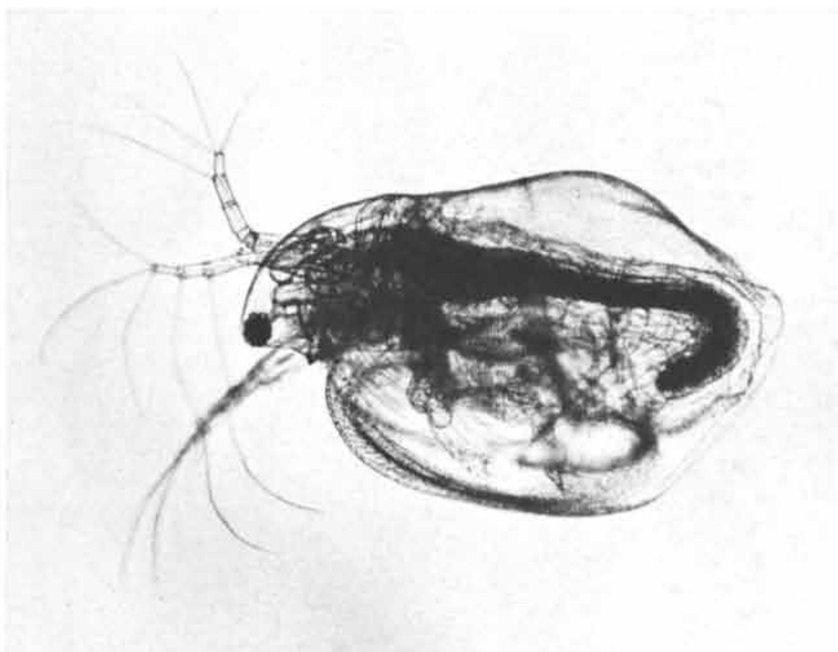
Fission of a hydra



A young Daphnia

taining the temperature. I am experimenting with a prepared culture in which *Daphnia* are fed bacteria. The bacteria, *Bacillus cereus*, are cultured on yeast extract procured from Difco Laboratories Inc., 920 Henry Street, Detroit, Mich. 48201. The solution consists of 250 milligrams of yeast extract in one liter of water. The mixture is sterilized in an autoclave, or pressure cooker, at 15 pounds for 15 minutes. When the solution has cooled to room temperature, it is inoculated with bacteria. The crustaceans are added the next day.

"As I write I have kept an adult female *Daphnia* in this medium for two weeks. The organism appears likely to have a normal span of life. I shall be pleased to communicate with anyone interested in the outcome of this experiment and others that can be done with small crustaceans. My address is 24012 Country Club Drive, Los Altos, Calif. 94022."



High-speed photomicrograph of a cleaned Daphnia

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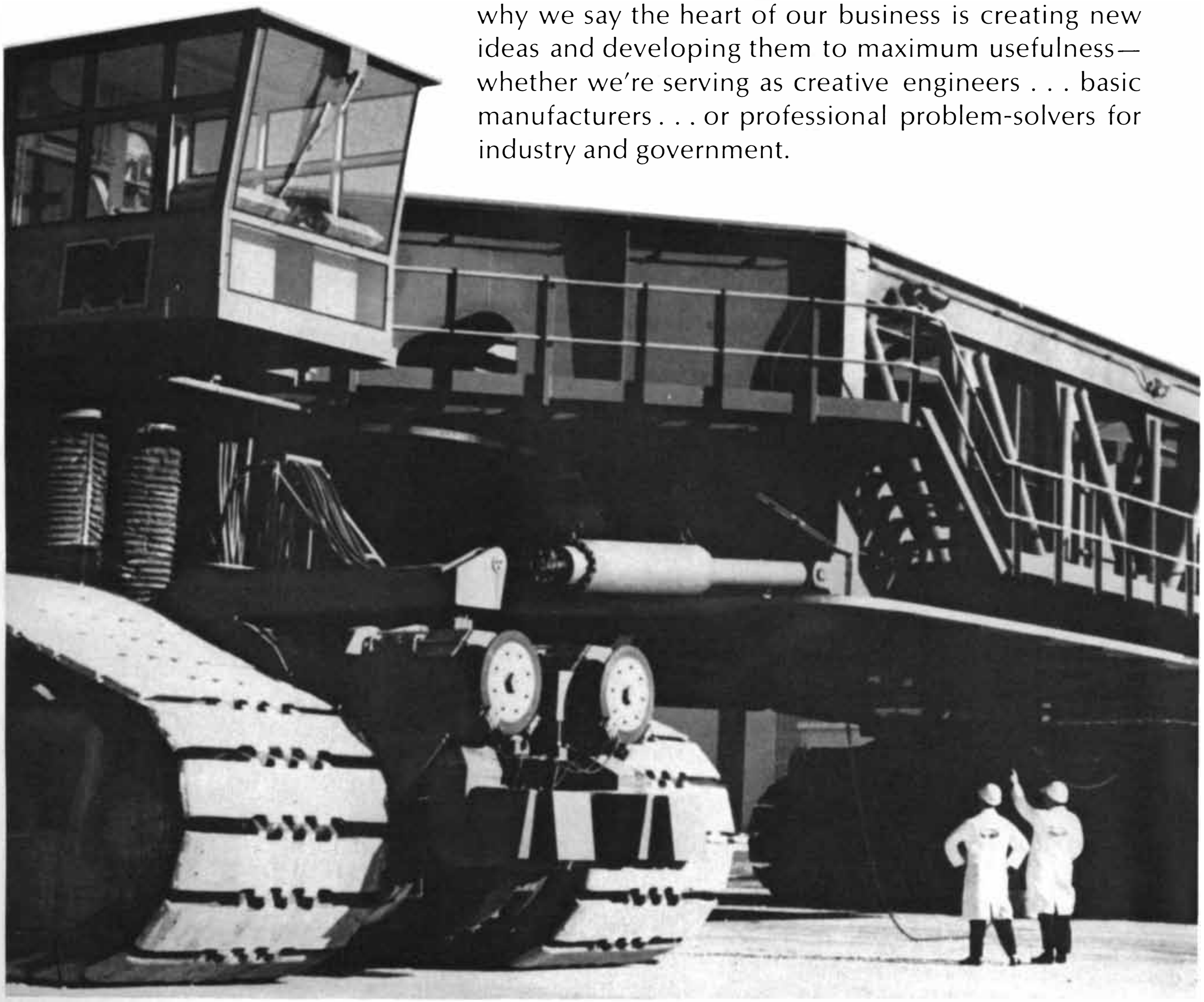

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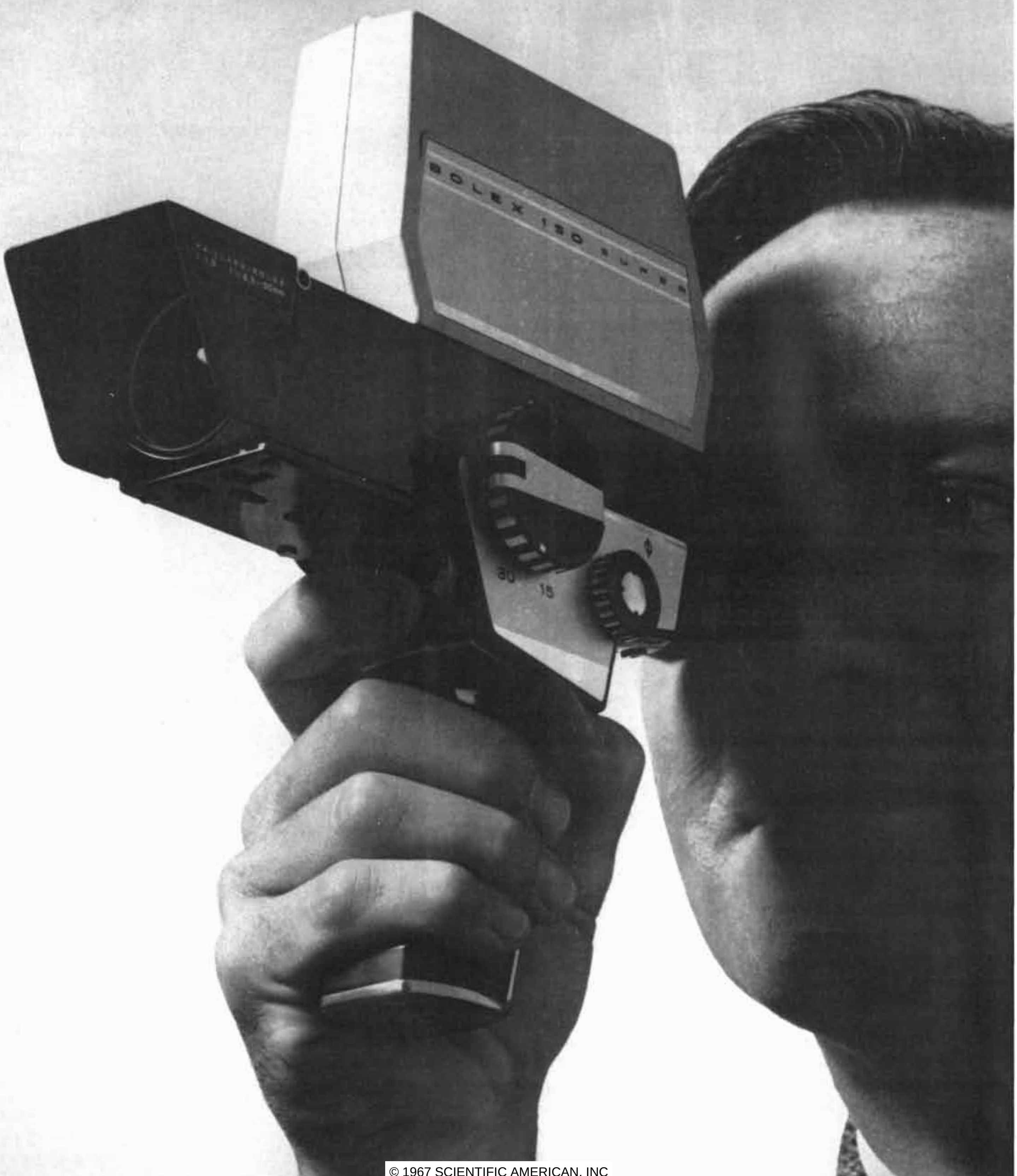

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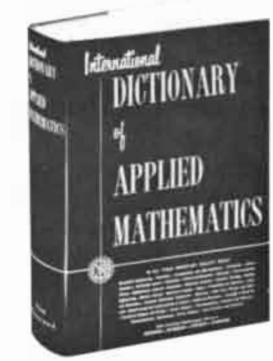

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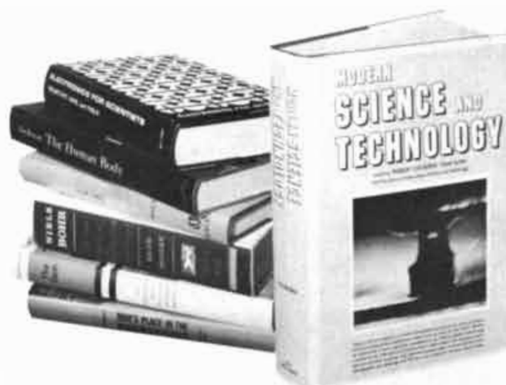

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BOOKS

How good are Audubon's bird pictures in the light of modern ornithology?

by Robert M. Mengel

THE ORIGINAL WATER-COLOR PAINTINGS BY JOHN JAMES AUDUBON FOR THE BIRDS OF AMERICA. Introduction by Marshall B. Davidson. American Heritage Publishing Co., Inc. ($75).

In Kentucky, where I grew up, nearly everyone seems to think that John James Audubon was born, came to fame and died in the bluegrass country. For me this presented special problems. As a boy I drew and studied birds (habits that have persisted into adult life). I was, so to speak, treading on sacred ground.

In the eyes of my family I was a prodigy, and at the gatherings of our large clan I would be exhibited with my latest bird pictures. Fame was pleasant, but I suffered mightily because it seemed impossible to communicate with an audience of adults whose ignorance of birds was almost as complete as their adulation of Audubon.

"Dear Bobby," one or another of my great-aunts would say, "you'll be a second Audubon!" I could never make them understand that this was not my fondest ambition, and my efforts only magnified my churlishness in rejecting the highest compliment they could offer.

It was even worse when I was shown the cherished Audubon prints that hung in the home of almost every relative and family friend. "The feet are all wrong," I would blurt. Or "No bird could fly in that position." The subject was quickly dropped. Thirty years later the feet are just as wrong, and the bird still would not be able to fly.

There are contradictions here. If Audubon's birds are technically inaccurate (and virtually all of them are in some way), why are they so successful? How can such a seeming blunderer be thought a great ornithologist by some ornithologists and a great artist by some artists, yet also have detractors in both groups? Why the enduring popularity of Audubon's birds among—one might say particularly among—people who have otherwise shown no interest in birds? Why are some of these same people unresponsive to the many birds that have since been drawn and painted with greater technical accuracy and a deeper understanding of the subject than Audubon ever achieved? Why are some ornithologists unresponsive, if not openly hostile, to whatever it is in Audubon that so excites laymen?

Any attempt to answer these questions must begin with the man, who cannot be separated from his work. He was born in 1785, the bastard son of Jean Audubon (by a Mlle Rabine), in what is now known as Haiti. His father, a French sea captain, took him to France, where Mme Audubon accepted him as a member of the family. As a boy he was charming but irresponsible, and strenuous efforts to discipline and educate him had little effect. His only visible talent seemed to be drawing, especially drawing birds.

In 1803 he was sent to a farm (Mill Grove) owned by his father near Philadelphia, where friends of the family could try their hand. It didn't work. After a few years of hunting, fishing and skating he impetuously married Lucy Bakewell, the daughter of a neighbor, and in 1808 they set off for the semifrontier in Kentucky. Audubon was to be a storekeeper in partnership with one Ferdinand Rozier.

That didn't work either—how could it with one partner regularly afield with gun, dog and horse or else dancing and fiddling into the night? Bankruptcy arrived in 1819, and soon Audubon moved to New Orleans, to the mystic Spanish moss and silent swamps and grape-tangled woodlands of the Creole South. His drawing of birds, continued in Kentucky, was intensified.

Here he lived for years, mostly separated from Lucy and his young sons Victor and John, making a precarious living as itinerant artist and tutor. He was constantly redrawing and revising the contents of a fattening portfolio, slowly developing the pictures that were to be the basis of a career that was still only a dream. The dream had formed in Louisville, where in 1810 he had met the great Alexander Wilson and had seen that his own crude birds were not so much worse than those with which Wilson had gained publication and fame with his *American Ornithology* (nine volumes published between 1808 and 1814).

Finally there came a critical moment, an early version of "publish or perish." Audubon decided to publish. He went East, seeking support diligently but in vain. In 1826, as a final resort, he went to England. Surprisingly he was an instant success. Almost from the start he found backers. The woodsman in buckskin, a nobody in Louisiana and Philadelphia, was a romantic sensation in England.

Subscriptions were obtained. He found a satisfactory London engraver, Robert Havell. The work of publication began. Overnight the former bankrupt became salesman, promoter, business manager, treasurer, bill collector, publisher, artist and art director of an immense undertaking.

In three years Havell had nearly run out of work, so Audubon recrossed the Atlantic (three times in all) in search of more birds and more subscriptions. He explored the wild south Atlantic coast; the white beaches, mangrove flats and emerald waters of the Florida Keys; the bleak, rocky coasts of Maine and Labrador. Lucy and his sons had rejoined him.

In 1838, the great work completed, Audubon went back to America for the last time. He had met and captivated the great: Baron Cuvier, Sir Walter Scott, Daniel Webster, President Jackson and many more, and had obtained subscriptions from most of them. Immediately he set about publishing an American edition. To this end in 1843 he undertook his last major journey, up the Missouri almost to the wilderness of the Yellowstone. His American edition was completed in 1844. Then, with Rev. John Bachman of South Carolina, he set about producing the massive *Quadrupeds of North America*. He had come a long way from Mill Grove.

But in 1846, with surprising rapidity, his tremendous energy failed. He died in 1851 in New York, in the only house he had ever owned. Lucy, surviving him by some years, gave art lessons to one George Bird Grinnell, who founded what was eventually to become the National Audubon Society. Moreover, in his last years Audubon had met and inspired the young Spencer F. Baird, a great American naturalist of the late 19th century and the architect of American vertebrate zoology at the beginning of the 20th.

What are the surviving, concrete results of Audubon's immense effort? First in importance is *The Birds of America* (1827–1838), whose four giant volumes of 39 by 29 inches are nearly the largest and among the most elegant books ever made. Their 435 hand-colored copperplate engravings display 1,065 figures of birds, representing some 440 species of the more than 750 now recorded for North America, with appropriate plants and backgrounds. Some 200 complete sets were issued at about $1,000 each. Perfect sets have recently commanded upward of $70,000. Fragmentary sets and broken copies account for the considerable number of individual prints in circulation. These have come to be known as Audubon "originals."

Although not impressive physically, the *Ornithological Biography* of 1831–1839 (five thick octavo volumes) is conceptually inseparable from *The Birds of America*, being the scientific text for its plates. Edited by the capable Scottish zoologist William MacGillivray (who contributed pioneer accounts of internal anatomy to it), it contains in addition to the accounts of birds a number of invaluable essays on the early American scene.

The "American" *Birds of America* (seven octavo volumes, 1840–1844) combines the text with much-reduced, lithographed and markedly inferior versions of the great plates. The new matter in this work is restricted to its appendix and 17 plates describing the finds made on the upper Missouri. There were several editions of the work in this form.

The last major item is Audubon's original drawings and paintings, of which only those for the *Birds* are of prime concern here. By happy circumstance all but two or three of these have been preserved by the New-York Historical Society. This has made possible the publication of the book under review.

It is a curious thing that, in spite of Audubon's fame, never before has the public—except those few (including me) fortunate enough to view one of the rare exhibitions of the originals themselves—been able to see what Audubon applied to paper with his own hands. All previous reproductions have been based on the Havell prints, and even if one has had access to the great folios, until now he has had no way of distinguishing Audubon the primary artist from Havell the secondary one.

The publishers have done a good job. Their two sumptuous volumes show the paintings about quarter-size, faithfully reproduced on fine paper with uniformly perfect register. If they seem a little weak in color and if they cannot provide the impact or quite impart the textural elegance of the huge originals, they are nonetheless revealing. The pictures are presented, of course, in their current rather than in their original state (some show the regrettable chemical deterioration of some of the strange combinations of media Audubon risked), with all the evidence of the vicissitudes that many of them have endured. Plainly visible are the notes Audubon scrawled on them and the paste-overs and other devices of correction sometimes employed. After an informative introduction by Marshall B. Davidson, a lucid commentary on the plates by Edward H. Dwight discusses valuable basic data provided by the originals. Scholars will regret the lack of documentation of some statements, but this is a minor complaint. The books are an indispensable acquisition for every major library and serious student of Audubon.

What, now that it is all before us, does this body of evidence reveal? Let us begin with the pictures.

First, Audubon, like nearly all painters before the traumatic invention of the camera, was attempting to state what he conceived to be the truth (whether directly or allegorically is unimportant). More precisely, he was trying to paint birds that were "correct" in every detail, and in a "correct" environment. We know this from incontestable evidence, for example his painstaking efforts to mount dead birds in lifelike positions by piercing them with wires, and his frantic haste to paint some specimens before the perishable colors faded.

He regularly failed in his main objective, sometimes badly. This should not be surprising. Recall that he had little training in draftsmanship, no predecessors of equal stature, no binoculars and no camera. Thus what he did right is all the more impressive.

He had a superb feeling for texture and a rare ability to render it, along with an extraordinary capacity for drawing delicate detail. He was equally solicitous of the diverse textures of feathers, the wet-soft nose of a deer, the wrinkled head of a vulture, the abrasive claws of an osprey, the gloss of a magnolia leaf or the bloom of a flower petal. He had a superb and evidently innate sense of dramatic and harmonious composition. This ability is perhaps the most important a print designer can have, and Audubon (who was always weak in the principles of landscape painting and the perception of space) was basically a printmaker. He may have been the best ever in the Western world.

Audubon, with his near-superhuman energy, combined these assets in pictures that must be forever unique. In some of them one may sense an essential "ugliness"—the messy residue of the bafflement and fury of supreme seeking—that Picasso has said is the hallmark of all true art, setting it apart from the complacent, "pretty" results of a lesser commitment. It is here that the new book is particularly revealing. We see from the originals that the truly great pictures are few, and most of them are fairly early. (It is hard to imagine any list of the 30 best that would not include the turkey gobbler, the adult bald eagle, the whooping crane, the ruffed grouse, the yellow-billed cuckoo, the mockingbird, the red-tailed hawk, the osprey, the mourning dove, the ivory-billed woodpecker, the chuck-will's-widow, the peregrine falcon, the pileated woodpecker, the Carolina parakeet and the ruby-throated hummingbird—all painted before 1830.)

To be sure, some of the later pictures are comparable in loveliness and state of finish (one would have to mention the white-crowned pigeons and the brown pelican), but their frequency decreases sharply with time and they are rare after 1834. The explanation is easy: as Audubon's powers grew the time available to him diminished. In the beginning there was only the goal of painting the best bird pictures ever made. Later there was a growing sense of urgency, of the enormity of the fundamentally unrealistic (and artistically suicidal) task of painting all the birds of America.

He had assistants working in the field, which undoubtedly helped. At first there was Joseph Mason, a young friend; later George Lehman, a hired apprentice; occasionally Maria Martin, who later married Dr. Bachman; toward the end sometimes his sons. They all rendered plants and backgrounds but rarely helped with the birds. The paintings that emerged, however, were always Audubon.

With Havell, an accomplished artist in his own right, it was different. In the early work Havell's task was simply to reproduce the originals that were given him, and he reproduced them very well indeed. Later, as the pressure increased, he came to be (albeit with notes and guidance) interpreter, improviser, finisher and alter ego. How worthy he was of this trust is revealed by the fact that "Audubon" and "Havell" are extremely difficult to separate in the finished prints. Without the originals for comparison one can have no idea of Havell's contribution.

Granting Audubon's immense talents, today one can be more interested in what he did "wrong." Here, I believe, lies the paradoxical key to understanding his immense popularity.

Careful study of the pictures will reveal three persistent types of failure. The first is a poor understanding of the avian eye and face and the resulting "expression." Why not? Most of the birds in Audubon's hands were dead; their eyelids, facial membranes and feathers were accordingly relaxed. The second type of failure, arising from the difficulties of observation in nature, was a weak comprehension of the positions birds assume. The third, due to the same difficulties, was a deficient grasp of the mechanics of flight.

Now, when Audubon was confronted by these deficiencies, he did an entirely natural thing: he endowed his birds with the *human* facial expressions and the *human* postures appropriate to the context of the picture. By the same token, when his birds are in flight or in other rapid movement (which he could not "correctly" arrest), they frequently assume the fluid, rhythmic positions of the dance. Again why not? Audubon himself, when it was necessary, had taught dancing, and is not the dance a form of composition?

Evidence for these assertions is plentiful. Consider the mockingbird, possibly the most famous Audubon picture. Here four mockingbirds assault a canebrake rattlesnake coiled around a nest amid gracefully composed fronds and blossoms of a yellow jessamine. Rattlesnakes, said the early critics, do not climb trees (they do); they do not have recurved fangs (they do). Few complained that the rattlesnake in the picture has round pupils (which rattlesnakes do not). The pupils in the picture are set in eyes that glare with remarkable expressiveness at a mockingbird whose terrified face is altogether human. So too is the frightened eye of another mockingbird that pecks at the snake's eye from behind. A third mockingbird has the bowed neck, bull shoulders and determined expression of a Churchill in wartime. The fourth, just arrived, has a look of cooler determination. All are frozen in the choreography of a dance with death. The picture is arresting, beautiful, chilling—a masterpiece of textures. But it contains not a single facial expression that can be observed in a bird or a snake!

Turn to the brown thrasher, where four birds are mortally involved with a blacksnake. A less ambitious picture, it is dramatic enough. We find the same essentials, with the touching addition of one thrasher draped helplessly over a coil of the snake. It is a lady in distress! The analogy is quite conscious, as Audubon obligingly tells us in the *Ornithological Biography*. The male, he says, "exerts all his powers to extricate his beloved mate from the coils of the vile snake which has already nearly deprived her of her life."

Take the barred owl, where the Havell version, at Audubon's instance, combines two different original drawings. The owl advances threateningly down a limb (Konrad Lorenz tells us that no predator bothers to "threaten" the "fresh cherry pie" represented by its prey), its eyes bulging fiercely in a most unowlish way, toward a gray squirrel whose eyes plead and whose paws are clasped in human supplication. The scene, incidentally, combines a nocturnal predator with an animal that happens to be abroad only during the day.

Equally instructive is the peregrine falcon. Perhaps no behavioral attitude among birds is more distinctive than the feeding posture of a falcon ("mantling," the falconers call it). That Audubon had never seen it is clearly indicated by his great picture of two young peregrines at a gruesomely sanguinary feast over a fallen teal and gadwall. The attitudes of the birds, however unfalconlike, are compelling: snarling, crouching barbarians, they quiver in triumphant bloodlust over their fallen victims. Still, the allegorical truth is there; the peregrine, the invincible and all-conquering predator, is convincingly described in human terms.

The pictures strong in the motifs of the dance are many: the yellow-billed cuckoo, the ruby-throated hummingbird—and virtually any of the great birds in flight. Certainly not in avian flight, the eagles and hawks thrust through space like leaping dancers in the ballet. The device serves remarkably well. I should not go on; once indoctrinated, anyone can play the game for hours. He will find surly old English gentlemen preparing to cane one another (the loggerhead shrike), doting mothers (the wild turkey hen) and even a dying martyr worthy of Raphael (the great black-backed gull).

It is relevant to my thesis that, when Audubon could study avian expression, he was quick to grasp it. For example, any perceptive ornithologist will quickly see that the faces of the white-tailed kites, particularly the bird drawn in side view, are authentic in every respect; there is no "human" expression here. Then Audubon reveals that these birds were drawn at leisure from living captive specimens in Charleston, S.C. ("The first I had ever seen alive")!

I think all this evidence goes a long way toward explaining the singular rapport between Audubon and his public. His birds communicate with a human audience for the precise reason that the "language" employed is human. For the same reason they baffle the well-equipped ornithologists of later generations, who have come to expect pictures of birds to look like birds. Indeed, perceptive ornithologists expect great pictures of birds to *epitomize* birds, to distill or heighten their essence—but in avian, not human, terms. It follows that even a Rembrandt attuned to this avian essence would pass unnoticed by all but the few equipped to perceive his mastery. Giants there have been; one may mention Joseph Wolf and Louis Agassiz Fuertes, excluding living persons. In a different world their fame might equal Audubon's.

So much for the graphic component. Audubon's principal text, the *Ornithological Biography*, can stand for all his prose. It is a remarkable work, and we can marvel at the very writing of its 3,000 tightly set pages in nine years. To be sure, MacGillivray's assistance and editing helped (Audubon's early deficiencies in English had never been wholly remedied), but what emerges is still Audubon. Nothing like it has ever been written.

It is a highly personal document. Its ingenuous earnestness carries across 130 years as Audubon repeatedly solicits our attention: "Dear Reader, I must now ask you to accompany me...." Often it is worth the trip. At his best he is engrossing; sometimes he is poetic (if sentimental); at his worst he departs on flights of florid fancy that have rarely been equaled, least of all in the literature of science.

Characteristically sparing no effort, he is obviously trying to tell all he knows or can remember (detailed note-taking did not become a habit with natural historians until decades later) of his beloved birds, of where they are found and when, of their habits and habitats. To these last two aspects he often devotes expansive and sometimes quite effective word pictures. He rarely cites others; the work is peculiarly his own, a work not of scholarship but of observation.

The result, however inexact and exaggerated, is pure and original field natural history. It came at an early stage of the important branching of outdoor natural history from indoor natural history—of the study of animals in their environment from the dissection and classification of specimens. From the outdoor branch were to arise such intensely focused disciplines as ecology and ethology, one day to be reunited with indoor taxonomy in the evolutionary framework called biosystematics. If Audubon's role at this early stage was highly influential, it was probably not so much for what he added to factual knowledge as for the impetus his strangely transcendental fame imparted to the outdoor study of animals.

Only late in life did Audubon begin to acquire a formal knowledge of terminology, anatomy, nomenclature and the literature necessary even in his day for effective work in systematic ornithology. Even so, he still left a considerable mark on taxonomy: inevitably some of the birds he described were new. Attributed to Audubon in the 1957 American Ornithologists' Union Check-list are one genus, 23 species and 12 subspecies. That he had basically a good eye for biological difference is clearly indicated by his detection of such obscure forms as Traill's flycatcher, the Carolina chickadee, Sprague's pipit, Bell's vireo, Baird's sparrow, Henslow's sparrow, Lincoln's sparrow and the western meadowlark.

In Pennsylvania, Audubon had conducted a pioneer experiment in birdbanding. He was also involved in another experimental venture. Constantly under attack by certain small spirits of his day (notably "Wilsonites" under the leadership of George Ord in Philadelphia), in 1826 he was explicitly criticized for his statement that vultures find their food by sight, not smell. Audubon and Bachman, with invited witnesses, conducted experiments at Charleston that tended to support Audubon's position. Although later experiments have yielded results interpreted both ways, the Audubon-Bachman "victory" has been cited by every sympathetic Audubon biography (including the book under review) as a triumph of virtue over vice. We now know, however, that the critics were right, although probably for the wrong reasons. It has been shown conclusively that turkey vultures, at least, do have a well-developed sense of smell, which they use whenever possible (K. E. Stager, *Los Angeles County Museum Contributions to Science*, No. 81, 1964).

No matter. Audubon had everything

essential to greatness: vast energy, personal charisma, some luck, talent and a total inability to accept defeat. Like a good idea, greatness will not be put down; not by pettiness and jealousy; not by rumor and slander; not by misunderstanding, even on the part of small boys dissatisfied with the mistakes in a drawing. It has the prerogative of error.

The fact remains that neither Audubon's powerful personality nor the virtues of his art nor his genuine contributions to science can explain his unique reputation today. This reputation stands in relation to the subsequent history of the things he believed in and most loved in a distorted and quite unnatural way. I have tried to show that many who think he was great do so for the wrong reasons, not for the love and appreciation of birds that were his own outstanding traits. We can place much of the blame on eulogists who repeat the claim, as Davidson does in the introduction to this book, that "Audubon has taught us to see birds." The result seems to have been quite the opposite. The eulogists betray themselves: when they say that Audubon's birds were vastly superior to any that had gone before, they imply that nothing has happened since. Audubon has painted the birds, they seem to say, and that takes care of that. As far as I know this curious situation has no parallel. It is not in the true spirit of art or science, or of Audubon himself.

Short Reviews

SURTSEY: THE NEW ISLAND IN THE NORTH ATLANTIC, by Sigurdur Thorarinsson. The Viking Press ($6). Some 20 years ago a small dark pit opened up in a peaceful cornfield in the state of Michoacán, to the west of Mexico City. That was the first sign of the birth of the half-mile-high volcano Paricutín. The first indication of the newest volcano—Surtur in the North Atlantic—was a bad smell. Farmers on the neighboring Vestmann Islands had noticed sulfurous odors for three days; then, just after dawn on November 14, 1963, Captain Tómasson saw through his binoculars black columns of ash rising from the sea a mile from his fishing vessel. Surtur had been born 425 feet below the surface of the sea and now had grown large enough to hurl its ejecta out of the water. The geologists (including the author of this personal, fascinating and handsome book) arrived before noon on the same day. By that time the eruption column towered two miles into the wintry air, and by the next morning Surtsey (Surtur's island) was 30 feet above sea level.

This book is the story of Surtur and Surtsey written in October, 1966, when the island, although it was still changing daily, had plainly come to stay 20 miles off the southwestern shore of Iceland. The island is no longer a mere heap of pumice and ash; more than half of its square mile of area is hard lava, 300 feet above sea level at the summit. Surtsey is made up of lava cliffs, cut in a few days by the indignant sea, great sea-worn boulders, tossed ashore only to be buried in the next flood of lava, and beaches of black glassy sand. The eruption is not yet over. A second new island appeared, only to be reclaimed by the sea; another islet aborted below the surface. Several fissures have been active, and the struggle between Pluto and Neptune has been enacted daily for three years before the eyes of tourists and scientists, pilots and fishermen. The color photographs that are the crown of the book bring the battle before our eyes too. That colorful eruption column drew aircraft as a lamp does moths; we can see them here, as well as their photographic prizes. Most awesome was the constant play of lightning flashes every few seconds above and within the rising column of electrically charged ash; we share the author's astonishment as he stands in a rolling coast guard cutter in the heavy seas of an Iceland winter, the sea steaming, whirlwinds spinning wildly around the rising thermal column of the volcano, lightning flashing, thunder constant amid the sound and the splash of the heavy bombs of lava falling into the lukewarm sea up to a mile away from Surtsey, while the ash rained down, turning the decks black. (The geologists found this an easy way to collect their samples; the deck-swabbing seamen grumbled.) The explosive phase lasted more than four months; the lava then began to flow, and was still flowing late last year.

Life has a precarious grasp on Surtsey. Microorganisms, flies and butterflies were found in the first summer season; on the beaches live many animals washed up by the sea; gulls and kittiwakes have nested there, in cliffs only half a year old. The first green plant to take root on Surtsey was a sea rocket, a species with a circlet of succulent coarse leaves close to the ground, found on sandy shores on the southern coast of Iceland. Its seeds are borne by the waves. Dozens of them struck root in the summer of 1965, but these first settlers were buried by ash falls. Surtsey is a legal sanctuary for all its life; a headquarters house for scientists was built there late in 1965. In the summer of 1966 that houseful of delighted watchers made the new island as densely populated overall as the mainland of Iceland!

Nine times in a period of 1,000 years men have seen submarine eruptions not far from Surtsey, where the great mid-Atlantic ridge emerges to make the fiery spine of Iceland. The land has known a volcanic eruption on the average of every five years. Other islets have emerged transiently, but Surtsey is the first to seem enduring. Herbert of Clairvaux wrote an account of Iceland in his *Liber miraculorum* of 1180, reporting the tale of the Archbishop of Lund, a guest at his monastery: "Fire is seen to break with stupendous force out of the ocean high above the waves." What Herbert only heard with wonder we can see pictured in the book's two dozen photographs. A cubic kilometer of material, and the equivalent of a couple of megatons of TNT in energy, are the measure of the splendid birth of Surtsey. It is all told here, briefly and vividly, with excellent maps and tables.

'HARD TIMES': HUMAN DOCUMENTS OF THE INDUSTRIAL REVOLUTION, by E. Royston Pike. Frederick A. Praeger, Publishers ($8.50). A century after those vivid footnotes in *Capital*, this volume collects contemporary documents, testimony, official reports, exposés and speeches concerning human life during the years when the first industrial society arose and the black country displaced England's green and pleasant land. There are some 250 documents in the book, with a number of contemporary drawings and engravings. This is the Industrial Revolution raw; we need to reflect on it in these days when so many lands are trying to scale the bitter cliffs of capital that guard the hope and the power of industry.

Hear Joseph Badder, a spinner in Leicester, testifying before the Factory Commission in 1833: "I have frequently had complaints against myself by the parents of children for beating them. I used to beat them. I am sure that no man can do without it who works long hours.... The master expected me to do my work, and I could not do mine unless they did theirs.... I have seen them fall asleep, and they have been performing their work with their hands while they were asleep, after the billy had stopped, when their work was over. I have stopped and looked at them for two minutes, going through the motions of piecening fast asleep, when there was really no work to do...." The House of Commons declined to pass Mr. Sadler's bill limiting employment in factories to children older than nine.

Margaret Leveston, a six-year-old coal-bearer in the East of Scotland in 1842, told Sub-Commissioner Franks (who found her "a most interesting child, and perfectly beautiful"): "Been down at coal-carrying six weeks; makes ten to fourteen rakes (journeys by ladder to the pit bottom) a day; carries full 56 pounds of coal in a wooden backit. The work is na guid; it is so very sair. I work with sister Jesse and mother; dinna ken the time we gang; it is gai dark."

A cloth-dresser from Leeds testified before Mr. Sadler's Committee in 1831: "As to their not having so many illegitimate children, the reason is plain enough; there are certain books which have gone forth to inform depraved persons of a way by which they may indulge their corrupt passions, and still avoid having illegitimate children."

"Do you mean that certain books, the disgrace of the age, have been put forth and circulated among the females in factories, to the effect you state?" "Yes."

THE NEW MATHEMATICS AND AN OLD CULTURE: A STUDY OF LEARNING AMONG THE KPELLE OF LIBERIA, by John Gay and Michael Cole. Holt, Rinehart and Winston, Inc. ($1.95). The Kpelle are a people numbering some 150,000 who live deep in the rain forest 50 miles inland from Monrovia in Liberia, where they struggle to grow swamp rice, peppers and palm oil from their washed-out laterite soil. They have known Lutheran and Mandingo missionaries, traders from Lebanon and engineers from Akron, and now their children go to some 60 English-using primary schools run by the Liberian government and the big companies. Theirs is the culture of the great secret societies such as the Poro, whose magnificent masks are found in museums the world over. The Poro secretly penetrates all life; birth, initiation, marriage, conflict and death are dominated by it more than the cathedral ever dominated the life of Chartres. The rote learning of words and tasks infuses the school; a child who brought in an insect to show its six legs to the teacher who had defined insects as eight-legged was naturally beaten.

This booklet is the fascinating story of tests in logical, geometrical and estimational tasks set to Kpelle schoolchildren and adults, and to their counterparts in New Haven, Conn. Most Kpelle, children or adults, simply cannot sort pictures of men and women, printed one to a few per card on red or green cards, into logical groups in more than one way. American 12-year-olds easily sorted them three times: by number, color and sex. But the Kpelle can estimate the number of cups of rice in a bowl to plus or minus 5 percent; Americans fail badly at that test. Kpelle schoolchildren learn logical associations by choosing from colored squares more quickly than either American children or adults. Their generally rich and subtle language has names, however, for only a few shapes.

What follows from this cross-cultural psychological and linguistic study is not yet very striking. Plainly the Kpelle have a hermetic, traditional culture that once had a high adaptive value. They are not easily led to make or to follow new rules on their own, although they are fully able to solve individual tasks whenever the task has had any roots in their lives. To teach them mathematics and science well means to draw on what they have of language and experience and to show them how a universal power can become theirs. That Kpelle life will change under this exposure is all but certain; that they themselves must choose and shape that changing is the hope of the authors, given in the final sentence of the book.

The booklet is part of a new and intriguing series of case studies in the relation between culture and education; three others have been published, treating of individual schools in Japan, Germany and Canada.

ARCHAEOLOGICAL CHEMISTRY: A SYMPOSIUM, edited by Martin Levey. University of Pennsylvania Press ($8.50). In the very fabric of every ancient artifact is somehow written how, when and where it was made. These ciphers can be read by the use of the entire arsenal of our present modes of the analysis of matter. Often the analyst cannot chip off from the precious whole a suitable sample; he must make his analytical bricks without straw or clay. This book presents 15 different studies in three tongues by scholars from such places as Madras, Nagoya, Leningrad, Mainz and Long Island, as reported five years ago. The reports are themselves a summary of methods: among the many are infrared spectroscopy, beta-ray backscattering, X-ray diffraction, spectrochemistry and metallography. All appear with careful statistical comparison and studies of ancient texts.

One of these analyses must here stand for the others. At Montefiascone, in an Etruscan tomb of the fourth century B.C., an iron spearhead was found. Heavily corroded, it was cleaned of its black crust by electrolysis; it is pictured in the book, a frayed laurel leaf four inches long. The spearhead could be sectioned, and the metallographer found that the piece had been made by the welded Damascus technique. The smith had forged a central sheet of hard steel, about .5 percent carbon, and to it on each side had forge-welded a five-layered deck mainly of soft steel sheets. The hardened central sheet formed the tip and edges, bared in use by honing. The thinnest layers—the entire blade is nowhere as much as a centimeter thick—were less than 100 microns thick. They were placed under the scanning electron microbeam for point-by-point X-ray analysis. Two layers, one on each side of the blade, proved to consist of a nickel alloy; the nickel content varied locally from 10 percent to 30, with traces of cobalt. The other layers were quite pure iron-carbon soft steels.

The authors conclude that the spearhead, so knowingly made by a patient and sophisticated craft, incorporated two layers of meteoritic nickel-iron. Indeed, a certain small axe found in Poland, dating from the ancient Hallstatt culture, is known also to have two layers of meteoritic iron. The natural nickel alloy is present in too thin a layer to have any utilitarian function, but it was the very "metal of heaven," as the Sumerians called iron itself. The microprobe, one feels, has penetrated not only a blade but also the minds of the men who made and used that spear when Rome was young, men whose written language we do not yet command but whose purposes we begin to see.

FIRST CONCEPTS OF TOPOLOGY: THE GEOMETRY OF MAPPINGS OF SEGMENTS, CURVES, CIRCLES, AND DISKS, by W. G. Chinn and N. E. Steenrod. Random House ($1.95). By now everyone knows about the topological surprises twisted into the Möbius strip. This clear and winning little book, for readers willing to come to genuine grips with the idea of a mathematical proof, presents topology otherwise—as mathematicians see it. The parlor tricks are gracefully alluded to here and there, but they are distinctly for after hours. The center of interest is the stuff itself: the powerful notions of set theory are honestly and not merely verbally exploited to define open sets and their coverings, and from them the key theorems, which go back only a few decades, built on the ideas of sets that are compact and connected. Topology is the study of such sets and their mappings. How this austere topic becomes "rubber-sheet geometry" is made quite plain in the exposition and in the examples, which carry the flavor of the elegance of mathematical proof but fill out its thin, severe line with uniform grace and interest. Having spent half the book in this vein to establish the proposition that a continuous function takes on all values between its extremes, the authors press this theorem into yeoman service. The same quest is embarked on in Part II but now in two dimensions, for two functions, and the winding number appears as a new topological concept. The two-page epilogue, which carries the matter into higher dimensions, is too sketchy, but with that single objection the book is otherwise satisfying. It conveys a sense of an understanding of the mathematics of today, or anyhow of yesterday. The interplay of strict theorem and picturesque example is sustained. One cannot any longer doubt that a single stroke of a knife exists that divides any irregular ham sandwich so that ham and both bread slices can be shared with perfect fairness by two consumers.

PRINCIPLES OF ASTROMETRY, by Peter van de Kamp. W. H. Freeman and Company ($6.50). Showy photographs of remote galaxies are the commonplaces of our magazines. They bear witness to the world leadership in observational astronomy that has been held in Wisconsin and California and Texas since the 19th century. This book tells quite another story: how the work of Frank Schlesinger and a handful of able colleagues and successors in America and later in Europe set the geometrical bench marks on which our map of the galaxy and indeed of the entire universe ultimately rests. For the visual micrometer screws and spider-web cross hairs of pioneers such as F. W. Bessel they substituted painstaking photography. They used the great telescopes not for light-gathering but for their long focal length, so that the images become of measurable size. Professor van de Kamp, himself a veteran authority in the field, has produced an almost unique book. It is a careful and straightforward introduction to the methods and results of long-focus photographic astrometry as now practiced, accessible for any reader with sophomore college mathematics or better. The unblinking care, and above all the depth of understanding of instrument and phenomenon, that it takes to learn stellar distances and motions (or one day to search out the planets of those distant suns) are made clear. Finding the dark companion of Barnard's star was the result of measurements made on about 2,500 plates, exposed three or four times each over 600 nights scattered across nearly 50 years, all with the same 24-inch instrument at Swarthmore College. The wiggles that signified the Jupiter-like companion of the star are a matter

Statue of Benjamin Franklin by James Earle Fraser in The Franklin Institute, Philadelphia of a micron either way, superimposed on fiftyfold larger motions from parallax, atmospheric refraction, lens changes, guiding-and-measurement errors and all the rest. The convincing result is its own highest praise. How photomultipliers, quartz and feedback will someday change this conservative and important field we do not know, but the impression gained from this fine book is that of a powerful technique at its culmination.

THE ART OF AMERICAN INDIAN COOKING, by Yeffe Kimball and Jean Anderson. Doubleday & Company, Inc. ($4.50). The clambake, properly layered in boiling seawater; baked beans, pit-steamed and flavored with maple sirup, and cranberry sauce for the oyster-stuffed turkey are the dainties of the Narragansett and the Penobscot, transmitted by way of the early settlers to our tables. The place of the Americas in setting the world's table, with tomato, potato, peanut, pumpkin, avocado and maize, is made real in this pleasant collection of 200 recipes, attractively illustrated with free line drawings of eggs and metates and oyster shells by Miss Kimball, herself an Osage. The red salmon caviar was dried in the sun and spread on buckskin bread for the men of the Northwest fishing peoples, and they enjoyed their smoked salmon with scrambled eggs (Bronx papers please copy!). Batter-fried squash blossoms—the larger male flowers are preferred—make an excellent hors d'oeuvre, and the Zuñi green chili stew, flavored with juniper berries, is a bubbling and substantial staple.

This imaginative and useful little cookbook celebrates the cuisine of the first men in our land, no mean monument to their patient and knowing gardening, to the huntsman's eye and to his wife's loving art. To be sure, these recipes are not pedantically pre-Columbian; the version given of *m'sick-quotash* of the Virginians calls for corn and beans from frozen packages and uses bacon instead of the authentic bear's fat. Wheat, flour, sugar, pork all appear. Supermarkets with good bear grease are hard to find.

Let the Kwakiutl have the last word: try whipped fresh raspberries in honey.

SYMMETRY ASPECTS OF M. C. ESCHER'S PERIODIC DRAWINGS, by Caroline H. Macgillavry. A. Oosthoek's Uitgeversmaatschappij NV, Utrecht, for the International Union of Crystallography ($10). The professor of chemical crystallography at the University of Amsterdam has organized this unique and beautiful book from the corpus of marvelous space-filling periodic drawings made over two decades by the artist Maurits C. Escher. Adding a few specially drawn for this work, Escher has here given us the classical crystal groups in the plane, and a good many more that exploit the latest extensions to color symmetry, foreseen by the artist before mathematicians had officially recognized and classified them. Here are 40 plates: fishes, knights, tadpoles, blossoms, starfish, angels and demons, all marching conformably to the laws of the crystal group, most in eye-filling color. A supple text page describes and points out what is noteworthy in each example for the student of crystallography. Tracing and translating the pattern skeleton for each example will be a royal road for undergraduate students and a joy for artists, indeed for all who have eyes to see and minds to delight at the bounty of symmetry. The fivefold violet flowers arranged in a threefold pattern among green leaves are an unforgettable sermon against the pentagonal crystal. Only the motion-picture screen might do it better.

CALDER: AN AUTOBIOGRAPHY WITH PICTURES. Pantheon Books ($15). Alexander Stirling Calder was a Philadelphia sculptor. His son Alexander was graduated from the Stevens Institute of Technology as a mechanical engineer. Somehow he found himself sliding out of the drafting room to the Art Students League. This hefty book is his conversational life story, frank and funny, told memory by memory to his son-in-law. The pictures tell the rest of the tale, from the wire circus to the great arching stabiles, delights across half the world.

THE POPPY AND OTHER DEADLY PLANTS, by Esther Baskin. Drawings by Leonard Baskin. Delacorte Press ($12.50). This thin volume holds its dozen large, strong prints and its text, sounding like some Gothic field guide, between end papers colored poppy orange. Mandrake, poison hemlock, deadly nightshade and henbane, with their poisonous peers, are spread in stunning and sinister beauty over these precise and varied plates.

SHIPS AND BOATS: THE NATURE OF THEIR DESIGN, by Douglas Phillips-Birt. Reinhold Publishing Corporation ($2.45). A study of the relationship of form and function at sea, from galleon, clipper and America's Cup racer—often a decadent form with "the fascination of sin"—to the battleship and the eventual obsolescence of sea-surface travel (and then of navies?). A beautifully made paperback.

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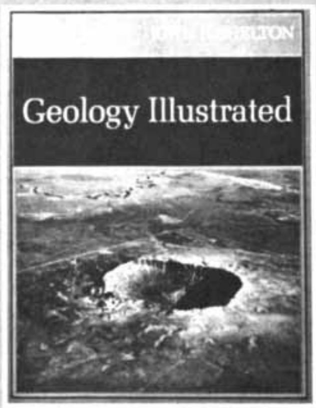

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