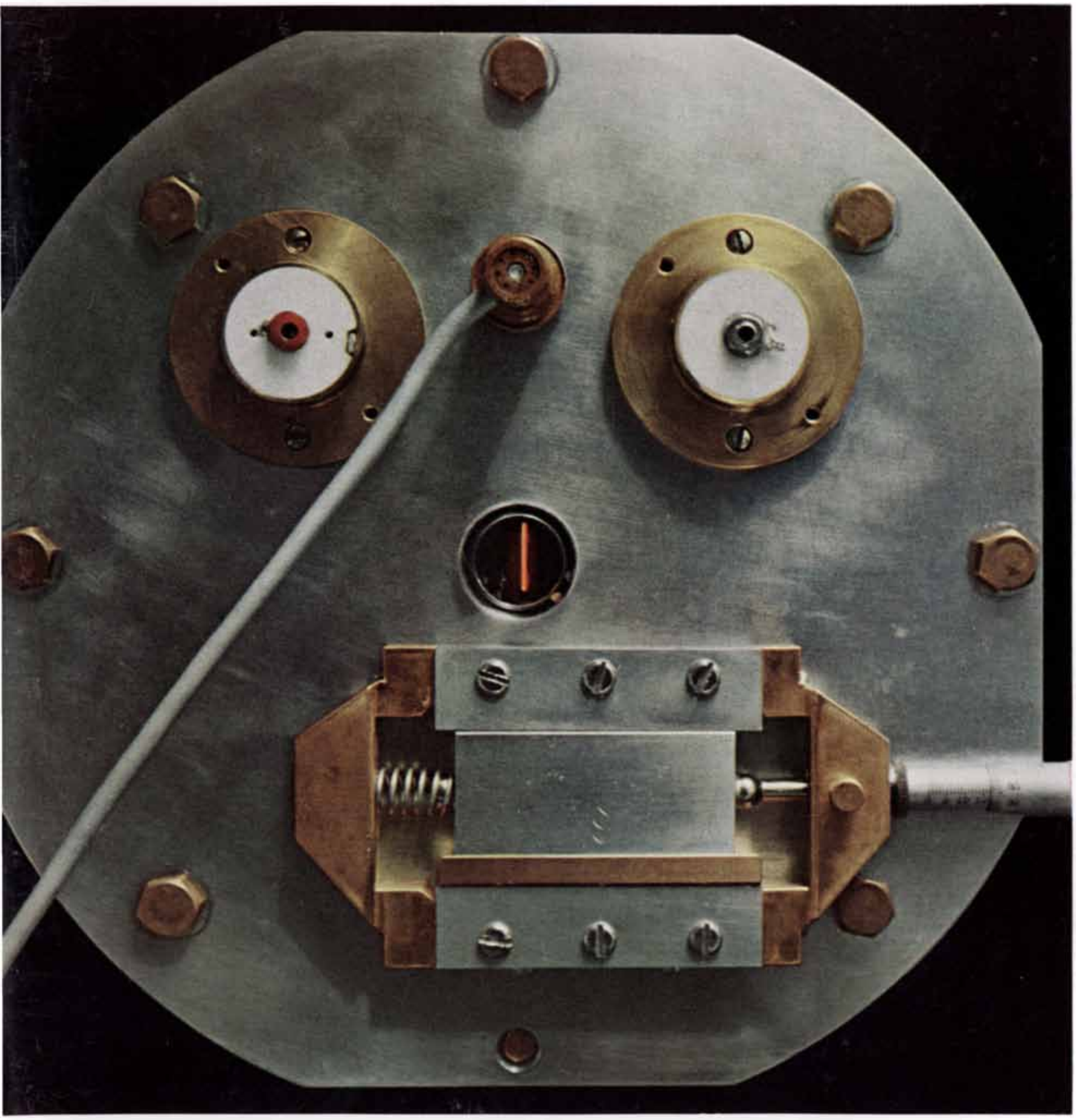
SCIENTIFIC AMERICAN



CESIUM CLOCK

SEVENTY-FIVE CENTS

June 1968

Established 1845 **SCIENTIFIC AMERICAN** June 1968 Volume 218 Number 6

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. COPYRIGHT © 1968 BY SCIENTIFIC AMERICAN, INC. ALL RIGHTS RESERVED. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $8 PER YEAR.

THE COVER

The photograph on the cover shows the "face" of the atomic clock that provides the U.S. and much of the rest of the world with its standard of time. It was built by the National Bureau of Standards and is located at a Bureau laboratory in Boulder, Colo. Another photograph of the atomic clock and a short description of how it generates time signals can be found on page 61, in the article "Standards of Measurement." The clock exploits the natural precession frequency of the nucleus of the isotope cesium 133 when it is in a particular energy state. This frequency, 9,192,631,770 cycles per second, is now the official definition of the second. The glowing wire visible in the window in the center of the plate on the cover is a filament that heats a small furnace containing atoms of cesium 133. When the atoms boil out of the furnace, they begin their timekeeping journey down a stainless-steel tube about 8½ inches in diameter and 18 feet long. The clock's margin of error is plus or minus one second in a period of 6,000 years.

THE ILLUSTRATIONS

Cover photograph by Sol Mednick

Page	Source	Page	Source
18–22	Jim Egleson	79	Foto Kleinfeldt, Tübingen
23	Bell Telephone Laboratories	80–83	Alfred E. Mirsky, Rockefeller University
25	J. L. Giddings, Jr., Brown University	91	Leonard E. Samuels, Defence Standards Laboratory, Commonwealth of Australia
26	U.S. Geological Survey	92–97	Allen Beechel
27–32	Eric Mose	98	B. Shiralkar, Massachusetts Institute of Technology (*top*); Allen Beechel (*bottom*)
33	Douglas D. Anderson, Brown University	103	R. D. Preston, University of Leeds
35–40	Joan Starwood	104–105	Tom Prentiss
51–53	Sol Mednick	106–107	Tom Prentiss (*top*); Tom Prentiss and R. D. Preston, University of Leeds (*bottom*)
54–56	Dan Todd	108	R. D. Preston, University of Leeds
57	National Bureau of Standards	113	Jerome Kuhl
58–60	Dan Todd	114	Chieko Yoshida
61	National Bureau of Standards	117	Jerome Kuhl
62	Dan Todd	122–126	Roger Hayward
64	Bunji Tagawa		
65	Laurence Jay Stettner, Wayne State University, and Bunji Tagawa		
66–75	Bunji Tagawa		

LETTERS

Sirs:

I agree with Victor F. Weisskopf's contention, in his review of Daniel S. Greenberg's *The Politics of Pure Science* [SCIENTIFIC AMERICAN, March], that basic science provides a tone and standard for all science and technology, and that this is one of the most compelling reasons for supporting basic science.

My disagreement with Professor Weisskopf revolves around his claim for urgency in pursuit of what he calls frontier sciences—high-energy physics, stellar astronomy, cosmology. It is not that one need doubt the intrinsic beauty and intellectual challenge of Professor Weisskopf's frontier. It is merely that there is no justification for imputing to these fields an urgency that matches the urgency of fields which do interact much more strongly with the rest of science, not to say technology, than do Professor Weisskopf's frontier sciences. Professor Weisskopf's argument that the human environment is likely to be vastly changed in the foreseeable future by discoveries at his frontier seem highly unlikely to me; the arguments for my belief were presented by Gerald Feinberg in his article "Ordinary Matter" [SCIENTIFIC AMERICAN, May, 1967].

Nor can I agree with Professor Weisskopf when he implies that such fields demand urgent support because they are so relevant to scientific education. By contrast, I should think that the "obviously applicable" sciences, even in their basic aspects, are much better vehicles for scientific instruction than are the frontier sciences. Examining bubble-chamber plates strikes me as being a less stimulating research experience than making a molecular accelerator work.

Professor Weisskopf does not address himself directly to just why basic physical science finds itself in its present bind. An important part of the answer is that such science has been supported primarily by three Government agencies—the Department of Defense, the Atomic Energy Commission and the National Aeronautics and Space Administration—that view these sciences as a means of accomplishing their missions, not primarily as ends in themselves. The budgets of these agencies (always excluding Vietnam) have hardly expanded, and in consequence the basic science they support suffers.

I see two avenues out of the impasse. The first, which has been discussed in the National Academy of Sciences report *Basic Science and National Goals,* is to support the National Science Foundation much more strongly than it has been supported. Had the Vietnam escalation not intervened, this might have happened; I hope it does happen after Vietnam has been settled.

The second avenue is to draw support for basic physical science from some of the new, "socially oriented" agencies such as the Department of Housing and Urban Development, the Department of Transportation and the Environmental Science Services Administration. Insofar as the hard sciences and technology bear on the mission of these agencies, they have a responsibility to contribute to the support of those basic sciences that underlie the relevant applied sciences and that promote a proper spirit for their creative pursuit.

ALVIN M. WEINBERG

Director
Oak Ridge National Laboratory
Oak Ridge, Tenn.

Sirs:

Stanley Coopersmith's article "Studies in Self-esteem" [SCIENTIFIC AMERICAN, February] seems guilty of such implicit value judgments as that high self-esteem, extroversion and adjustment are good. If one is an applied scientist rather than a disguised moralist, such ethical assumptions are made explicit. Had Coopersmith done so, one wonders if even he would willingly carry these value premises (in conjunction with his empirical assumptions) to their logical conclusions.

The high self-esteem he apparently considers a goal of psychotherapy is cheerfully espoused in that vulgarization of pragmatic philosophy called "the power of positive thinking." But those not yet blinded by this glittering euphemism have recognized "positive thinking" as a camouflage for anti-intellectualism. And the "well-adjusted extrovert" is most likely to be the "positive thinker."

The relationship between high self-esteem, "positive thinking," adjustment and extroversion depends on the schizophrenic character of Western civilization. On the one hand it espouses a Christian-brotherhood ethic; on the other, a cutthroat competitive value. Hence its typical citizen is taught conflicting values; strange bedfellows thus come to lie within the chambers of his unconscious. If consciously aware of such conflict, he will not enjoy high self-esteem—knowing that success by one part of himself implies failure by another. If, however, he remains compartmentalized (unaware that his values contradict), high self-esteem may be his. For refusal to think negative thoughts (that is, living in a fool's paradise) raises self-esteem. And spending much time with other compartmentalizers (that is, being an "extrovert") helps to prevent those self-reflections which would render him painfully aware that his values clash.

Consider the Christian businessman. On Sunday he piously proclaims: "Do unto others as you would have others do unto you!" On Monday he retorts: "Do others before others can do you!" On Sunday: "I've got to look out for my brother!" On Monday: "I've got to look out for Number One!" Sunday: " 'Tis better to give than to receive!" Monday: "There's a sucker born every minute! Business is business! Caveat emptor!"

Yet if he remains unaware that the conflict is there, all will seem right with the world—our "positive-thinking," extroverted businessman will enjoy high self-esteem. In Coopersmith's view such a man would be mentally healthy, whereas Socrates, Christ, Gandhi, Martin Luther King and many other such

Scientific American, June, 1968; Vol. 218, No. 6. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Allan Wittman, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 20 cents.

Microfilm correspondence and orders should be addressed to Department SA, University Microfilms, Ann Arbor, Mich. 48107.

Subscription rates: one year, $8; two years, $15; three years, $21. These rates apply throughout the world. Subscribers in the United Kingdom may remit to Midland Bank Limited, 69 Pall Mall, London SW 1, England, for the account of Scientific American, Inc.: one year, two pounds 18 shillings; two years, five pounds eight shillings; three years, seven pounds 11 shillings.

Change of address: please notify us four weeks in advance of change. If available, kindly furnish an address imprint from a recent issue. Be sure to give both old and new addresses, including ZIP-code numbers, if any.

prophets and philosophers would be in need of psychotherapy.

LAWRENCE LA FAVE

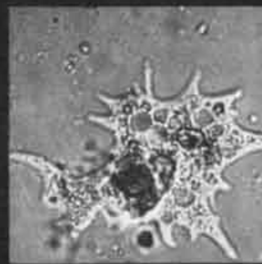
Indiana State University
Terre Haute, Ind.

Sirs:

I believe La Fave is tilting at a windmill of his own design. The sport apparently intrigues him, but it is confusing for those of us who appreciate attentive reading of scientific studies. The results reported in my article represent the findings obtained in studies of contemporary American children and their families. La Fave's disagreement with these findings leads him to believe they derive from my value judgments and assumptions about the goals and ethics of human conduct. While this is a charge that can easily be made against any social research, I must graciously decline the definitions, values and ethical judgments he imputes to me. The underlying issue raised by his letter is whether judgments of psychological health have any objective, cross-cultural validity or are necessarily embedded in a particular social matrix. On this score, diatribes against positive thinking, Western civilization and the Christian businessman provide little knowledge or insight. La Fave may not believe the citizens of this society are worthy of their own respect but this is a conviction based on his personal values and ideology. From such empirical evidence and theoretical formulations as are available indications are that persons who take a favorable view of themselves are more effective in attaining their personal goals, more accepting of themselves and others, and less likely to suffer from psychic or physical distress. They are, La Fave to the contrary, more independent, innovating and outspoken than are persons who place a lesser value upon themselves. The question of compartmentalized value conflicts he raises is certainly important but I do not see it necessarily associated with or limited to persons with high self-esteem, or Western civilization. I would be pleased to learn of any modern society where these conflicts do not exist and equally pleased to learn why they are limited to any given occupation or segment of society.

STANLEY COOPERSMITH

University of California
Davis, Calif.



50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1918: "The third great drive of what may be called the battle for Paris began on May 27th by a rush of the Germans on the Aisne front which, when compared with the second, or Flanders, drive in April, makes the latter simply a side show or an introduction. So far the results show a bulge made by the Germans 40 miles wide and 20 miles deep. This salient would give every facility for continuing on a great scale the war of movement if the Germans could muster enough reserves to obtain an advance from their present positions. There is but little doubt that a great crisis in the present war has come and that the fate of the Allies or the Germans may be told in a short time. It would certainly appear from our present knowledge that the Austro-German alliance is at the height of its military powers; but if striking military gains are not obtained in a few days, that alliance must gradually lose strength and must finally be defeated."

"It is too early as yet to estimate the recent German submarine attack on U.S. ships in U.S. waters at its true value. It may be the opening phase of a really serious submarine campaign against the transports which are carrying our troops to Europe, or it may be merely another of those curious and utterly futile attempts of the Hun to break down the morale of the civilians of Allied countries. The sending of one, two, three or more submarines across the Atlantic for a raid upon our coasts has long been recognized by our naval men as perfectly possible; but it has been expected that the appearance of enemy U-boats would be sporadic and devoid of any marked military result."

"It is significant of the spirit of the times that the French government has created, at the suggestion of the Academy of Sciences, a new division in that body under the title 'Application of Science to Industry.' The new division of the Academy will consist of six members, who are to enjoy the same privileges as the 'free members' (not attached to any section), without restriction as to residence. It is intended that the six new members of the Academy shall be chosen from among those persons in the industrial world who have achieved important scientific advances in their several lines and made the results of their work public."

"The American concrete steamship *Faith,* the first large ocean-going vessel of concrete in the history of the world to make a successful voyage with cargo, completed her maiden and trial trip on June 2nd by tying up to the dock at the Canadian port of Vancouver. The *Faith,* loaded with a rough cargo of salt and ore, left San Francisco on May 22nd, touching at Tacoma and Seattle to unload. The voyage has been watched with anxiety and hope by men high in shipping circles of the Allies, for with the success of concrete ships proved, the way lay open to solving the ship shortage problem, as concrete ships can be built much more quickly and easily than either those of wood or steel."

SCIENTIFIC AMERICAN

JUNE, 1868: "The quickest passage ever made by a sailing vessel between America and France has just been accomplished by the ship *Mercury.* She left New York on the evening of April 9th and arrived at Havre on the morning of the 22nd. The voyage thus occupied some hours over 12 days. Sixteen days has been hitherto considered remarkably good time."

"The grant of special monopolies to private parties by Congress is repugnant to the spirit of our institutions and should never be tolerated except under extraordinary circumstances, when the welfare of the whole country clearly demands it. Monopolies are burdens upon the people and had their origin in oppression. To call them patents or to issue them under pretense of rewarding inventors does not alter their real character. They are still the same old legalized forms of enriching the few at the expense of the many. The people already have burdens enough to carry without being tormented by hordes of private tax collectors, armed with the special Acts of Congress. Some of the hugest patent swindles have been passed by the present Congress, and others are in a forward state for passage. Indeed, the Capitol has become a second Patent Office and is

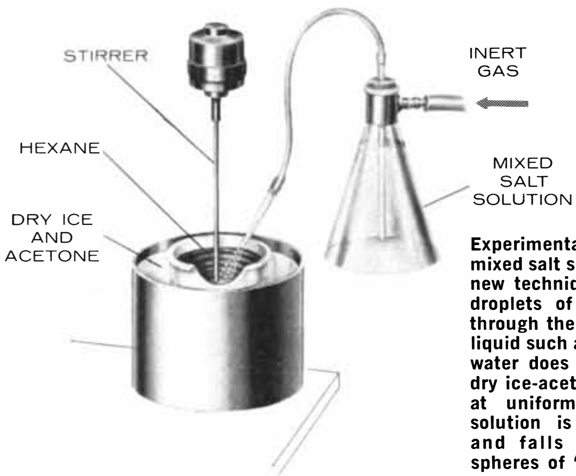
Report from

BELL LABORATORIES

Ceramics from Liquids

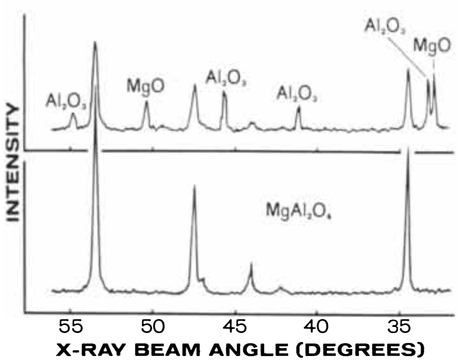
Ceramics preparation has been relatively unchanged for many years. But electrical communications are now calling for new methods; one is described below.

Spheres of ceramic powder, precisely formed, intimately mixed, and homogeneous —product of a new freeze-dry process devised at Bell Telephone Laboratories. A common pin indicates approximate size.



Experimental setup for freezing mixed salt solutions, a step in the new technique. Inert gas forces droplets of solution from flask through the nozzle into a chilled liquid such as hexane, with which water does not mix. Stirrer and dry ice-acetone bath keep liquid at uniform temperature. Salt solution is immediately frozen and falls to bottom as tiny spheres of "ice."

X-ray diffraction patterns of a magnesium aluminate, demonstrating the homogeneity possible with Bell Labs' new technique. The lower trace, from an aluminate made this new way, shows the characteristic spinel pattern of the substance. The top trace shows the pattern of an aluminate prepared by a conventional milling process; it has spikes indicating the presence of magnesium oxide and aluminum oxide phases, as well as the desired magnesium-aluminum-oxide phase.



Ceramics with precise electrical, magnetic, and chemical properties are widely used in electronics—as ferrites for computer memories, as substrates for integrated circuits, and the like. Since ceramic properties depend on microstructure, preparation must be precisely controlled. And for many purposes, current methods do not sufficiently control crystal size and composition. Grinding and precipitation from solution, for example, often introduce contamination or cause nonuniformities.

Now, scientists Frank J. Schnettler and Frank R. Monforte of Bell Laboratories have devised an improved technique, suitable for many compositions. It combines ingredients in liquid form, freezes them as tiny spheres, and converts them to oxides without changing their spherical shape. The resulting compositions are precisely controlled and uniformly mixed.

The process begins with water solutions of salts of the elements to be combined. To make a magnesium aluminate ceramic, for example, magnesium sulfate and aluminum sulfate are used. Next, as in the drawing, the solution is sprayed into a coolant and "instantaneously" frozen. Since the ratio of salts can change with temperature and with time, rapid freezing helps to maintain uniform composition. The resulting solid spheres, a fraction of a millimeter in diameter and all of identical composition, are dried at low temperature and pressure, where the water can sublime —go directly from solid to vapor.

Finally, the freeze-dried material is baked at about 1000°C to convert the salts to oxides. When this step is completed, the spheres are actually agglomerates of fine, intimately mixed or completely reacted ceramic powders. They are clean, free-flowing, and easily handled. They are easily crushed into fine powder for conventional methods of ceramic manufacture, such as extrusion or casting. Because there is no dust, toxic material can be handled safely.

If a powder is to be used directly, as in pigments or abrasives, its particle size can be controlled over a range from 100 to 5000A by varying the dilution of the original solution or the time and temperature used to convert the salts to oxides.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

doing a large and flourishing business, but not creditable or beneficial to the country."

"The long series of trials and tribulations which the much-to-be-commiserated owners of the *Great Eastern* have been called upon to bear have been duly recounted in these columns. But the misfortunes of the 'big ship,' it would seem, are to end only in its final annihilation. Our latest foreign exchanges have an account of the disposal by auction of all the steamer's furniture and fittings under a bill of sale held by a leading firm in Liverpool and a heavy creditor of the company. As to the future of the *Great Eastern*, it is not difficult to foretell. At present she lies nearly high and dry in the Sloyne, a useless hulk fit only for barnacles. Her owners are without funds to fit her for sea, her value as a gift is on a par with that of the celebrated 'white elephant,' and her inevitable fate must be her speedy demolition for her materials and engines."

"An English engineer proposes employing solar heat in generating steam. By using a lens of small diameter the sun's rays have been concentrated in a vessel containing water to such a degree that enough steam has been generated to drive a small engine. Increasing the size of the lens will, he contends, have the effect of still further intensifying the solar heat, and the power that may be obtained is only to be limited by the dimensions of the apparatus employed."

"From the annual recurrence of rains, meteoric showers and the explosions of steam boilers in various parts of the country Professor Loomis suggests a very uncomfortable theory in regard to the safety of the earth itself. He thinks it not impossible that sufficient steam might be generated in the burning center of the world to blow the whole globe to pieces. A volcanic eruption under the sea, or near it, like that of Vesuvius now in progress, may at any moment convert the earth into a huge steam boiler by letting the water in upon the central fires, to be followed, for aught we know, by an explosion that shall rend it apart and send the fragments careering through space as small planets or meteors, each bearing off some distracted member or members of the human family, to make, perchance, new discoveries and new acquaintances in other parts of the planetary system now revolving with us. So that the final catastrophe may after all be only a boiler explosion on a magnificent scale of grandeur and destruction."

In hope of doing each other some good

Patent lawyers: Besides these three we have some 75 more on the payroll and find that isn't nearly enough. Challenged as to what good they do *you,* the public, they might plead thus:

Among all the things Kodak makes, you may imagine there are hundreds of camera models. Wrong. There are less than 20. They compete against about 330 models offered by others. Those others are pretty quick to send to Washington for all the details in any camera improvement patent that one of those lawyers gets through. That's exactly what Thomas Jefferson and his friends had intended when setting up the U.S. patent system.

"Aha!" gloats the competitor as he scrutinizes our patent, "I have a far, far better idea than Kodak's." So his lawyer gets him a patent. Perhaps his improvement depends on our improvement. If he therefore asks for a license, he will not find us unreasonable on timing and royalties. And vice versa, we hope.

Which is why, if you don't care for the first 349 models you are shown, there is a 350th. To keep your options wide on products that might affect you even more than cameras, but with stability to support a society beyond old Jefferson's imagination, patent lawyers are in short supply.

Why do bacteria come out red?

There is a challenge here. Why do bacteria come out red in "false color"? The term "false color," as is now widely known to phytopathologists, ecologists, agronomists, and other users of aerial photography, refers to what is seen with the unique KODAK EKTACHROME Infrared AERO Film. This picture, however, was made with a microscope, not an airplane. It was taken by L. E. Casida, Jr. of Pennsylvania State University to illustrate his puzzling report in *Science 159,* 199 that bacteria, live or dead, can be visualized *in situ* in habitats like soil, marine muds, or the inside of the living, unstained clover root-hair in this photograph.* Unlike use of stains or phase attachments, Casida finds, there is no confusing bacteria with other microorganisms or with humic or inorganic particles of similar size and shape. Only the bacteria consistently photograph red, he reports.

Why? We designed the film to represent the 710-910mμ infrared band by red. Is there something about the curvature of the bacterial outer membrane that involves infrared? Casida mentions that possibility among others.

If not content to await further word from him on what is going on, ask Eastman Kodak Company, Department 942, Rochester, N.Y. 14650 how to obtain and process KODAK EKTACHROME *Infrared* AERO *Film.*

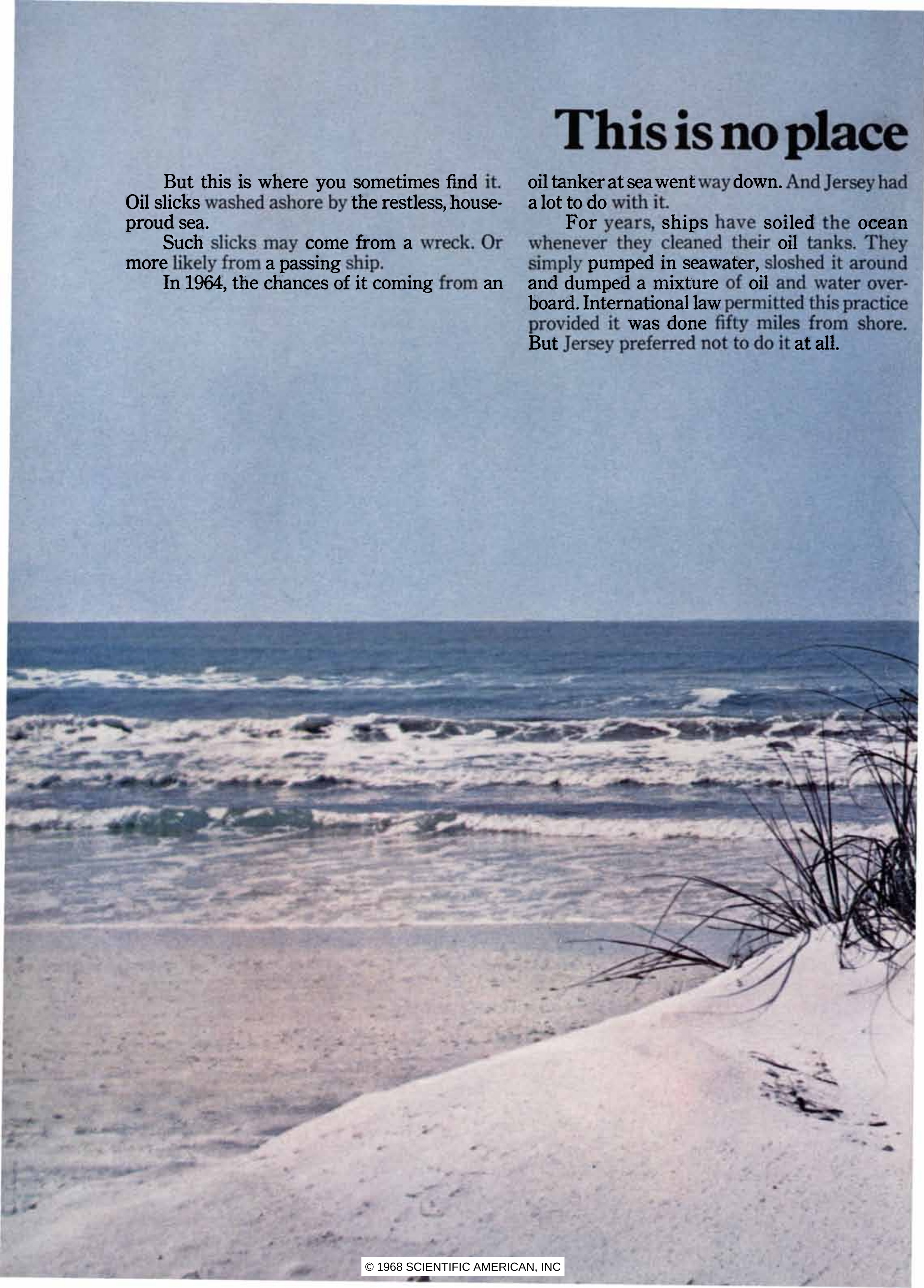
*It's more striking when the color slide is projected.

Sit down and be comforted

Try writing down exactly why one upholstered chair or sofa feels good and another does not. Better yet, go to a furniture showroom and ask to see some items that have been built with a new polyester product of ours that we have named "EKTAFILL." You may not care deeply why a new and ingenious concept for bonding together layers of fiber of different diameter promotes a just-right combination of support, softness, and resiliency along with rugged resistance to the passage of the years and responsiveness to the realities of furniture design and production. Just sit down and assess the results. Subjectively, please.

EASTMAN KODAK COMPANY

An equal-opportunity employer


This is no place
But this is where you sometimes find it. Oil slicks washed ashore by the restless, house-proud sea.
Such slicks may come from a wreck. Or more likely from a passing ship.
In 1964, the chances of it coming from an oil tanker at sea went way down. And Jersey had a lot to do with it.
For years, ships have soiled the ocean whenever they cleaned their oil tanks. They simply pumped in seawater, sloshed it around and dumped a mixture of oil and water overboard. International law permitted this practice provided it was done fifty miles from shore. But Jersey preferred not to do it at all.

The leopard was made by a taxidermist. Its coat is a modacrylic textile fiber made by Union Carbide from several basic chemicals. It's called Dynel.

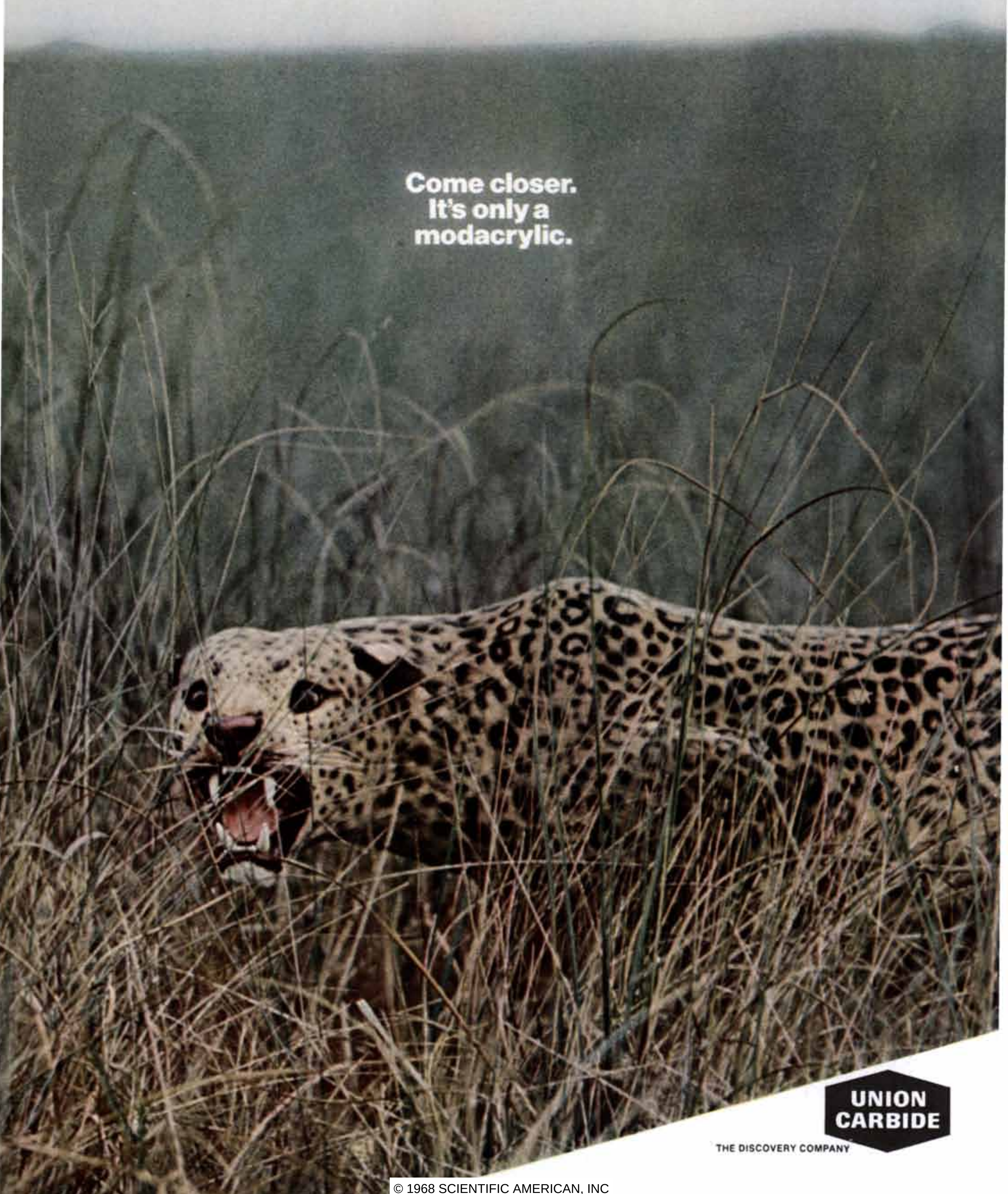
Of course, man-made fibers aren't new. But for versatility, Dynel probably has no equal. We can make it as soft and warm as fur for your coat. Or so tough it approaches the strength of steel.

You'll find it in blankets, work clothes, automobile upholstery, toys, jewelry. In carpets, towels, drapes, paint rollers.

And since Dynel is chemical-resistant, durable and virtually nonflammable, it's used in many more ways. On laminated decks of boats. For tents. As overlays for storage tanks and air ducts.

But regardless of all its practical uses, Dynel is most famous for something else. It's great for making wigs. For blondes and brunettes and redheads.

Remarkable fiber? We think so. But haven't you found that a lot of remarkable things come from Union Carbide?



THE AUTHORS

DONALD F. NELSON ("The Modulation of Laser Light") is professor of physics at the University of Southern California. He did all his undergraduate and graduate work at the University of Michigan, where he received bachelor's and master's degrees in 1952 and 1953 respectively and a Ph.D. in 1959. From 1959 until he took his present position last year he was in the research division of the Bell Telephone Laboratories. Soon after joining Bell Laboratories he began experiments to explore laser action in solids. He collaborated in the first measurements of spatial coherence, relaxation oscillations, cavity loss and polarization of the pulsed ruby laser. Working with W. S. Boyle, he built the first continuously operating ruby laser. He has also been interested in a variety of optical properties of semiconductors.

DOUGLAS D. ANDERSON ("A Stone Age Campsite at the Gateway to America") is assistant professor in the department of sociology and anthropology at Brown University and is also affiliated with the university's Haffenreffer Museum of Anthropology. A graduate of the University of Washington, he obtained a master's degree at Brown in 1962 and a Ph.D. from the University of Pennsylvania in 1967. He first studied Arctic archaeology under J. L. Giddings, Jr., of Brown, accompanying him to Alaska in 1960 and 1961 to help with excavations at Cape Krusenstern, an important archaeological site in northwestern Alaska. He has also excavated along the Noatak River in Alaska. After the death of Giddings in 1964 Anderson was asked to take charge of the excavations at Onion Portage, which is the setting for his article. Anderson has also participated in archaeological work in Denmark and Thailand.

O. J. EGGEN ("Stars in Contact") is director of the Mount Stromlo & Siding Spring Observatories of the Australian National University and professor of astronomy at the university's Institute for Advanced Study. Born in Wisconsin, he was graduated from the University of Wisconsin in 1940 and received a Ph.D. there in 1948. From 1948 to 1956 he was an astronomer at the Lick Observatory of the University of California. He spent the next five years at the Royal Greenwich Observatory as Chief Assistant Astronomer Royal. In 1964, after a period as professor of astronomy at the California Institute of Technology and as a member of the staff at the Mount Wilson and Palomar Observatories, he was deputy chief scientific officer at the Greenwich Observatory.

ALLEN V. ASTIN ("Standards of Measurement") is director of the National Bureau of Standards. He joined the Bureau in 1932 as a research associate and became director in 1952. By training he is a physicist, and he has spent many years in physics work at the Bureau of Standards. In the 1930's he did work in dielectrics and electronic instrumentation. In dielectrics his contributions include the development of improved methods of measuring dielectric constants and the power factors of dielectric materials and a better understanding of the nature of energy losses in air capacitors. In electronic instrumentation he worked on the development of radio telemetering techniques and instruments and applied the results of the work to studies of meteorological problems in the earth's atmosphere and to studies of cosmic rays. During World War II he was closely involved with the development of the proximity fuze. Astin was graduated from the University of Utah in 1925 and obtained a Ph.D. at New York University in 1928. Before joining the Bureau he worked for four years as a research associate in physics. Astin has been a member of the International Committee on Weights and Measures since 1954. He is also a member of the National Academy of Sciences.

LAURENCE JAY STETTNER and KENNETH A. MATYNIAK ("The Brain of Birds") are on the staff of Wayne State University; Stettner holds the rank of associate professor of psychology and Matyniak is a research assistant. Stettner is spending the year as a special research fellow of the National Institutes of Health, working in the laboratory of perinatal physiology of the National Institute of Neurological Diseases and Blindness in San Juan, Puerto Rico. He went to Wayne State in 1963 after receiving a Ph.D. from Stanford University. Earlier he had taken bachelor's and master's degrees at Brooklyn College. Matyniak was graduated from Wayne State in 1965. He has worked with Stettner since 1964.

ALFRED E. MIRSKY ("The Discovery of DNA") is professor of general physiology at Rockefeller University, where he has worked since 1927. Since 1965 he has also been its librarian. Mirsky is one of the modern pioneers in the study of DNA. He has worked on many chemical aspects of the cell and the nucleus: chromosomes, nucleoprotein, hemoglobin and other proteins. Mirsky was graduated from Harvard College in 1922 and obtained a Ph.D. in physiology from the University of Cambridge in 1925. He was the author of "The Chemistry of Heredity" in the February 1953 issue of SCIENTIFIC AMERICAN and co-author with Vincent G. Allfrey of "How Cells Make Molecules" in the issue of September, 1961.

ERNEST RABINOWICZ ("Polishing") is professor of mechanical engineering at the Massachusetts Institute of Technology. A native of Germany, he moved to England at the age of 10. Later he did undergraduate and graduate work in physics and physical chemistry at the University of Cambridge, where he took a bachelor's degree in 1947 and a Ph.D. in 1950. He went to M.I.T. in 1950. He writes that his interest in polishing phenomena and wear dates from his university days in England and that recently he has "branched out into the reliability area." His article, which describes work he has done with the sponsorship of the Alfred P. Sloan Foundation, is his third in SCIENTIFIC AMERICAN; the others were "Stick and Slip," which was published in May, 1956, and "Wear," which appeared in February, 1962.

R. D. PRESTON ("Plants without Cellulose") is professor of plant biophysics and head of the Astbury Department of Biophysics at the University of Leeds, where he received his undergraduate and graduate training. After obtaining a Ph.D. in botany in 1931 he held the 1851 Exhibition Fellowship at the university for three years and then spent two years at Cornell University as a Rockefeller Foundation Fellow. In 1936 he returned to Leeds and took the position of lecturer in botany, becoming in turn senior lecturer, reader and professor. He has published some 150 articles and a book on the molecular architecture of the walls of plant cells. In 1954 he was elected a Fellow of the Royal Society.

J. BRONOWSKI, who in this issue reviews *Death in Life: Survivors of Hiroshima*, by Robert Jay Lifton, is a senior fellow of the Salk Institute for Biological Studies.

Established 1845 SCIENTIFIC AMERICAN June 1968 Volume 218 Number 6

The Modulation of Laser Light

The great potential of the laser for use in long-distance communication systems has been brought closer to realization by the development of large-bandwidth, low-power modulators

by Donald F. Nelson

Ever since the first laser was operated in 1960 the project that has attracted the most intense effort in the field of laser applications has been the attempt to exploit the potentially enormous information-carrying capacity of the laser beam for use in intercity communications [see "Communication by Laser," by Stewart E. Miller; SCIENTIFIC AMERICAN, January, 1966]. In general the problem can be broken down into five parts, corresponding to the five basic components essential to any long-distance electrical communication system. These components are: an oscillator to generate the carrier wave, a modulator to impress information on the wave, a transmission medium to convey the wave, a detector to receive the wave and a demodulator to extract the information from the wave.

In the past few years considerable progress has been made in the development of several of the components needed for laser communication. The most promising candidates for the oscillator now include such lasers as the helium-neon gas laser, the carbon dioxide gas laser and the neodymium-doped yttrium-aluminum-garnet crystal laser. The transmission medium may in some circumstances be simply the atmosphere, but the criterion of high reliability will probably require that the laser beam be transmitted through underground pipes containing numerous lenses to focus the beam periodically as well as mirrors to reflect the beam around corners. The detector is likely to be a small semiconductor diode that generates an electric current when light strikes it.

Until recently the most serious obstacle to the construction of an optical communication system has been the lack of a suitable high-frequency modulator (and a compatible demodulator). Three new light modulators developed within the past year at the Bell Telephone Laboratories point the way to the eventual solution of this crucial aspect of the laser communication problem.

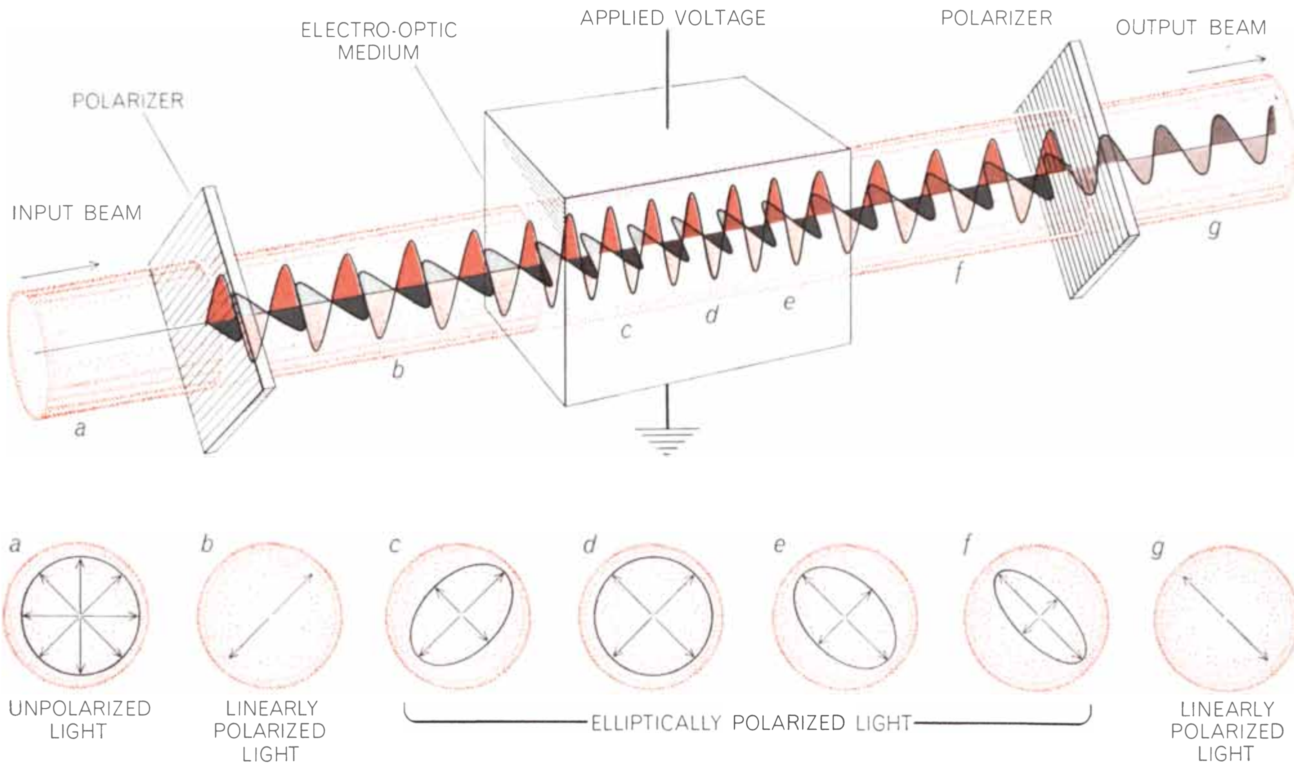
The modulation of a light wave means the controlled variation of some property of the wave such as its amplitude, frequency, phase, polarization or direction of propagation. Of these five possible approaches only modulation of the propagation direction is not currently envisioned for a laser communication system and so will not be discussed here. Polarization modulation has not been used by itself, but it does come into play as an intermediate step in two of the modulators that will be described later in this article.

We are left with the optical equivalents of the two best-known modulation methods of radio-wave and microwave communications, namely phase or frequency modulation (FM) and amplitude modulation (AM). As in the earlier technologies, amplitude modulation can be of two types. In one a small variation in the amplitude of the carrier wave is proportional to the electrical signal that is supplied to the modulator. This type of modulation can be used to transmit an analogue signal, such as the signal provided by the human voice.

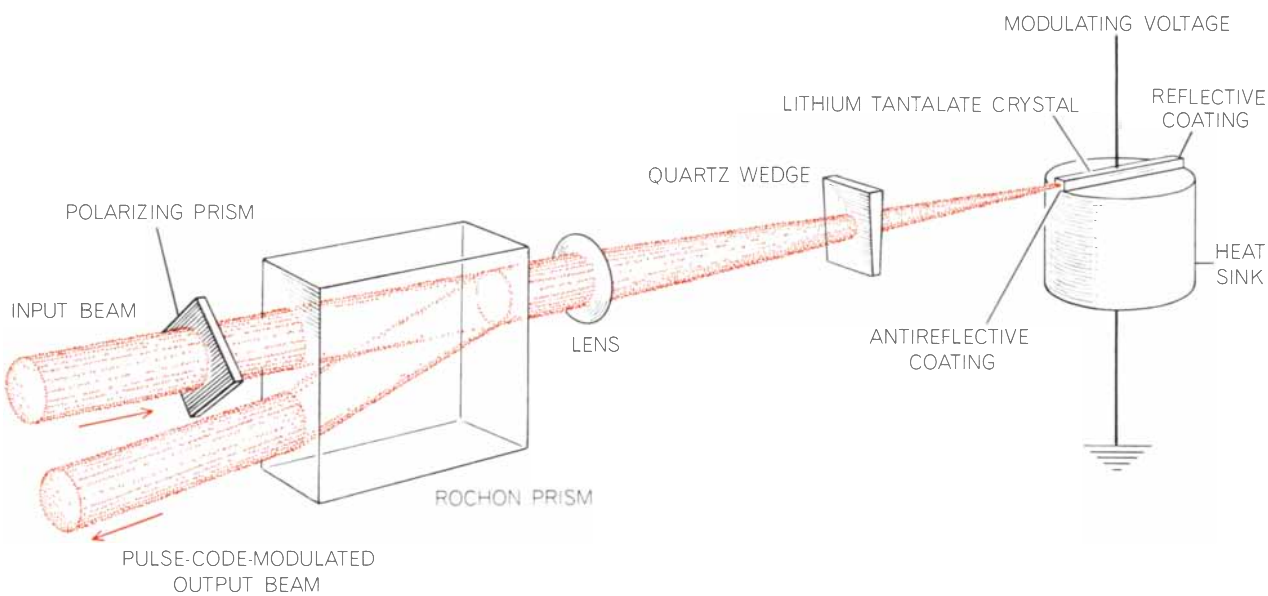
Another type of amplitude modulation, called pulse-code modulation (PCM), is currently finding increased use in communication technology; it is simply the abrupt turning on and off of the carrier wave [see "Pulse-Code Modulation," by J. S. Mayo; SCIENTIFIC AMERICAN, March]. This type of modulation is used to transmit digitized information of the kind that is manipulated by computer circuits. In PCM one "bit" of information is transmitted by the presence or absence of a pulse at a particular instant of time. In order to be carried by PCM the information must first be reduced to yes or no answers, that is, to a binary code.

The main attraction of an optical communication system is the large range of frequencies, or bandwidth, available for carrier waves. This means that far larger amounts of information can theoretically be transmitted by means of the visible portion of the electromagnetic spectrum than by all the radio-wave and microwave portions combined. Accordingly designers of optical communication systems are primarily concerned with systems that have a large bandwidth and hence a large capacity for information transmission.

Modulators for large-bandwidth systems must be capable of responding to



ELECTRO-OPTIC EFFECT is the basis for one class of laser-beam modulators. In general the electro-optic effect refers to the changes brought about in the light-refracting properties of a solid or liquid medium by the application of an electric field across the medium. In the demonstration at top a beam of unpolarized light from a laser is first sent through a polarizer. The linearly polarized light that emerges has its electric field oscillating in the plane defined by the axis of polarization of the polarizer. This linearly polarized beam can be represented by its vertical and horizontal components (*colored curves*), which are in phase. As the two components pass through the electro-optic medium they are slowed down at different rates and hence gradually become out of phase. They emerge from the medium to form an elliptically polarized light beam. Another polarizer placed in the path of this beam, with its polarization axis oriented at 90 degrees with respect to that of the first polarizer, allows only the component that is parallel to its transmission axis to be transmitted. By varying the applied voltage the polarization of the beam can be made more or less elliptic, and as a result the amplitude of the output beam can be changed accordingly. The cross sections of the beam at bottom show polarization at various stages.



LITHIUM TANTALATE MODULATOR is the most highly developed electro-optic modulator. The laser beam passes through an input polarizer and is focused into the modulator crystal by a lens. It is reflected from the far end of the crystal and emerges in a state of elliptic polarization. After being re-formed as a parallel beam by the lens, the component of polarization perpendicular to the input component is deflected by a Rochon prism to form the output beam. When used for pulse-code modulation, the voltage on the modulator crystal is adjusted so that the light leaving the crystal is linearly polarized perpendicularly to the input polarization and so is entirely deflected by the Rochon prism. A wedge is inserted in the beam to offset the crystal's natural birefringence.

electrical modulating signals with frequencies of hundreds or even thousands of megacycles per second. This would allow tens or even hundreds of television programs to be transmitted simultaneously. Thus the physical effect on which the modulator is based must be fast enough to respond to such frequencies. Electric and magnetic fields acting through the electro-optic and magneto-optic effects are sufficiently fast. Thermal methods and most mechanical methods of modulating light beams are too slow. Ultrasonic vibrations, which are mechanical in nature, may nonetheless be found useful in the future.

The physical effect that has received the most attention for laser-beam modulation is the electro-optic effect. In this effect the application of an electric field across a solid or liquid medium causes a small change in its refractive index. If the index is lowered, the light travels faster through the medium; if it is raised, the light travels slower. Furthermore, under the influence of an electric field the medium becomes birefringent, that is, light beams of two different linear polarizations travel through it at different velocities.

Since changing the light velocity affects the phase of the wave, an electro-optic modulator is basically a phase modulator. It can be converted to an amplitude modulator by a scheme that involves placing a light polarizer oriented at 45 degrees to the electric field in front of the electro-optic medium [*see top illustration on opposite page*]. The orientation of the polarizer causes the resulting linearly polarized light to be equally divided between the two principal directions of the electro-optic medium. The electro-optic effect causes these two components to travel at different velocities and therefore to get out of phase with each other. After traversing the medium they no longer combine to give a linearly polarized light wave as they did on entering the medium. Instead their sum is an elliptically polarized light beam, that is, the tip of the optical electric-field vector traces out an ellipse in space once every cycle of the light wave. In this way two phase-modulated light components can be made to form a polarization-modulated light wave.

This wave can in turn be easily converted to an amplitude-modulated wave by passing it through another polarizer. The transmission axis of the second polarizer is placed at an angle of 90 degrees with respect to the axis of the first polarizer. Only the projection of the optical electric-field vector on the polarization axis is transmitted through the second polarizer. If the proper amount of voltage is applied to the crystal, the output polarization can be made to be linear in a direction at 90 degrees to the input polarization. In this case complete transmission of the light through the output polarizer occurs. With no voltage applied, no light emerges. By alternating the voltage between these two values one can pulse-code-modulate the laser beam.

There are actually two types of electro-optic effect. For one type the change in the index of refraction is proportional to the square of the applied voltage. This is called the Kerr effect after John Kerr, a Scottish physicist who discovered it in liquids in 1875. The Kerr effect can also operate in any crystal. For the second type of electro-optic effect the change in refractive index is proportional to the first power of the applied voltage. It is called the Pockels effect after F. Pockels, a German physicist who made the first careful study of it in 1893. The Pockels effect can occur only in crystals that lack a center of symmetry, that is, lack a point through which every atom of the crystal can theoretically be reflected to obtain the identical crystal structure.

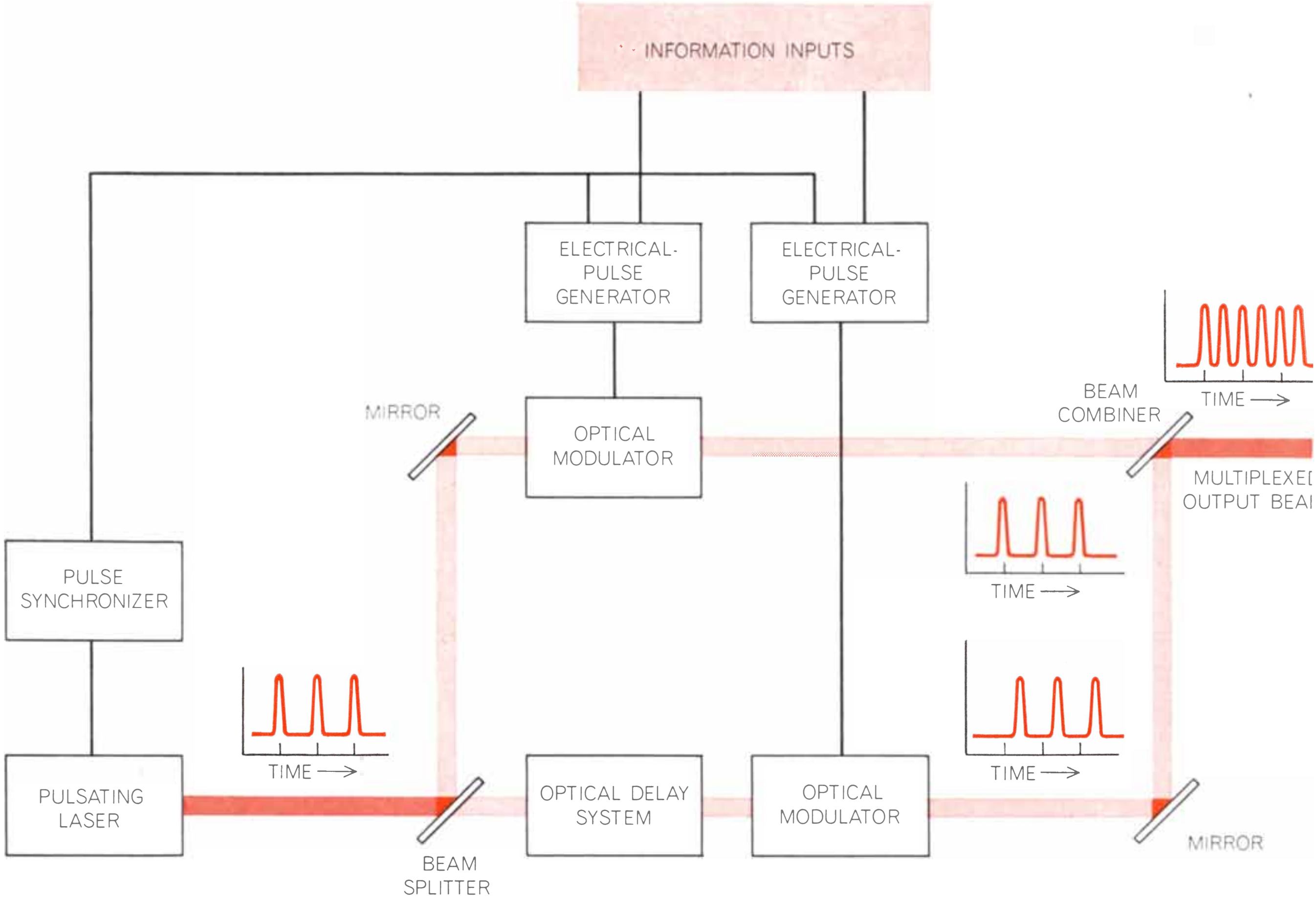
Kerr cells containing nitrobenzene have been used for years as light shutters in a variety of specialized applications. The first useful Pockels cell was made in 1949 from a crystal of potassium dihydrogen phosphate (KDP) by Bruce H. Billings, then at Baird Associates. None of these devices was capable of the extremely high-frequency operation needed for broad-band communications. In 1961 Ivan P. Kaminow of Bell Laboratories demonstrated a high-frequency modulator for lasers based on the Pockels effect in KDP. The Kaminow modulator required too much power for a practical communication system, but it served to stimulate a search for materials that would show a still larger effect. Many new crystals have been grown for this purpose since then. Lithium niobate, lithium tantalate, potassium tantalate-niobate (KTN) and potassium-lithium niobate are a few of the more promising materials. All of these exhibit a Pockels effect except KTN, which shows a Kerr effect. All are transparent to electromagnetic radiation in the visible portion of the spectrum and in a large portion of the infrared region and so can be used to modulate a great variety of lasers.

It is difficult to say which electro-optic material will ultimately be the best for a given laser wavelength, but already lithium tantalate has been incorporated into a very useful broadband modulator by Richard T. Denton, F. S. Chen and T. S. Kinsel at Bell Laboratories. This modulator is the most highly developed one at present. It differs in several important details from the generalized electro-optic modulator discussed above. First of all, by means of a reflector at one end of the crystal the light passes through the crystal twice [*see bottom illustration on opposite page*]. This doubles the modulating effect for a given applied voltage. In addition, lithium tantalate is naturally birefringent. Even with no electric field present the two different linearly polarized light components travel at different velocities. They get out of phase during their passage through the crystal and emerge to produce a state of elliptic polarization. To prevent this another birefringent crystal in the form of a wedge is inserted in the path of the beam and adjusted so that in the absence of an electric field the beam is in the same state of linear polarization when it emerges as when it entered.

The birefringence of lithium tantalate creates another problem. When the temperature changes, the birefringence also changes and causes the output polarization to do so. This can be cured only by precise temperature control of the crystal. It has been found that the temperature must be held constant to within .04 degree centigrade. The metal blocks that apply the voltage to the crystal help to hold its temperature constant. They also perform a third function by reducing the amplitude of mechanical vibrations that the application of the voltage creates in the crystal by means of the piezoelectric effect.

The lithium tantalate crystal is long (one centimeter) and thin (quarter of a millimeter), since the change in phase brought about by the Pockels effect is proportional to the distance traversed by the light as well as to the electric field, the field being larger when the thickness over which the voltage is applied is reduced. Because of the small thickness of the crystal a lens is used to focus the parallel laser beam into the crystal and to re-form a parallel beam again after it emerges. The component of polarization at right angles to the input polarization is deflected by a birefringent element called a Rochon prism to form the output beam.

The lithium tantalate modulator has been used both in a conventional AM mode and in a PCM mode. In the AM mode it can produce 80 percent modulation of the intensity (the square of the amplitude of a wave) of a red helium-



OPTICAL COMMUNICATION SYSTEM based on the pulse-code modulation of laser beams would make use of the principle of multiplexing: the simultaneous transmission of diverse information on the same beam. In the multiplexing operation (*left*) a beam of laser pulses is split and each part is modulated separately. One beam is delayed and then the two beams are recombined. The information-carrying capacity of the beam is thereby doubled. If the laser pulses are short compared with their spacing, this process can

neon laser beam over a bandwidth of 220 megacycles per second, using only 200 milliwatts of power from a transistorized amplifier. At present the effectiveness of the modulator is limited by the capabilities of this amplifier rather than by any characteristics of the modulator crystal. With an improved amplifier the bandwidth could be expanded to 1,000 megacycles per second.

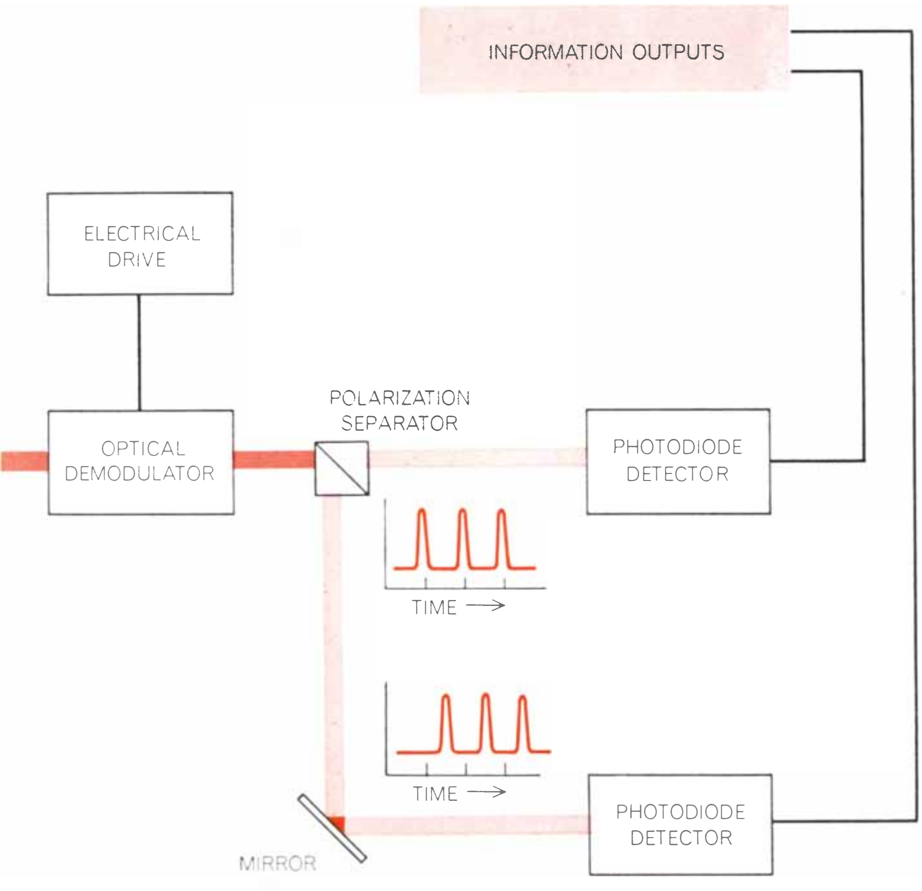
The PCM mode of operation may prove to be the most practical for light modulators. It has the advantage that the amount of modulation need not be strictly proportional to the modulating electrical signal, as must be the case for conventional AM. Since information is conveyed in PCM by the presence or absence of a light pulse, such transmission is less affected by the presence of optical "noise" received with the signal. The third advantage is that PCM makes it easier to transmit simultaneously unrelated information, such as several television, telephone or data channels, over the same light beam. This mechanism of simultaneous transmission of diverse information on the same beam is called multiplexing.

The lithium tantalate modulator has been used for PCM by applying to the crystal a train of voltage pulses, each of which is capable of producing an output polarization at 90 degrees to the input polarization. This polarization is deflected by a polarizing prism to form a train of output pulses. Thus the crystal acts as a gate with "on" and "off" positions. Although the device could modulate a continuous laser beam, it is more convenient for it to modulate a laser beam that consists of a regular train of pulses that are synchronized with the modulator and are narrow compared with their spacing in time. The modulator acts as a gate for these pulses by allowing some to pass and not others.

Additional information can be "time-multiplexed" into the pulse train by first splitting the laser beam into two pulse trains and then modulating each separately [*see illustration above*]. One of the beams is delayed with respect to the other and then the pulse trains are combined into one beam again. The narrower the pulses are compared with their original separation, the greater the number of separate beams that can be made, modulated, delayed and recombined, allowing greater information transmission. The demultiplexing process, illustrated on the opposite page, is essentially the reverse of this process.

The lithium tantalate modulator has already been operated at 224 million bits per second. With a pulsating helium-neon laser as a source fourfold multiplexing could be done to quadruple the rate of information transmission. Even higher rates are envisioned when pulsating lasers that have narrower pulses are used.

All the crystals that have been mentioned so far are dielectric crystals, that is, crystals that do not carry electric current. There are other crystals that have a sizable electro-optic effect but carry current when voltage is applied to them. This causes too much power



be repeated several times. In the demultiplexing operation (*right*) a demodulator changes the polarization of alternate light pulses, which are then separated from each other by the separator prism. Photodiodes then detect the two trains of pulses. Modulators consist of output polarizers plus electro-optic crystals; demodulators are just electro-optic crystals.

consumption for broad-band modulator use. One crystal of this type is the semiconductor gallium phosphide, which exhibits a Pockels effect. F. K. Reinhart and I have found a way around this problem that involves the use of the electric field that exists within a *p-n* junction in gallium phosphide. A *p-n* junction is an electric potential barrier to the flow of current and is the heart of semiconductor diodes and transistors. This potential barrier must necessarily contain an electric field, even when no voltage is applied to the junction. If voltage is applied in what is called the reverse direction, no current flows but the electric field within the junction is increased. It can reach values close to a million volts per centimeter—a very strong field compared with what can be placed across large crystals. This strong electric field in turn leads to a large Pockels effect.

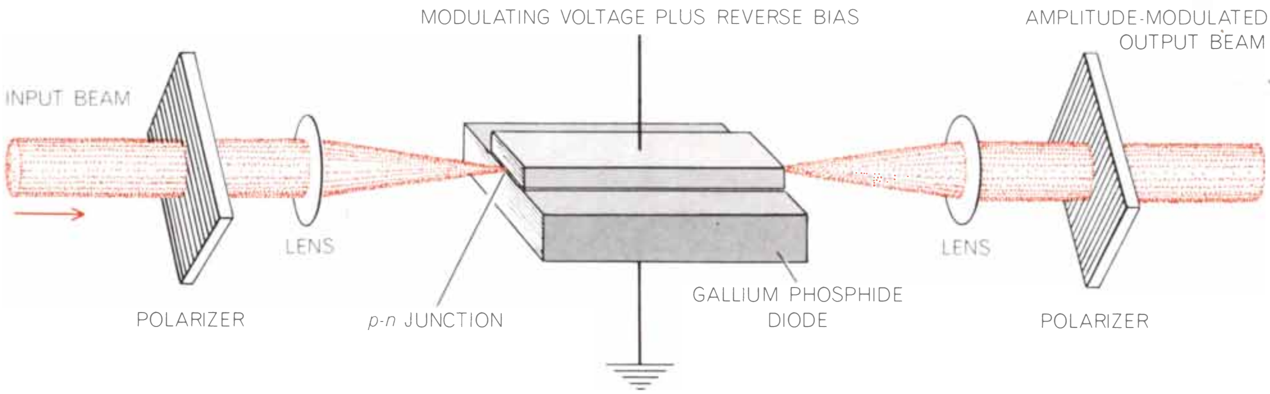
Along with this gain, however, comes a new problem. The *p-n*-junction region that possesses this huge field is less than a ten-thousandth of a centimeter wide. This means that the laser beam that is to be modulated must be very carefully focused on the junction for it to pass along this thin, sheetlike region. Worse yet, because of the diffraction of light—the inherent tendency of light to spread out—one would expect it to be impossible to hold the light in the high-electric-field region where the Pockels effect occurs. Here, however, nature helps out and, for reasons that are not yet well understood, produces a "light pipe" effect that holds the light in the high-field region. A conventional light pipe, such as a plastic rod, prevents light within it from escaping through the sides by total internal reflection. In the *p-n* junction the "light pipe" has sides that are two parallel planes rather than the cylindrical surface of a rod. Such a structure is called a planar dielectric wave guide.

Apart from the narrowness of the electro-optic region and the necessity of lenses to direct the light into and out of this region, our arrangement is similar to other electro-optic modulators [*see top illustration on next page*]. It should be remembered that this modulator is on a much smaller scale, the *p-n* junction being only about a millimeter long. Another difference is that gallium phosphide is an orange crystal and will transmit only light of wavelengths spanning the green, yellow, orange, red and near-infrared spectral regions. This range does, however, include a number of prominent laser wavelengths.

Although the *p-n*-junction modulator has not yet been developed to the extent that the lithium tantalate modulator has, it has been studied enough for its capabilities and limitations to be known. The limitation on its modulation ability arises from the fact that power is dissipated within the diode crystal. This dissipation in turn arises from the charging and discharging of the junction's capacitance through the resistance of the bulk crystal. The power-dissipation limit places a limit on the product of the bandwidth of modulation times the voltage that is applied to the crystal, which determines the amount of the modulation. In addition, the junction's capacitance and the crystal's resistance also determine a practical upper limit to the modulation frequency, which is called the cutoff frequency.

Modulator diodes have been fabricated with cutoff frequencies as high as 7,000 megacycles per second. One 1.5-millimeter-long diode is capable of modulating the intensity of a red helium-neon laser beam as much as 80 percent with a power dissipation of only 1.5 milliwatts per megacycle per second of bandwidth. In the present mode of mounting about 150 milliwatts can be dissipated; this leads to a bandwidth of 100 megacycles per second. Improvements in the mounting to allow greater heat dissipation, and other improvements in the *p-n* junction itself, are expected to extend the bandwidth. If the light were passed through the junction twice as it is for the lithium tantalate modulator, the bandwidth could be extended by a factor of four for the same power dissipation. Further development work is needed to accomplish these improvements.

Although the gallium phosphide diode modulator can modulate light of wavelengths ranging from the green to the infrared, its efficiency for modulating the longer wavelengths is lower. It will modulate green laser light more effectively than the red laser light described above, and it will modulate infrared light more poorly. This points up the fact that eventually many light modulators will be needed; no one modulator can be optimal over the entire range of



***P-N*-JUNCTION MODULATOR makes use of an electro-optic effect in a semiconductor crystal. Because the *p-n*-junction region is extremely narrow, careful focusing of the laser beam is required. A constant reverse bias is applied to augment the electric field across the junction and the modulating voltage is impressed on top of this constant field. The polarizers are at 90 degrees to each other.**

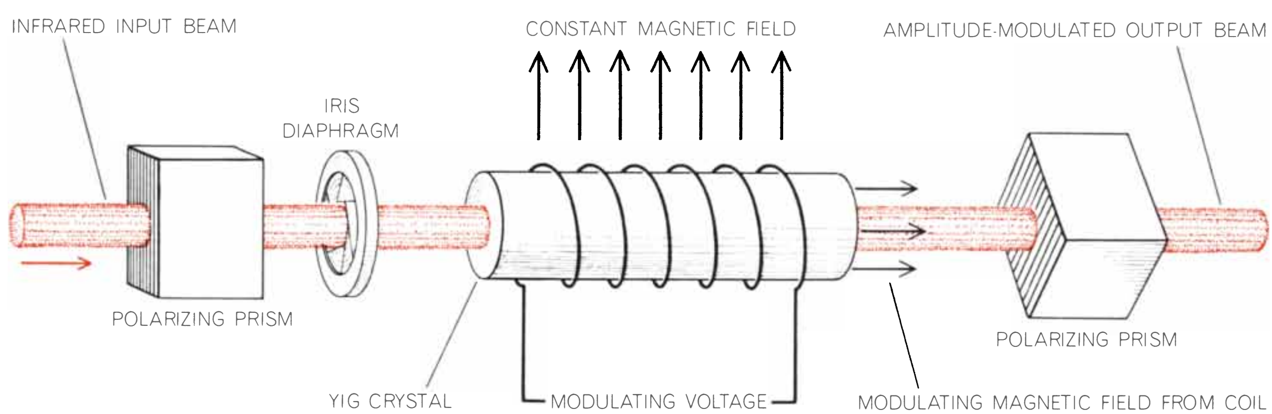
wavelengths. For instance, the magneto-optic modulator described below is better in the near infrared than either the gallium phosphide diode or the lithium tantalate modulators.

I have mentioned that magneto-optic effects in crystals are fast enough to be used for large-bandwidth modulators of light. Recently such a modulator has been developed by R. C. LeCraw at Bell Laboratories using the Faraday effect. The Faraday effect is the rotation of the plane of polarization of a light wave as it travels through a substance in a direction parallel to an applied magnetic field. It can occur in a variety of gases, liquids and solids. It is named after Michael Faraday, who discovered the effect in glass in 1845.

The rotation of the plane of polarization of light is a phenomenon quite different from the conversion from linear to elliptical polarization described above. In a medium exhibiting Faraday rotation the states of polarization that are preserved on passage through the medium are the right-handed and left-handed components of circularly polarized light, not linearly polarized light as in the case of the birefringent medium discussed above. When a linearly polarized light wave is introduced into a medium exhibiting Faraday rotation, it divides into a combination of right and left circularly polarized waves of equal amplitude. These two states of circular polarization travel at different velocities in the magnetized medium. The resulting change of phase between them causes their sum to produce a state of linear polarization but with its plane of polarization rotated with respect to its initial orientation. The amount of rotation is proportional to the component of magnetization along the direction of propagation. This component can be varied by changing the applied magnetic field. The resulting variation of the plane of polarization can be converted to amplitude modulation by passing the beam through a polarizer.

An efficient magneto-optic modulator requires a material that gives the largest Faraday rotation per unit of optical loss from absorption. This ratio is large only for ferromagnetic materials. Until recently the best material on this basis was the crystal chromium tribromide, which has been studied by J. F. Dillon, Jr., at Bell Laboratories. From a practical viewpoint this crystal nonetheless had a crucial defect: it had to be cooled to within a few degrees of absolute zero in order to have the needed magnetic properties.

Recently a region of exceedingly high transparency in the near infrared has been found in the magnetic crystal yttrium-iron-garnet (YIG). Because of the low optical loss in this region, the ratio of Faraday rotation to optical loss is at least 30 times higher than it is for chromium tribromide. Furthermore, YIG can be used at room temperature. Its use in a high-frequency modulator is further aid-



MAGNETO-OPTIC MODULATOR is based on the Faraday effect: the rotation of the plane of polarization of a light wave as it travels through a substance in a direction parallel to an applied magnetic field. In this particular modulator the plane of polarization of an infrared laser beam is rotated in a crystal of yttrium-iron-garnet (YIG). The amount of rotation is determined by the modulating magnetic field along the axis of the YIG rod. The second prism converts the polarization modulation to amplitude modulation.

ed by its having the lowest internal heating arising from rapidly varying magnetic fields of any known ferromagnetic material. The region of transparency of YIG lies between the wavelengths of 12,000 and 45,000 angstrom units in the near infrared. It is useful as a modulator throughout this region but will operate most efficiently at the short-wavelength end of the region. YIG is a synthetic insulating crystal that has ferromagnetic properties. It has the same crystal structure as the many types of gem-quality garnets found in nature. It was discovered in 1956 by two French workers, F. Bertaut and F. Forrat.

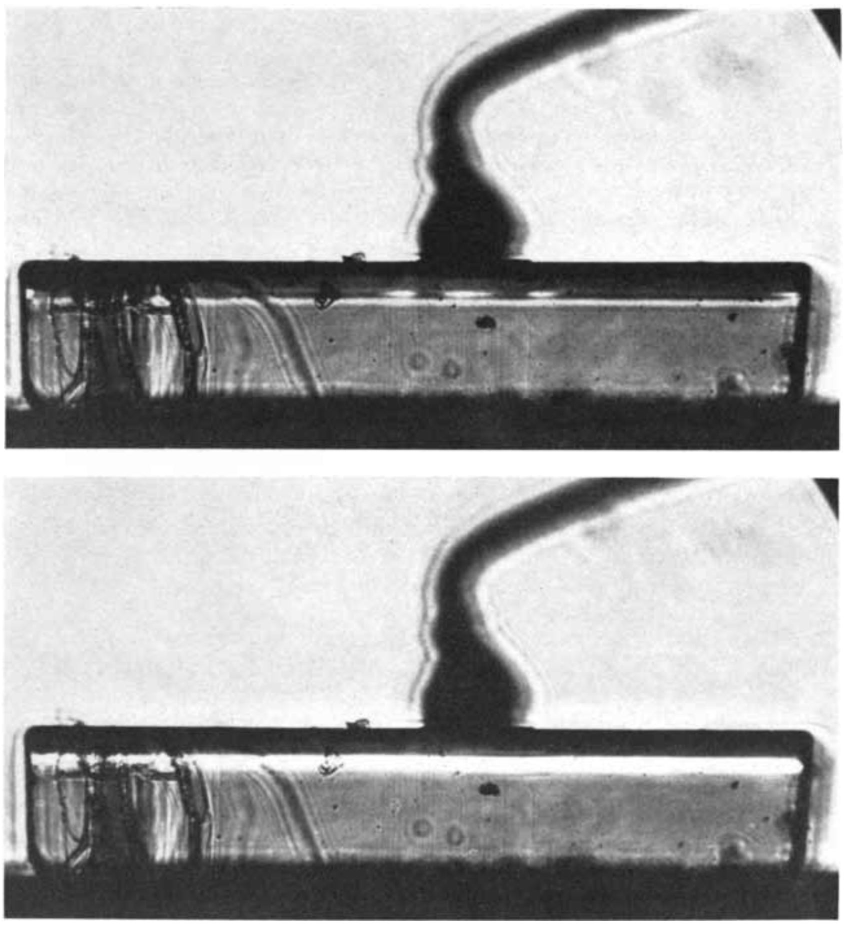
The magneto-optic modulator invented by LeCraw has been used to modulate a helium-neon gas laser whose output beam has a wavelength of 15,200 angstroms. This wavelength was chosen for study because it falls near the short-wavelength end of the high-transparency region and also because it is a wavelength to which high-speed germanium photodiode detectors are sensitive. After passing through a polarizer the beam encounters an iris diaphragm, which is used to define the beam diameter in its passage through the one-centimeter-long rod-shaped YIG crystal [*see bottom illustration on opposite page*]. In the final form of the device a lens would be used for this purpose to avoid any loss of light.

A constant magnetic field is applied across the axis of the rod. This field is sufficient to saturate the magnetization of the YIG crystal. This means that all the magnetization vectors of different "domains" in the crystal are forced to align themselves along the constant magnetic field. Current flowing through the coil that surrounds the YIG crystal creates an additional magnetic field parallel to the axis of the rod. This added magnetic field causes the magnetization vector to tilt toward the axis. The resultant component of the magnetization along the axis of the rod is responsible for the Faraday rotation. Hence varying the magnetic field produced by the coil around the YIG rod varies the magnetization direction and so varies the Faraday rotation. A second polarizer placed at the output end of the YIG rod converts the polarization modulation to amplitude modulation. Although this polarizer could be placed at many orientations, maximum linear modulation is obtained if it is at 45 degrees to the axis of the first polarizer.

The overall efficiency of the magneto-optic modulator is improved further by two alterations. First, the YIG rod is cut from a YIG crystal in a certain orientation with respect to the crystal axes. By so doing the magnetization vector finds it easiest to be tilted toward the rod axis, as is desired, and resists any tendency to be tilted in a plane perpendicular to the rod axis. Second, it has been found that incorporating a certain amount of gallium in the YIG crystal during growth greatly reduces the saturation magnetization, to which the power expended in the modulator is proportional, without significantly reducing the ability of the crystal to produce Faraday rotation.

With these two improvements the YIG modulator has been able to produce 20 percent amplitude modulation with a bandwidth of 200 megacycles per second at a power expenditure of less than .1 watt. Amplitude modulation of 40 percent has been obtained by passing the infrared light through the YIG crystal twice as was done in the lithium tantalate modulator. It is also worth pointing out that the YIG modulator can be used in a PCM mode of operation if desired.

Although the three modulators described above are the most promising ones now available, other approaches are being actively pursued in many laboratories. The use of ultrasonic vibrations in a crystal as a modulating mechanism was mentioned above. Still another approach is to perform the modulating function inside the laser itself rather than on the light beam after it has left the laser. K. Gürs and R. Müller at the Siemens and Halske research laboratory in Germany, for instance, have performed very interesting experiments on a modulator of this type. Only time will tell which modulators are finally used in optical communication systems, but enough is known now for one to predict confidently that the modulator problem will finally be solved.



MODULATED LIGHT BEAM is shown being transmitted in the shape of a thin sheet of light through the *p-n*-junction region of a gallium phosphide diode. The two micrographs represent the "on" and "off" modulation states of the *p-n* junction as seen through a polarizer on the output side of the diode. A light beam from a mercury-arc lamp is focused on the input side. In the "off" state (*top*) no bias voltage is applied to the diode through the contact wire at top and as a result very little light passes through the junction. In the "on" state (*bottom*) reverse bias is applied and more light emerges from the *p-n* junction.

A Stone Age Campsite at the Gateway to America

Onion Portage in Alaska is an unusual Arctic archaeological site. It provides a record of human habitation going back at least 8,500 years, when its occupants were not far removed from their forebears in Asia

by Douglas D. Anderson

It seems virtually certain that men first migrated to the New World from Asia by way of the Arctic, yet for some time this fact has presented archaeology with a problem. By 10,000 B.C. Stone Age hunters were killing mammoths on the Great Plains. There is evidence suggesting that man was present in Mexico even earlier, perhaps as early as 20,000 B.C. Until 1961, however, the Arctic gateway region had yielded few traces of man before 3000 B.C. In that year excavations were begun at a site in Alaska where the remains of human occupation are buried in distinct strata, affording the investigators a unique opportunity for reliable dating.

The site is Onion Portage, on the bank of the Kobuk River in northwestern Alaska. It has been intensively excavated from 1964 through 1967. The findings may eventually demonstrate that man was present in Alaska as long ago as 13,000 B.C. Already they show that men with strong Asian affinities were there by 6500 B.C.

Why is the stratified site of Onion Portage so unusual? Archaeological evidence concerning the hunters of sea mammals who lived on the shores of Alaska and northwestern Canada is quite abundant. North of the Aleutian Islands, however, no coastal site has been discovered that is more than 5,000 years old. The reason is that the sea, rising as the last great continental glaciers melted, reached a point close to its present level some 5,000 years ago, thereby drowning the former coastline together with whatever evidence of human habitation it harbored.

The change in sea level would not, of course, have affected early sites in the interior. Such sites are scarce and usually unrewarding for other reasons. One is that the environment of tundra and taiga (treeless barren land and northern forest) could not support as many hunting groups as the game-rich shore. Another reason is that campsites on interior rivers were likely to be washed away or buried as the river shifted its course. In fact, throughout the interior only places where the ground is elevated and dry offer much archaeological promise.

The remains of numerous hunting camps have in fact been found on elevations in the Alaskan interior. These camps were apparently established to enable the hunters to catch sight of caribou on the tundra. As the hunters waited they made or repaired weapons and other implements; the campsites are littered with broken stone projectile points and tools and with the waste chips of their manufacture.

Herein lies another problem. At a rocky site where little or no soil is forming a 6,000-year-old spearpoint may lie beside one discarded only a century ago. It is nearly impossible to prove which is the older or exactly how old either one is. Even where soil has developed and the artifacts have been buried, the Arctic environment plays tricks. The upper layers of soil, soaked with water and lying on top of permanently frozen lower layers, tend to flow and disarrange buried objects. As a result both absolute and relative dating of archaeological material from sites in the Arctic interior was rarely possible before the discovery at Onion Portage.

Some 125 miles upstream from where the Kobuk River enters the Chukchi Sea the course of the river is a lazy meander five miles long. Situated at the upper end of the meander, Onion Portage is bounded by steeply cut banks on the upstream side and by a long natural levee downstream. The terrain has not been radically altered by stream erosion for at least 8,000 years. The name Onion Portage comes from the wild onions that grow profusely along the gravelly shore and from the overland haul across the base of the point, which saves five miles of upstream paddling. Today the boundary between trees and tundra is only a few hundred yards north of Onion Portage. Beyond the trees the open tundra continues all the way to the Arctic Ocean, 270 miles farther north. To the south the terrain is open taiga, dotted with patches of spruce, willow and (in sheltered places) birch.

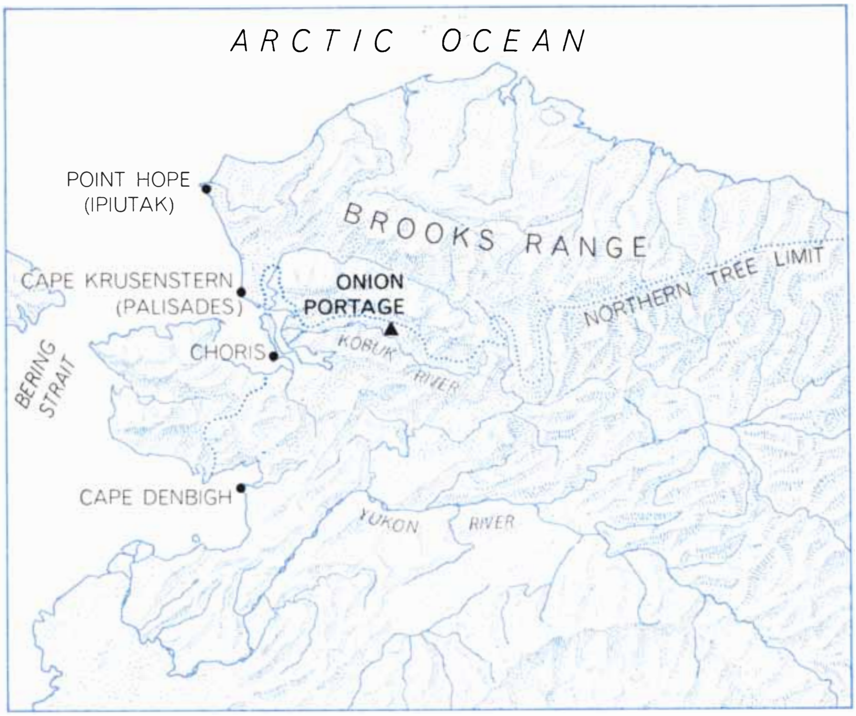
A sandy knoll dominates the wooded landscape at the site. Hunters both ancient and modern have used this vantage as a lookout for the thousands of caribou that cross the river at Onion Portage, moving north in the spring and south in the fall. From the knoll the approaching animals can be seen soon enough for men to be stationed for the kill at points where the herd is likely to cross the river. The fishing at Onion Portage is also good; several species of

DEEP PIT at Onion Portage shows the characteristic layering of soil at the site. Each thin, dark horizontal band was formed when charcoal from hunters' fires or other material was buried under sand or silt. Artifacts found below the lowest band may be as much as 15,000 years old. The measuring stick at right center is three meters long.

ONION PORTAGE SITE is located by the white triangle *(top center)* in this aerial photograph. The site lies on the upstream bank of a point of land enclosed by a wide meander of the Kobuk River, 125 miles from the sea in the interior of northwestern Alaska.

salmon migrate upstream during the summer. The prized sheefish, which is scarce in other Alaskan rivers, is also caught by the local Eskimos.

Over thousands of years the lower and flatter parts of Onion Portage have been buried several times under sand eroded from gullies in the knoll. In places the alluvial fans that spread out from the gullies have built up layers of sand as much as three feet thick. Unusually high spring floods have also engulfed the site from time to time, leaving thin deposits of silt. Windstorms too have spread thin sheets of drifted sand across the site. Each such covering killed the turf buried under it; the new turf that formed on the fresh surface was separated from the dead turf below by a sterile layer of sand or silt. All the deposits combined make up the sequence of strata at Onion Portage. In places the sequence is 20 feet thick. More than 70 of the surfaces show evidence of human occupation. The layers of turf are concentrated in bands, each of which contains from three to 14 occupation levels. The bands have been given consecutive numbers, starting with Band 1 just below the surface and ending with Band 8, the deepest dated series of occupation levels at the site.



ALASKAN SITES at which artifacts have been found that resemble those unearthed at Onion Portage include the four located on this map. Onion Portage, the first known stratified site in the New World's Arctic interior, was discovered by J. L. Giddings, Jr., in 1941.

The Onion Portage site was discovered in 1941 by the late J. L. Giddings, Jr., of Brown University, who was traveling down the Kobuk on a raft. He stopped and excavated several 500-year-old Eskimo house pits to gather material for an Arctic tree-ring chronology he was then establishing. He returned to the site 20 years later; test digging that year revealed the stratified layers. Giddings began a full-scale excavation in 1964, with the support of Brown University and the National Science Foundation. In the same year he died. Recognizing the uniqueness of the site, both institutions urged that the work be continued the following season. Froelich G. Rainey, director of the University Museum at the University of Pennsylvania, an Arctic specialist and a longtime colleague of Giddings', and I, one of Giddings' former students, were invited to take over the excavation. In the 1966 and 1967 seasons the work at Onion Portage has continued with the same support under my direction.

Our study is by no means complete. Soil samples from various levels at the site, for instance, are still being analyzed at the University of Uppsala, the University of Alaska and the University of Arizona for their chemical constituents, pollen content and even for microscopic diatoms. Samples of charcoal from each of the eight bands have already yielded carbon-14 dates that will enable us to fit the expected biological and geological information into a sensitive chronology. The chronology now spans a minimum of 8,500 years and may eventually go back another 6,500. Even now a preliminary correlation of the carbon-14 dates with the stone tools, weapons and other remains unearthed at Onion Portage has produced some surprising results. One finding substantially alters assumptions about cultural developments in the New World Arctic.

In presenting our preliminary results I shall start with the earliest of the three main cultural traditions we have found at Onion Portage. American archaeologists use the word "tradition" to describe a continuity of cultural traits that persist over a considerable length of time and often occupy a broad geographical area. A single unifying tradition may be shared by several distinct cultures. The word "complex" is used to describe the distinctive remains of a culture. A tradition usually includes more than one culture complex. It is with the earliest culture complex of the earliest tradition at Onion Portage that I shall begin.

The complex has been named Akmak, after the northern-Alaskan Eskimo word for chert, the flintlike stone that the hunting people of this complex most commonly employed to make tools and weapons. Most of the Akmak implements have been found on the sandy knoll at the site, between six inches and two feet below the surface. Some have been uncovered along the side of one of the gullies that cuts into the knoll and at the bottom of the gully's ancient channel, which is 10 feet below the bottom of the present channel. Others have been found below Band 8, where, having been carried down the gully, they had lain since before the first levels of Band 8 were formed. The fact that some of the material comes from below Band 8 indicates that the Akmak artifacts are at least 8,500 years old. They may be as much as 15,000 years old. Two fragments of excavated bone are being dated by carbon-14 analysis, but the sample is unfortunately too small to produce a reliable carbon-14 reading. We hope that future work at the site will produce material to settle the matter.

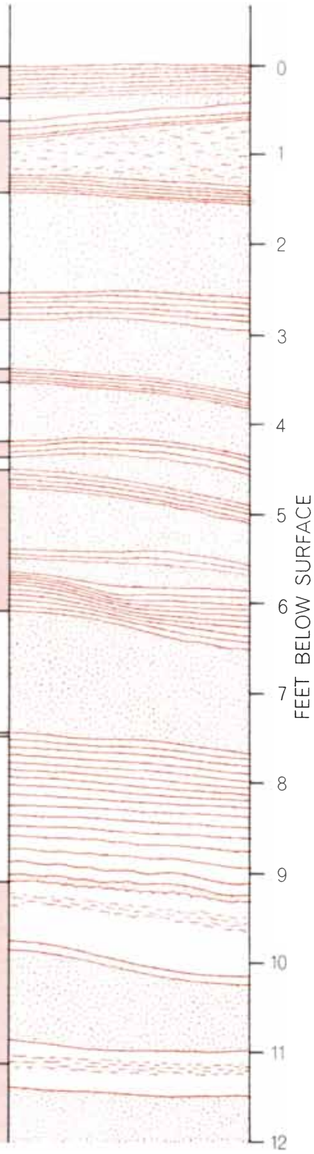
Most Akmak implements are of two classes. Comprising one class are large, wide "blades," the term for parallel-edged flakes of stone that were struck from a prepared "core." The other class consists of "bifaces," so named because the stone from which they were made was shaped by flaking surplus stone from both sides. From the blades the Akmak artisans produced a variety of tools. They include long end scrapers, curved implements with a sharp protuberance resembling a bird's beak and knives shaped by flaking one or both faces of a blade. The bifaces, which have the general form of a disk, were usually made by first striking the side of a slablike core; the detached flakes left scars that end at the center of the disk. Numerous smaller flakes were then removed around the margin of the disk to give it a sharp edge. Nothing like these implements has been found in Alaska before. Indeed, the tools that most resemble Akmak disk bifaces come from the area around Lake Baikal in Siberia, where they are found at sites that are between 12,000 and 15,000 years old.

Using a technique similar to the one for producing large blades, Akmak artisans also made "microblades." Most microblades are about an inch long and quarter of an inch wide. They were struck from a small core prepared in a way that is characteristic of "campus-type microcores," so named because the first to be discovered in America were found at a site on the campus of the University of Alaska. Campus-type microcores have been found in many other parts of Alaska and also in Siberia, Mongolia and Japan. The oldest ones come from the island of Hokkaido in Japan and the Kamchatka Peninsula in the U.S.S.R.

Many Akmak microblades were made into rectangular chips by breaking off both ends of the blade. Prehistoric hunters set such chips in a groove cut in the side of a pointed shaft of wood, bone or antler. The razor-sharp bits of stone gave the pointed weapon a wicked cutting edge. Grooved shafts of antler associated with rectangular microblades have been found both in Siberia and in the Trail Creek caves in western Alaska. Although grooved shafts have not been found at Onion Portage, it is reasonable to assume that the Akmak rectangles were intended for mounting in them.

The Akmak artisans also made burins: specialized stone tools with a sharp corner particularly useful for making grooves in antler and bone. The Akmak technique for producing burins was to strike a blow that left a chisel-like point at the corner of a flake [*see illustration on page 30*]. Akmak burins show signs of wear both at the tip and along the edge,

TRADITION	CULTURE	DATES	STRATIGRAPHIC LOCATION
ESKIMO	ARCTIC WOODLAND ESKIMO	A.D. 1000–1700	BAND 1
	?		
?	NORTHERN INDIAN?	A.D 400–800	BAND 2
ARCTIC SMALL-TOOL TRADITION	NORTON/IPIUTAK		
?	CHORIS COMPLEX	1500–500 B.C.	BAND 3
ARCTIC SMALL-TOOL TRADITION	DENBIGH FLINT COMPLEX	2200–1800 B.C.	BAND 4
NORTHERN ARCHAIC TRADITION	PORTAGE COMPLEX	2600–2200 B.C.	BAND 5
	PALISADES II COMPLEX	3900–2600 B.C.	BAND 6
		4000–3900 B.C.	BAND 7
		HIATUS	
AMERICAN PALEO-ARCTIC TRADITION	KOBUK COMPLEX	6200–6000 B.C.	BAND 8
	AKMAK COMPLEX	? 13,000–6500 B.C.	BELOW BAND 8



EIGHT MAIN BANDS in the stratigraphic column uncovered at Onion Portage are related in this chart to the evidence of human occupation they contain. Starting before 6500 B.C., and probably much earlier, three major cultural "traditions" succeed one another. The third tradition, interrupted about 1800 B.C., was initially represented at the site by the culture named the Denbigh Flint complex. It was evidently ancestral to the Eskimo tradition that appeared at Onion Portage about A.D. 1000 and continued thereafter.

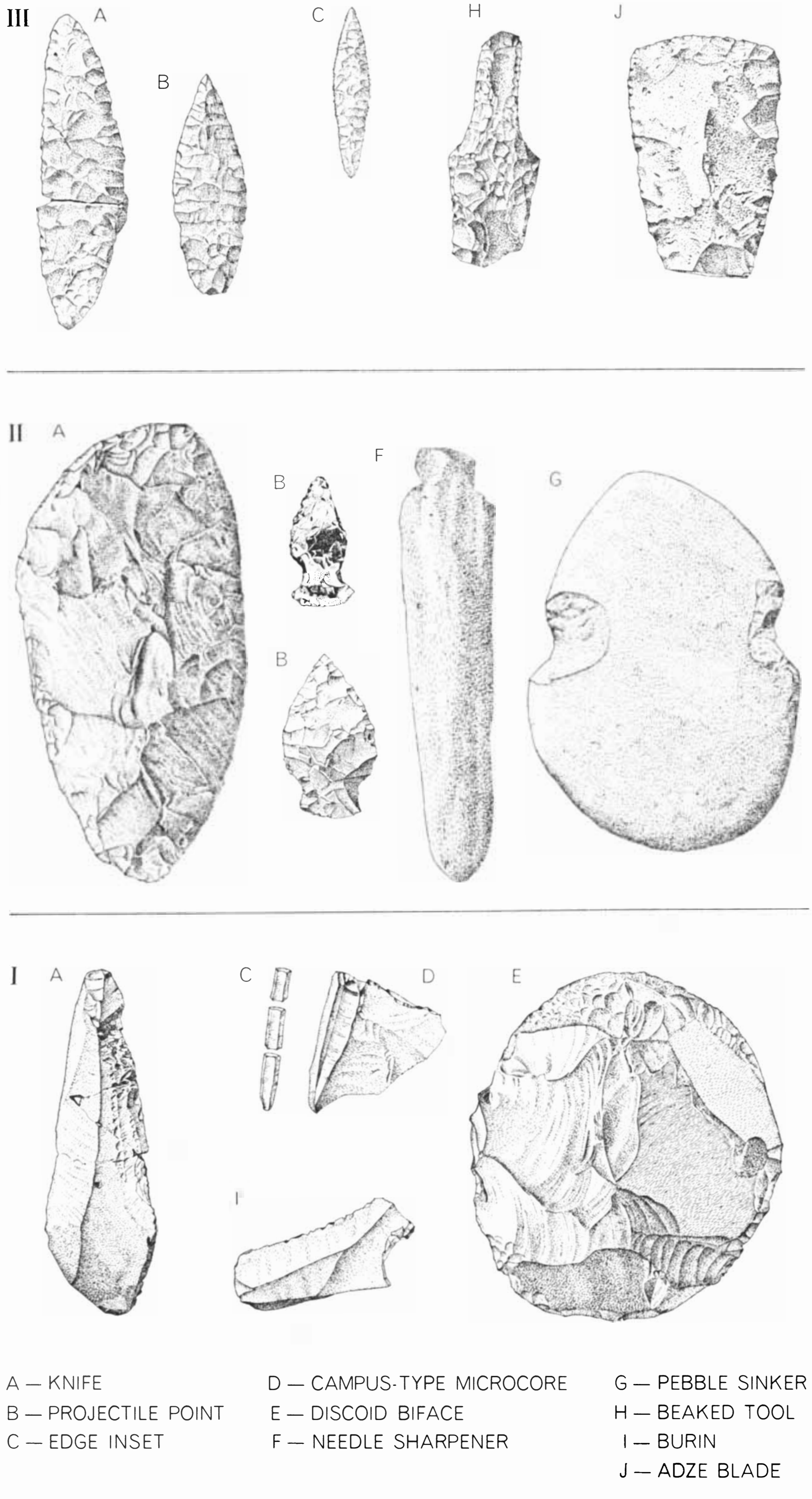
indicating that they were used not only for grooving but also for cutting.

The Akmak tools suggest relationships between Onion Portage and Asia. Considering the changes in Arctic geography during the past 30,000 years, this is scarcely surprising. At the height of the last continental glaciation Asia and North America were connected across what is now the Bering Strait. The land area that the lowered sea level had exposed was more than a mere isthmus. At its maximum extent between 20,000 and 18,000 years ago it was virtually a subcontinent, a tundra-covered plain 1,300 miles wide that must have been populated by herds of game and hunters pursuing them. The great plain, which has been named Beringia, made Alaska an extension of northern Asia. At the same time two continental glaciers in North America effectively cut ice-free Alaska off from the rest of the New World. The isolation of Alaska did not end until sometime between 14,000 and 10,000 years ago, when the glaciers began to melt rapidly. By then Beringia had already been twice drowned and reexposed by fluctuations in the level of the sea. Then, about 10,000 years ago, Beringia began its final submergence, a process that was not completed until some 5,000 years ago.

To repeat, the Akmak period at Onion Portage ended about 6500 B.C. and may have begun as early as 13,000 B.C. Between these dates dry land connected ice-free Alaska with Siberia while glaciers forbade or at least inhibited contact with the rest of North America. The resemblances between the Akmak culture and Siberian cultures, and the lack of resemblances between the Akmak culture and Paleo-Indian cultures to the south, reflect this geographic history. At the same time there are significant differences between the Akmak culture and the Siberian cultures, suggesting that the Akmak complex resulted from a long period of isolated regional development. Because the tradition of which the Akmak complex is the earliest appears to have been an indigenous development, arising from earlier Arctic-adapted cultures, I have named it the American Paleo-Arctic tradition.

The next evidence of human habitation found at Onion Portage is in two levels of Band 8. Carbon-14 analysis of material from the higher level suggests that the people who camped there did so sometime between 6200 and 6000 B.C. I have termed the remains from Band 8 the Kobuk complex.

The limited variety of Kobuk-complex



ARTIFACTS OF THREE PERIODS at Onion Portage reveal the presence of three separate cultural traditions: the American Paleo-Arctic (I), the Northern Archaic (II) and the Arctic Small-Tool tradition (III). Knives (*A*) are present in all three traditions and stone projectile points (*B*) in the last two. Hunters of all three traditions had projectiles, but the two Arctic traditions favored points made from antler or ivory and inset with tiny stone blades (*C*). Unique to the earliest tradition are "campus-type microcores" (*D*) and disk-shaped bifaces (*E*). Characteristic of the non-Arctic Archaic tradition are stones for sharpening needles (*F*) and sinkers for nets (*G*). Burins appear in both of the Arctic traditions; the one shown (*I*) is Akmak. Unique to the later Arctic tradition are peculiar beaked tools (*H*) and small adze blades (*J*). All the implements are reproduced at one-half natural size.

artifacts suggests that the material found at Onion Portage represents only a part of a larger assemblage of stone tools. Fewer than 100 worked pieces of stone have been recovered from the two levels. Most of them are rectangles made from microblades. There are also two burins made from flakes, a few remnants of campus-type microcores, a single obsidian scraper and several flakes, some of which have notched edges. All the implements were found adjacent to hearths on deposits of silt. The silt suggests that Onion Portage was a wet and uncomfortable place when the Kobuk hunters camped there. The hearths are probably those of small groups that stayed only briefly.

At a number of surface sites in the Brooks Range I have collected stone implements that are almost identical with those of the Kobuk complex. The only major difference is that the Brooks Range tool assemblage includes biface knives, which are missing from the Kobuk levels at Onion Portage. I suspect that the difference is more apparent than real; if we had unearthed a larger Kobuk inventory at Onion Portage, it probably would have included biface knives. In any case, the presence in both the Akmak and the Kobuk assemblages of microblade rectangles and campus-type microcores suggests that, although the Kobuk complex represents a later period, it is nonetheless a part of the American Paleo-Arctic tradition.

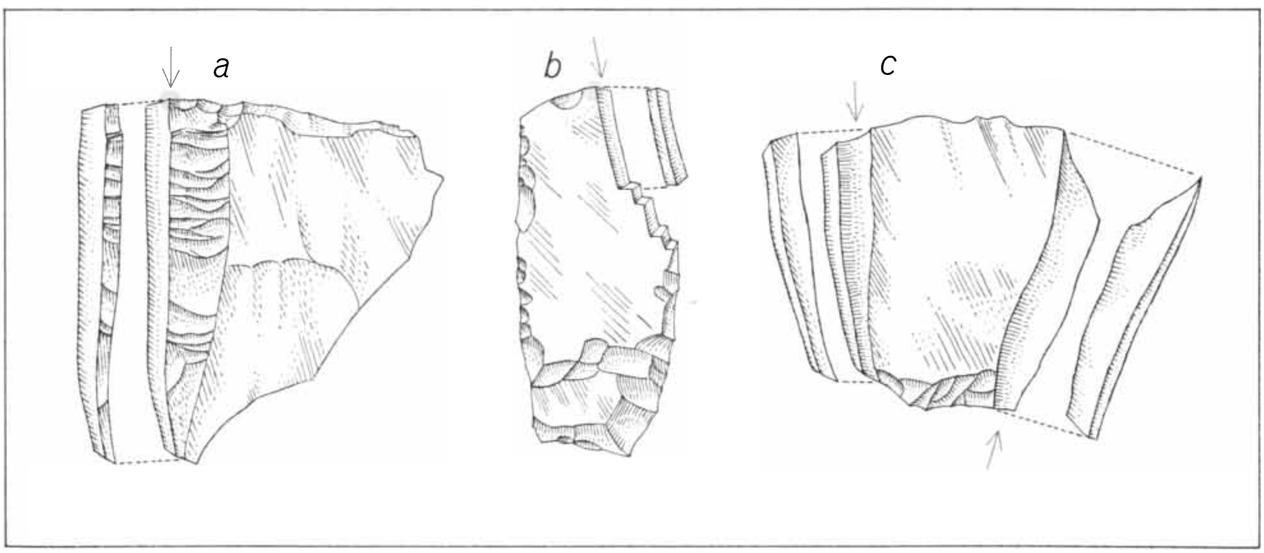
Quite the opposite is true of the material we have unearthed in Band 7, Band 6 and Band 5. After a hiatus of some 2,000 years an entirely new cultural tradition arrived at Onion Portage. Its lowest levels are dated by carbon-14 analysis at around 4000 B.C. There are no microblades among its tools. Instead of using weapons with microblades inserted in them the newcomers hunted with projectiles tipped with crude stone points that had notched bases and were bifacially flaked. The new assemblage also includes large, irregular knives made from flakes, thin scrapers, notched stone sinkers and large crescent-shaped or oval bifaces. We also unearthed two heavy cobblestone choppers.

The tools from Band 7 and Band 6, which contain the early and middle phases of the new tradition, are nearly identical with a group of tools from a cliff site overlooking Cape Krusenstern on the Alaskan coast 115 miles west of Onion Portage. The cliff site is known as Palisades; the name "Palisades II complex" has been given to these phases of the new tradition at Onion Portage. The tools of the Palisades II complex reflect an uninterrupted continuity, marked only by gradual stylistic changes, for 1,400 years. One such change affected the hunters' projectile points. The notched base characteristic of the early phase gave way in the middle phase to a base with a projecting stem.

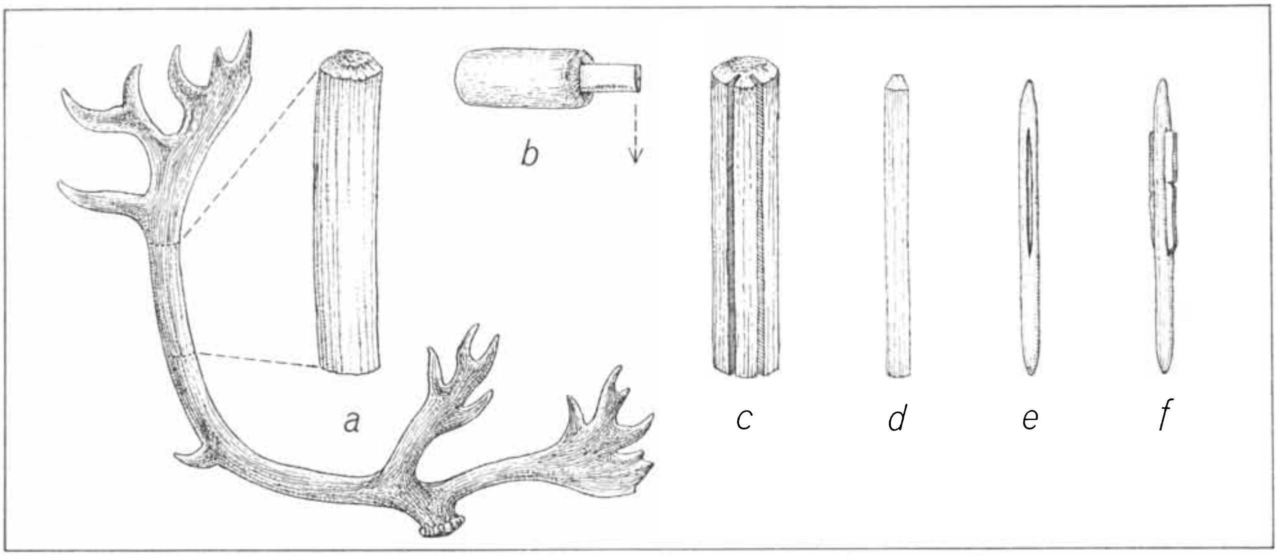
The contents of Band 5 indicate that around 2600 B.C. a period of rapid change began at Onion Portage and continued for 300 years. Several new types of tools appear; projectile points, for example, are neither notched nor stemmed but have a straight base. These and other differences in the assemblage indicate that the occupation levels in Band 5 belong to later phases of the new tradition. They warrant a label of their own, and I have named them collectively the Portage complex.

How is the arrival of the new tradition at Onion Portage to be explained? It is noteworthy that the duration of the new tradition coincides almost exactly with a major alteration in the climate of Alaska. About 10,000 years ago, as the region's last glacial period drew to a close, the Alaskan climate entered a warming phase that reached its maximum between 4000 and 2000 B.C. Throughout the period of milder weather the forest margin moved northward, steadily encroaching on the tundra. By the time of the maximum the boundary between tundra and taiga had probably advanced well beyond the position it occupies today. During the 2,000 years of the maximum it seems likely that Onion Portage lay well within the northern forest zone.

Far to the southeast, in the forests of the eastern U.S., an Indian population had pursued a woodland-oriented way of life beginning as early as 6000 B.C. Its weapons and tools reflect a forest adaptation; they belong to what is known as the Archaic tradition, as op-



GROOVE-CUTTING TOOLS, or burins, were made by Akmak (*a*) and Denbigh (*b*) knappers at Onion Portage. The Akmak knappers chipped a notch into the edge of a prepared flake before striking a blow (*arrow*) that knocked off a long, narrow spall, giving the flake a sharp, chisel-like corner (*color*). The Denbigh knappers, using the same burin blow (*arrow*), knocked much smaller spalls off flakes carefully prepared in advance. They used the tiny spalls as tools for engraving. Choris knappers (*c*) used the burin blow to strike fine, regular spalls from flakes of irregular shape. This produced no burins; the knappers made tools from the spalls instead.



PROJECTILE POINTS can be made from antler and microblades as shown here. A length of antler (*a*) is deeply grooved (*c*) with a burin (*b*) mounted in a handle for easy use. The triangular antler segments (*d*) are then rounded and pointed, and grooves are made in one or both sides (*e*). Razor-edged bits of microblade are then set in the grooves (*f*) to form a cutting edge. The Akmak, Kobuk and Denbigh levels at Onion Portage contain edge insets. Akmak and Kobuk insets are rectangles; Denbigh insets are crescents.

posed to the older Paleo-Indian tradition. I find it significant that, during a time when the forest had shifted northward, an assemblage of tools with many resemblances to the Archaic tradition should appear at Onion Portage. Crescent-shaped bifaces, projectile points with notched and stemmed bases, heavy choppers and notched stones that the Indians of the Archaic tradition used as sinkers for nets are among the elements common to the two assemblages.

Up to now evidence for the early diffusion of the Archaic tradition northward and westward from the woodlands of the eastern U.S. does not go much beyond the Great Lakes region. Artifacts that resemble Archaic-tradition tools have been found in central and northwestern Canada and in central Alaska, but their age is undetermined. The fact that the tools are distributed throughout this area nonetheless suggests the possibility that Archaic peoples, or at least the art of making tools in the Archaic tradition, moved northward into the Arctic along with the advancing forest. The findings at Onion Portage seem to support this suggestion. I have therefore named the Palisades II complex and the Portage complex together the Northern Archaic tradition. The differences between the second tradition at Onion Portage and the American Paleo-Arctic tradition that preceded it seem great enough to suggest that they were the products of two different populations. They may have been respectively early Northern Indians and proto-Eskimos.

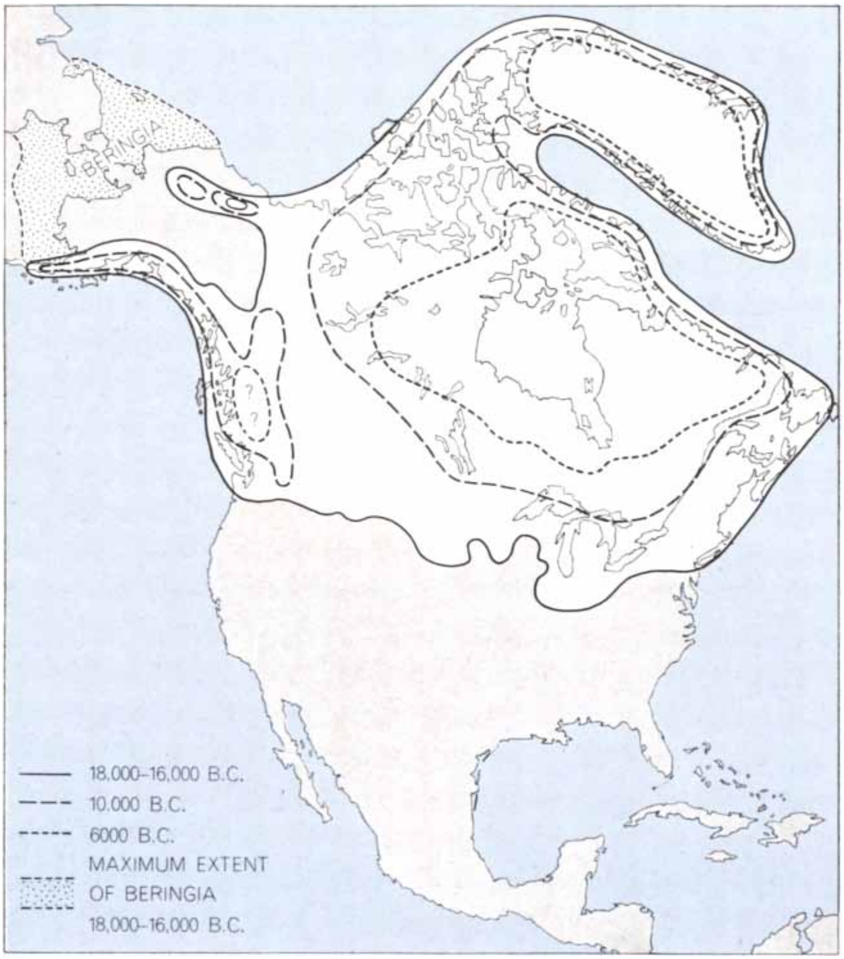
Almost immediately after 2300 B.C. there was a resurgence of Arctic culture at Onion Portage. The evidence in Band 4 marks the arrival of hunters representing the Arctic Small-Tool tradition. This tradition is well known from other Arctic sites. It is the culture of the earliest people in the New World Arctic who were equally at home on the coast and in the interior. The element of the tradition that is present at Onion Portage is the Denbigh Flint complex, first recognized at an Alaskan coastal site on Cape Denbigh [see "Early Man in the Arctic," by J. L. Giddings, Jr.; SCIENTIFIC AMERICAN, June, 1954].

The characteristic implements of the Denbigh people are burins and edge insets—the sharp stones shaped for insertion into grooved weapons. Some Denbigh edge insets were made from microblades, but all of them differ from the rectangular Akmak and Kobuk insets in that they are delicately flaked into halfmoon shapes. The Denbigh people produced microblades for a variety of other uses. For greater efficiency they devised a new form of microcore. It is wider than the campus-type core, and it allowed them to strike off wider and more easily worked blades.

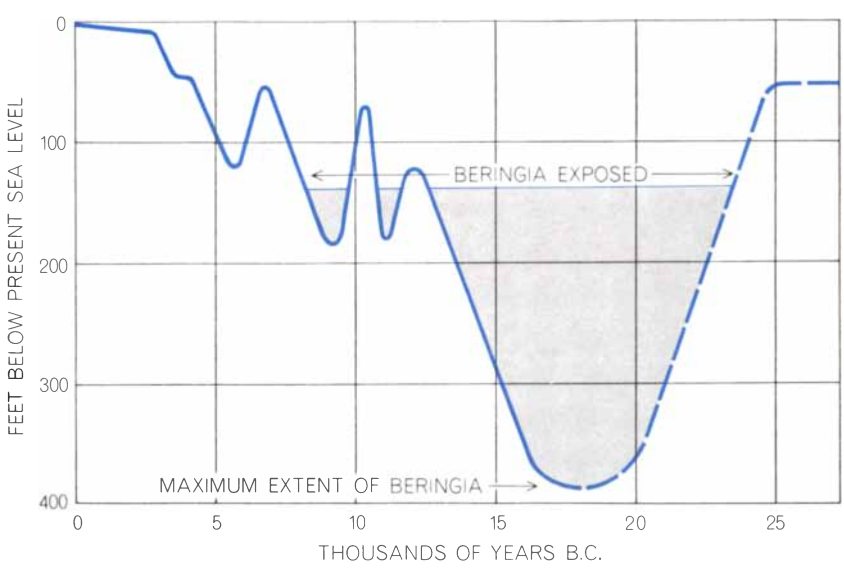
The people of the Denbigh Flint complex flourished widely in the Arctic between 2500 and 2000 B.C. Many students of Arctic archaeology consider them to be the direct ancestors of today's Eskimos, pointing out that the geographic distribution of Denbigh sites almost exactly coincides with the distribution of Eskimos in historic times. Parallels between the Denbigh Flint complex and the American Paleo-Arctic tradition, including the use of microblades and edge-inset weapons, suggest that the Denbigh culture may well have descended from the Akmak and Kobuk cultures.

After 2000 B.C. the New World Arctic and coastal subarctic area supported a number of Eskimo regional groups, none of which developed along exactly the same lines. Choris is the name given to one regional people that inhabited the Alaskan coast near the mouth of the Kobuk River, hunting caribou and living in large oval houses. The Choris-complex people have an involved history that spans 1,000 years from 1500 to 500 B.C. At Onion Portage, Choris artifacts are found in Band 3.

The earliest known pottery in the New World Arctic comes from Choris sites. The pottery was well made, was decorated by stamping patterns on the surface and was fired at a reasonably high temperature. In the earliest phases of the Choris complex, evidence for which is found at sites on the coast but not at Onion Portage, the pots were decorated by striking the wet clay with a cord-wrapped paddle. The pots are too skillfully made for it to be likely that the Choris people were experimenting with clay for the first time. Instead a fully developed industry must have been introduced from the outside. Exact counterparts have not yet been found abroad, but the basic Choris pottery patterns suggest a source in Asia. This is appar-



ICE BARRIER, formed by union of two continental glaciers, cut off Alaska from the rest of North America for perhaps 8,000 years. The era's lowered seas exposed Beringia, a vast area that made Alaska into an extension of Siberia. Arctic and Temperate North America were not reunited until the final withdrawal of the two ice sheets had begun (*broken lines*).



CHANGING SEA LEVEL in late Pleistocene times drowned Beringia 8,000 years ago. The link between Alaska and Siberia had been exposed earlier for two short periods and one long period when it was quite large. The graph is based on one by D. M. Hopkins of the U.S. Geological Survey; dating of sea-level changes before 18,000 B.C. is conjectural.

ently not the case for Choris-complex tools such as knife blades and skin scrapers. Some of the Choris edge insets for weapons resemble Denbigh types, but the other tools do not. If anything, they resemble Northern Archaic artifacts.

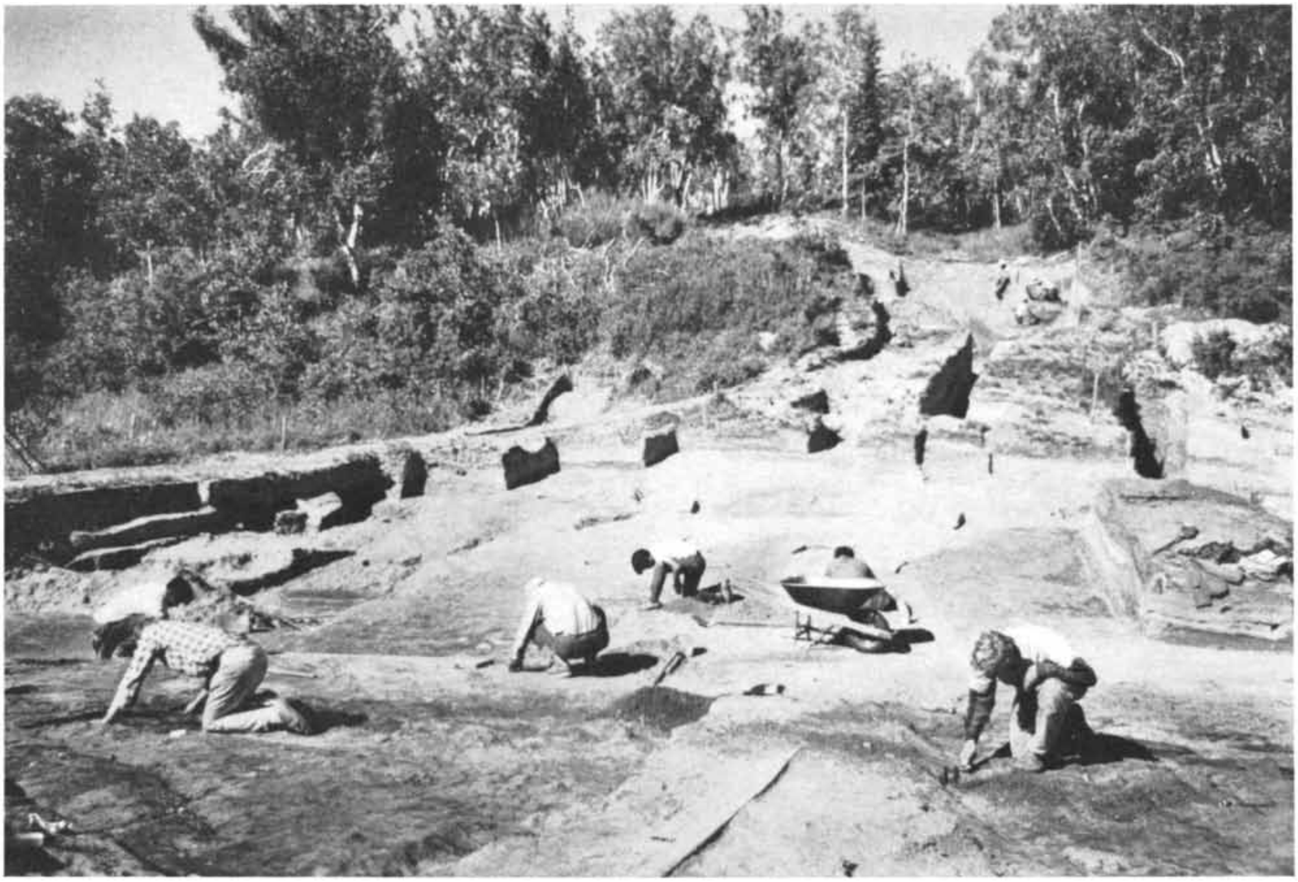
The Choris tool assemblage presents a puzzle in the form of large, regularly flaked projectile points that look very much like the Scottsbluff, Plainview and Angostura points made by the Paleo-Indian hunters of the Great Plains. The nearest Paleo-Indian sites, however, are removed from the Choris complex by some 2,500 miles and 3,000 years. What this likeness means in terms of a possible cultural relation between the Arctic and the Great Plains is a question to which I shall return.

From 500 B.C. to A.D. 500 the hunters who camped at Onion Portage left a record of steady Eskimo cultural evolution that includes evidence of increasing communication between the coast and the interior. Some of the artifacts recovered from the middle levels of Band 2, for example, are typical of those found at the seacoast site of Ipiutak, some 200 miles away on Point Hope. Regional variations nonetheless persist. Tools ground out of slabs of slate are found along with Ipiutak-complex tools at Onion Portage, but ground slate is unknown in the Ipiutak assemblage on Point Hope.

One final break in the continuity of Arctic-oriented cultures is apparent at Onion Portage. It is found in the upper occupation levels of Band 2, which were inhabited around A.D. 500 or 600. The artifacts in these levels are totally unlike those of contemporaneous Eskimo cultures along the coast. It seems logical to assume that forest Indians moving up from the south were responsible for the new cultural inventory. Whatever the identity of the newcomers, they did not stay long. Around A.D. 1000 Onion Portage was again in Eskimo hands.

Measured in terms of the number of artifacts and wealth of information, the modern period recorded in Band 1 is the best-known in the Onion Portage sequence. Our current studies, combined with Giddings' earlier ones, give a remarkably detailed picture of the Kobuk River Eskimos' gradual change from a part-time coastal economy to a full-time way of life adapted to tundra and taiga conditions, in which networks of trade maintained communication with the Eskimos of the coast.

Taken as a whole, the stratigraphic record at Onion Portage has cast much



WORK CREW on the flats below the hill at Onion Portage slowly exposes one of the site's more than 70 levels with traces of human occupation. Silt carried by floodwaters and sand eroded from the hillside had accumulated in the flats to a depth of 20 feet in places.

new light on the relations between various poorly dated or undated Arctic archaeological assemblages. At the start we see Arctic peoples with cultural roots in Siberia adapting themselves to a life of hunting on the treeless tundra of interior Alaska, and later to hunting along the treeless coast. As we can infer from the abundance of microblade edge insets found at Onion Portage, a part of this adaptation involved the efficient use of materials other than wood for weapons, among them antler (and later ivory) spearpoints edged with stone. This indigenous tradition, based on Asian origins, had an uninterrupted development from perhaps as early as 13,000 B.C. until about 6000 B.C.

Sometime before 4000 B.C. we see the arrival at Onion Portage of a forest-adapted tradition that had its origins in the eastern woodlands of the U.S. The advance of the Archaic tradition into Arctic terrain coincided with the postglacial shift in climate that allowed the forests to invade the northern tundra. With the reexpansion of the tundra at the end of the warm period Arctic cultures once again dominated the Kobuk River region. At the same time they spread rapidly across the entire Arctic area occupied by Eskimos today.

Until Onion Portage was excavated the archaeological record in the Arctic favored the view that early cultural developments there were somehow connected with the Paleo-Indians of the Great Plains. Many scholars suggested that the Arctic and Paleo-Indian cultures shared essentially the same cultural tradition, perhaps originating in the north or perhaps in the Great Plains but in either case occupying northwestern Alaska and Canada sometime between 7000 and 3000 B.C. The suggestion derived its strength primarily from the presence of projectile points almost identical with Paleo-Indian ones at several sites in Alaska and Canada. The projectile points found in the Arctic could not be dated, but it was speculated that they were as much as 7,000 or 8,000 years old. Such antiquity, of course, added strength to the Paleo-Indian hypothesis.

Even before the Onion Portage excavations some contrary evidence had come to light. For example, the Choris complex is rich in projectile points that are Paleo-Indian in appearance. Yet the Choris complex is firmly dated between 1500 and 1000 B.C.—scarcely half of the minimum age suggested by the Paleo-Indian hypothesis.

The findings at Onion Portage, in my opinion, cast even more doubt on the hypothesis. During the millenniums between 7000 and 3000 B.C.—nearly the entire interval of the postulated contact between (or identity of) the Arctic and the Paleo-Indian cultures—nothing from any occupation level at Onion Portage shows any hint of Paleo-Indian influence. On the contrary, the influence in the earlier part of the interval is Siberian and in the later part Archaic.

We hope that future work at Onion Portage will push the firmly dated record of Arctic prehistory back to even earlier times. We should also like to learn what cultures were developing along the Kobuk River between 6000 and 4000 B.C.—the period for which we have no record at Onion Portage. Meanwhile what we have already learned substantially clarifies the sequence of events at the gateway to the New World.

STARS IN CONTACT

About one star in 1,000 is in actuality a pair of stars so close together that their atmospheres exchange material. These contact binaries have something to tell us about the evolution of stars

by O. J. Eggen

If one could conduct experiments with stars, the instructions for a key experiment might begin: "Take two stars and place them in contact." Fortunately for astronomy this experiment is performed by nature. Many binary stars—double stars that rotate around a common center of gravity—are so close together that they are literally in contact; their atmospheres bulge toward each other and intermix. Indeed, nature seems to be rather fond of the experiment—about one star in 1,000 is a contact binary. The contact binaries have much to tell us about the origin and evolution of stars, which must be understood before we can explain the origin and evolution of galaxies and of the universe as a whole.

Contact binaries were discovered 185 years ago by a Yorkshireman named John Goodricke. (His observation was the more remarkable because he was 18 years old and a deaf-mute.) Goodricke found that the second brightest stars in the constellations Perseus and Lyra exhibited rhythmic variations in brightness. The star in Perseus, called Algol or Beta Persei, took two days 20 hours to complete a cycle of variation; the period of Beta Lyrae was 13 days. Although Newton's laws of gravitation had not yet been tested outside the solar system, Goodricke boldly conjectured that the stars were double and that the variations in brightness resulted from the alternate eclipse of each star by its companion. (For his discovery and his explanation Goodricke was awarded the Copley medal and elected a Fellow of the Royal Society. Two weeks after his election he died.)

The variations Goodricke observed and the physical explanation he gave for them are presented in the illustrations on pages 36 and 37. In Beta Persei one of the stars is much brighter than the other, so that alternate eclipses differ greatly in the amount of light they extinguish. As one would expect, the light is steady at its maximum value when both stars are fully visible and diminishes when one of them is eclipsed by the other.

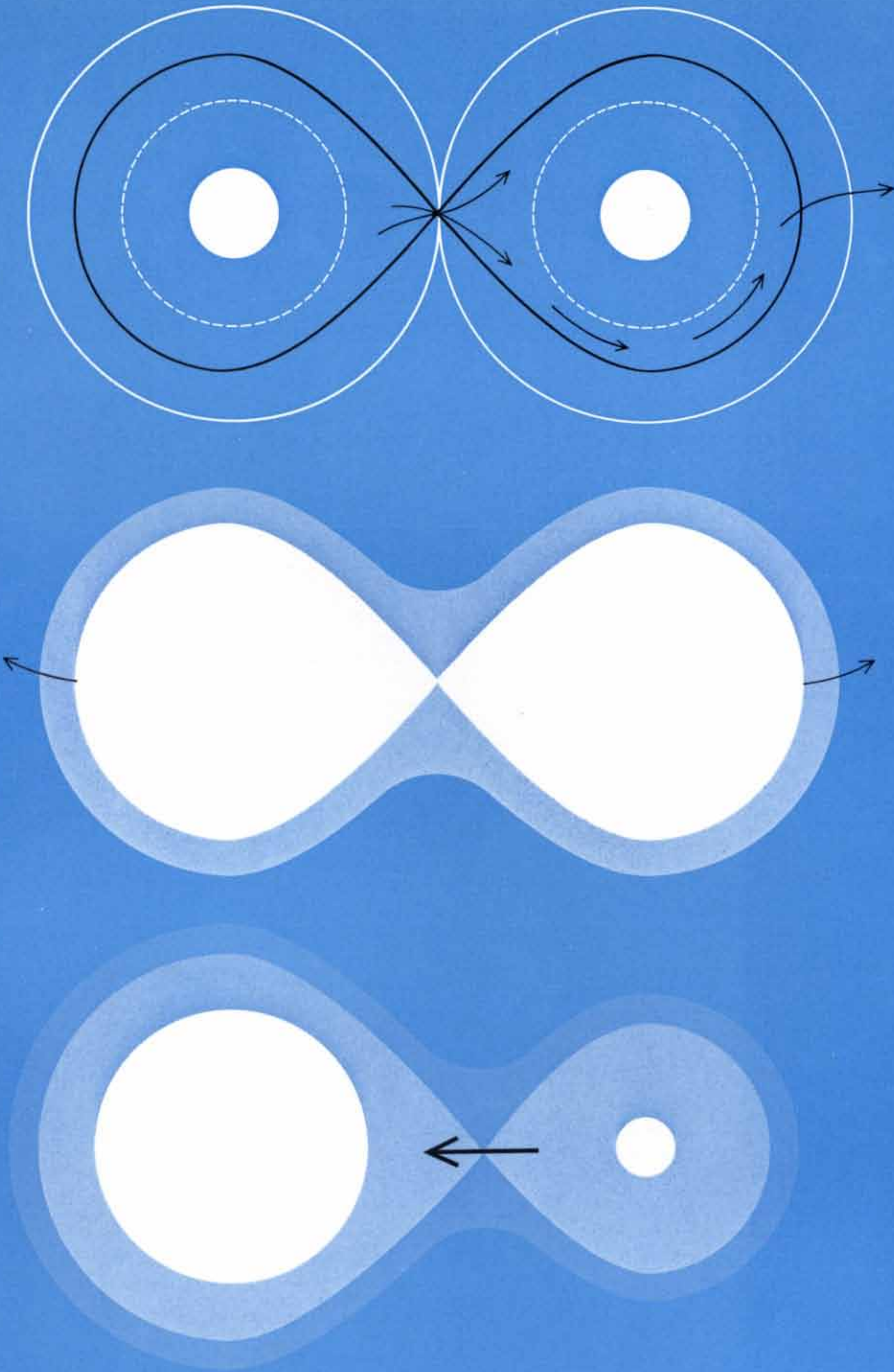
In the case of Beta Lyrae, Goodricke was less sure of his explanation and could not see exactly how it applied. From the illustration one can understand the difficulty. The two stars are so close to each other that they raise enormous mutual tides. As a result the two stars resemble American footballs with their long axes pointed toward each other. As they swing around their orbits, locked nose to nose, they present to an observer on the earth an aspect that changes in a rather complex way.

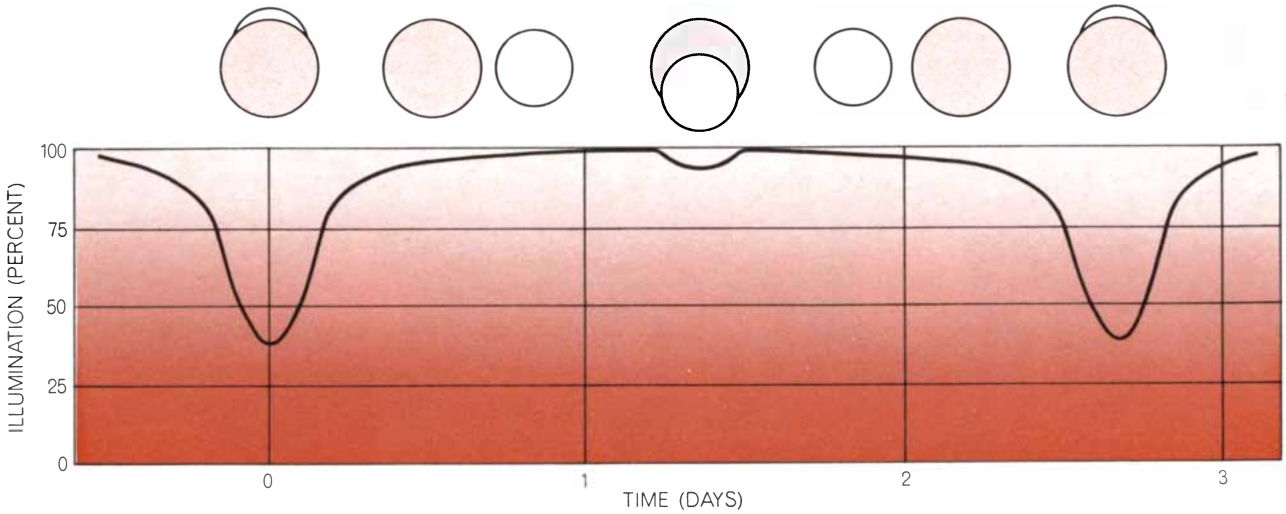
Hundreds of systems of the Beta Lyrae type are now known. A few have periods as long as Beta Lyrae's 13 days, but in most cases the period is less than a day. It can be as short as a quarter of a day. Even now we can do little better than Goodricke did in observing such a system and describing the physical processes that are taking place in it. We can, however, hope to understand nature's reason for the experiment in the context of stellar evolution.

Briefly stated, the theory of stellar evolution is as follows. A star is born from a condensation of gas, mostly hydrogen, that heats up as it is compressed by gravitational forces. Eventually the gas is heated to the point at which it begins "burning" hydrogen by means of thermonuclear reactions. When the luminosity of stars in this long "adult" phase is plotted against their surface temperature, the stars are found to be distributed along the celebrated curve called the main sequence [*see illustration on page 38*]. After a long time the star will have consumed much of its hydrogen. It then begins to undergo a series of comparatively rapid changes. Gravitational contraction begins again in the central core, causing its temperature to rise. The rising temperature of the core causes the outer layers of the star to be pushed outward, so that the star swells even though its core is contracting. The star moves off the main sequence and becomes a red giant. When the star has entirely consumed its nuclear fuel, it undergoes further contraction until it becomes the extremely dense body known as a white dwarf.

In addition to the theory of stellar evolution, which did not exist in Goodricke's time, we now have good estimates of the size, mass and luminosity of many stars. We know that in a main-sequence star, size, mass, temperature and luminosity are all closely linked and are unique functions of one another. For example, it can be seen in the illustration on page 38 that a star 100 times brighter than the sun is three times more massive than the sun, is about 7,000 degrees Kelvin (degrees centigrade above absolute zero) hotter than the sun and has

CONTACT SYSTEMS that may represent three stages of evolution are depicted on the opposite page. Y Cygni (*top*) is a young system; its two stars have not distorted each other through gravitational effects. With age the outer regions expand and would be in contact (*large circles*) in about three million years if it were not for the gravitational boundary represented by the black figure-eight curve. Gravity and an exchange of mass through the neck of the figure eight slowly distort the two stars, resulting in a system such as AO Cassiopeiae (*middle*). Systems such as V444 Cygni (*bottom*) may be third step in evolution.





VARIATION IN LIGHT is visible as the two stars in the contact system known as Algol or Beta Persei alternately eclipse each other during their orbits around a common center of gravity. One of the stars is much dimmer than the other, so that the alternate eclipses differ significantly in the amount of light lost as seen by an observer on the earth. The maximum light is seen between eclipses.

nearly twice the radius of the sun. A star 1,000 times brighter than the sun has five times the mass of the sun, is about 13,000 degrees K. hotter than the sun and has 2.5 times the radius of the sun.

The contact binaries should present a test of the accuracy of these numbers. If one could place our sun in contact with a similar star—ignoring for the moment the tidal effects each star would have on the shape of the other—they would travel around each other in a period of a little less than a quarter of a day. Brighter and therefore larger stars would take longer; stars smaller than the sun would take less than a quarter of a day. Since the size and temperature of the stars are uniquely related, one might then construct a predictable relation between the period and the temperature of contact binaries.

First, however, one must take into account the gravitational effects. Two stars in contact will exert tidal forces on each other. Since the stars are essentially vast masses of gas, they will react to the forces much as the earth's seas do to the lunar and solar tides. The problem of these distortions was solved in a general way 25 years ago by Subrahmanyan Chandrasekhar of the University of Chicago. Two stars in contact will deform each other to the extent of increasing their radius by nearly 20 percent at the point of contact and flattening the poles by almost the same amount [*see top illustration on page 39*].

One can now construct two predicted period-temperature relations, one of them for undistorted stars and the other for distorted ones [*see bottom illustration on page 39*]. The relation can then be compared with the observed periods and temperatures of all the real contact binaries within about 300 light-years of the sun. The comparison yields an agreement that is better than one usually finds in dealing with such massive and distant objects as stars. Although there is some spread in the observed periods of contact binaries with a given temperature, the spread does not go beyond the predicted period-temperature curve for distorted stars. The agreement between prediction and observation confirms that we are dealing with contact binaries.

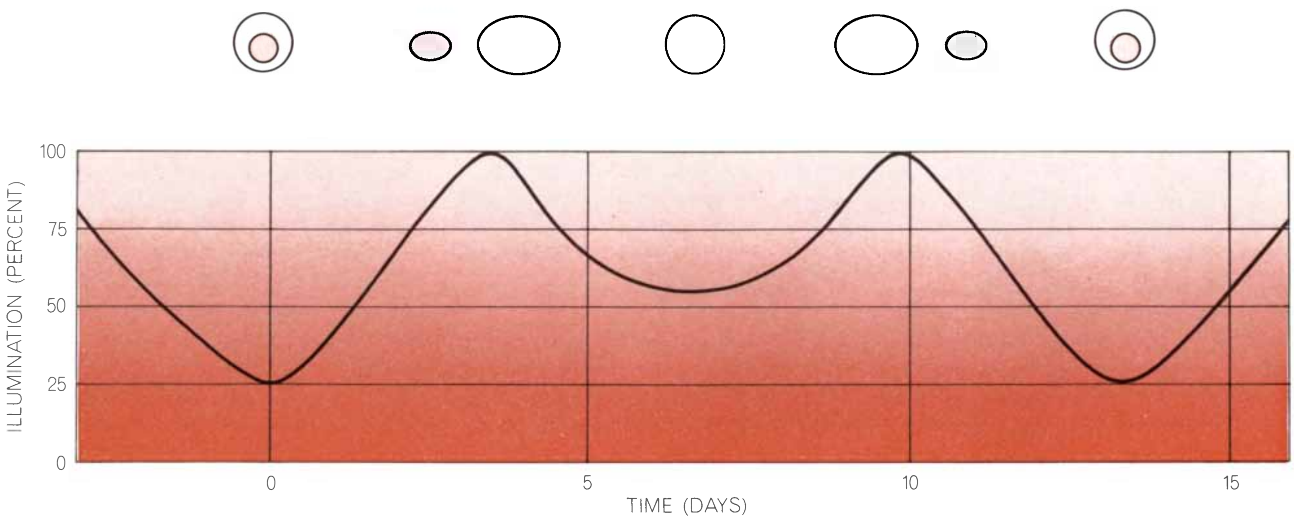
The distribution of temperatures and periods of the real contact binaries tells us more than that our knowledge of the sizes of main-sequence stars and our theories of stellar tides are correct. As one can see in the bottom illustration on page 39, the observed contact binaries adhere closely to the predicted temperature-period curve up to periods of about half a day. Thereafter they begin to fall increasingly short of the curve as the periods increase. Moreover, there are no systems of this kind with periods longer than two-thirds of a day. The cutoff at two-thirds of a day and the absence of systems with periods shorter than a quarter of a day may be telling us something useful about how stars evolve.

The argument takes us somewhat more deeply into the theory of stellar evolution. The unique relation between stellar temperatures and radii reflected in the illustration on page 38—the relation on which the predicted period-temperature curve was based—applies only to stars that have not begun to evolve off the main sequence. Consider a star that has begun such an evolution. As the hydrogen in the core of the star is consumed, more energy is generated in the core than can be radiated away at the surface of the star. The star begins to swell and to lower its surface temperature.

The largest, most massive and therefore most luminous stars burn hydrogen at a prodigious rate. They are the first to show the swelling caused by the excess generation of energy at the core. The rate of hydrogen consumption decreases regularly with luminosity; in the case of a comparatively small star such as the sun the process (fortunately for life on the earth) takes place on a very long time scale.

A star 10,000 times more luminous than the sun will double its radius in 10 million years and then will expand to 1,000 times its original size in the next 25 million years, meanwhile decreasing its surface temperature by more than 10,000 degrees K. Less profligate stars have longer lives with less expansion. For the sun, which is already some 4.5 billion years old, another two billion years will see only a fractional increase in its size and a reduction in temperature of less than 1,000 degrees K.

Bearing these elements of the theory of stellar evolution in mind, one can attempt to understand the puzzle presented by three different eclipsing systems: Y Cygni, AO Cassiopeiae and V444 Cygni. (Stars in a constellation are identified by Greek letters, Roman letters or Arabic numerals; it is customary to follow the letter or number with the Latin genitive form of the constellation's name, so that star Y in Cygnus becomes Y Cygni.) The orbital period of each system is four days, but the form of the variation in light is distinctly different



CLOSE STARS in Beta Lyrae have distorted each other by gravitational effects, so that the stars resemble American footballs with their long axes pointing toward each other. As the system revolves it presents a variety of aspects of light to an observer on the earth. Loss of light varies according to whether dimmer star (*color*) is eclipsing brighter one (*left*) or brighter one the dimmer (*center*).

for each one. All three systems have stars of about the same temperature (close to 30,000 degrees K.) and are approximately 100,000 times brighter than the sun.

Y Cygni is what might be called a model system. Its nearly equal stars are widely enough separated so that mutual tidal effects are not strong enough to disturb their spherical shapes [*see top illustration on page 40*]. The light curve is a clean one in that the only variation in light is caused by the alternate eclipse of each star by the other. The eclipses are identical. (It is the length of the eclipses that provides the basis for calculating the relative sizes of the stars.)

From what is known of stellar evolution, however, such a system cannot last very long. In only a million years the radii of both stars will be elongated as shown by the broken circles in the illustration. In three million years, if the stars could evolve at the same rate, they would be the size of the large circles, which are just in contact.

In actuality they can never reach this large size. The black figure-eight surface, which is called a zero-velocity surface, represents a boundary in the gravitational field of force surrounding the two stars. The relative sizes of the two lobes of the figure eight are governed by the ratio of the masses of the two stars, with the larger lobe around the more massive star. The stars cannot expand beyond the zero-velocity surface, because at that surface the path of least resistance for any particle of material in either star is no longer directly away from the star but along the figure-eight surface and through the neck of the figure eight to the other star.

Since the rate of evolution is directly related to the mass of the star, the slightly more massive component of Y Cygni will reach the zero-velocity surface first. Further expansion will pump material directly into the lobe around the less massive star. The stars differ little in mass, so that their rate of expansion will differ by a comparatively small amount. Hence there may be a period of a few thousand years before a state of equilibrium is reached; during that period a dog-eat-dog situation may exist, with material being pumped back and forth between the two lobes.

Two paths of least resistance other than the one at the neck of the figure eight must be taken into account. They are at opposite ends of the figure. Through them some material is almost certainly pumped out of the system. Most of the ejected material will stay near the stars, enveloping them in a thin shell. The resulting object resembles an egg with a double yolk. It is a star with two separate cores burning within a single atmosphere.

If this prediction of the way Y Cygni will evolve during the next two million years is correct, the system will exhibit a form of variation in light drastically different from the one observed now. The sharply defined and equal eclipses, with constant light between them, will be gone. In their place will be a continuously changing aspect of a nonspherical light source. Because of the likelihood that gas would still be streaming between the stars, each period might reveal small changes in the form of light variation.

Interestingly enough, this description rather neatly fits AO Cassiopeiae and systems like it. Indeed, the described transformation of such systems as Y Cygni follows so completely from the theory of stellar evolution that if systems like AO Cassiopeiae did not exist, some very good explanation would have to be devised for their absence. Furthermore, since the transformation of a Y Cygni to an AO Cassiopeiae takes only some two million years, the observed fact that Y Cygni systems are rare whereas those like AO Cassiopeiae are common is to be expected.

Predicting the subsequent evolution of a system that has reached the stage of AO Cassiopeiae is more difficult than predicting the evolution of a Y Cygni system. What is learned from the evolution of single stars can no longer be applied because of the interaction of the two components of the system. The interaction takes the form of pouring new, hydrogen-rich material from the atmosphere of one star into that of another. Since this situation is confined to contact systems, knowledge gained from other kinds of stars is no longer applicable.

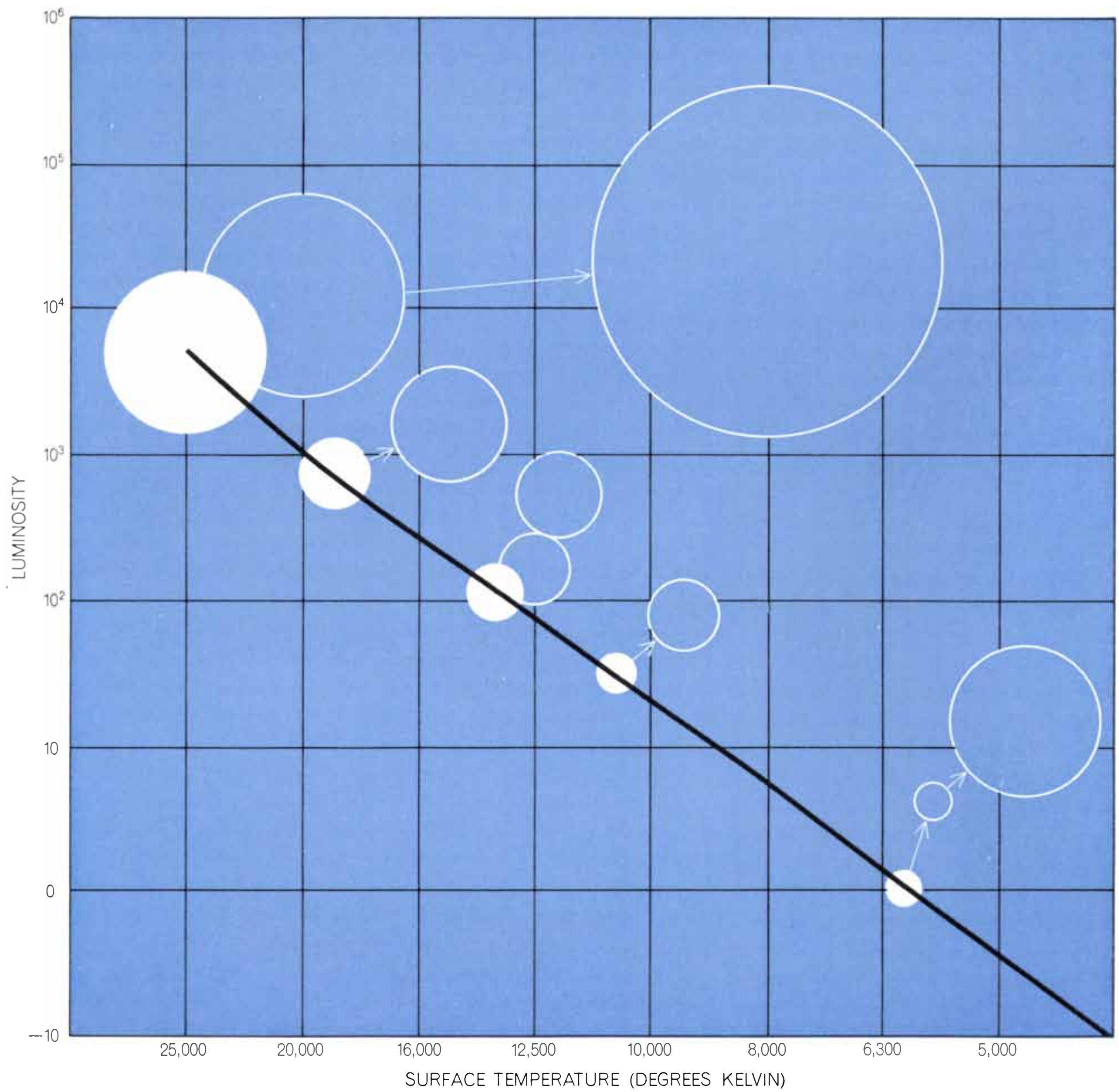
One way to proceed is to search for systems that have the same total mass, temperature and period as Y Cygni and AO Cassiopeiae but show a variation in light that is markedly different. V444 Cygni is such a system. Its light variation shows, like Y Cygni's, sharply defined and symmetrical eclipses, but the two eclipses differ greatly in width because the stars are markedly different in size. Although the total mass is 35 solar units, as in the case of Y Cygni and AO Cassiopeiae, the ratio of mass between the components is 25 to 10 rather than the more equal distribution in Y Cygni and AO Cassiopeiae.

As for light, the resemblance of V444 Cygni to Y Cygni extends only to the form of variation. V444 Cygni systems share with AO Cassiopeiae systems the erratic changes in light from cycle to cycle. The cause is the presence of a common atmosphere and the flowing of gas streams in the system.

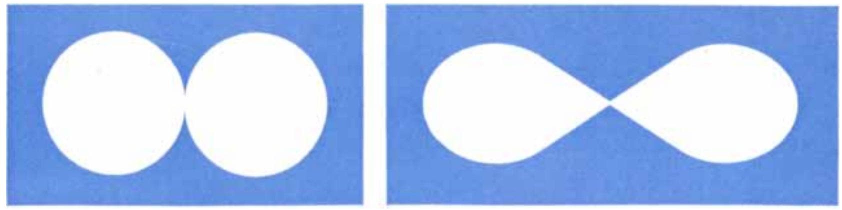
It is premature to say with certainty that V444 Cygni systems represent the stage of evolution that will eventually be reached by AO Cassiopeiae systems. The difficulty lies in the coarseness of the present methods of ascertaining the age of stellar systems. One cannot differentiate accurately over the few million years of development represented by Y Cygni, AO Cassiopeiae and V444 Cygni. The problem of the subsequent evolution of systems of the AO Cassiopeiae type is recognized as an important one, and much theoretical and observational work is being brought to bear on it.

As is evident from the illustration of period-temperature relations [*bottom of opposite page*], contact binaries with periods of less than two-thirds of a day greatly outnumber such massive systems as AO Cassiopeiae. In fact, the wide separation of these two kinds of system in the period-temperature relation suggests that the systems may have only one thing in common: the contact nature of the component stars. As I have pointed out, there is good reason for believing the AO Cassiopeiae systems developed from the Y Cygni systems. Do the short-period systems also represent a development from an earlier form of contact binary?

On the basis of stellar evolution the answer probably is no. Many of the



MAIN SEQUENCE for the sun (*lower right*) and other stars in the "adult" stage of evolution shows a close relation among size, mass, temperature and luminosity, which is represented in terms of the sun's luminosity. Larger shapes above main-sequence curve represent what happens after the stars have consumed much of their nuclear fuel. From main-sequence relations one can predict curves of period and temperature that would result if such stars were in contact with similar stars. Curves appear on opposite page.



EFFECT OF GRAVITY on two stars in contact is gradually to deform them by raising mutual tides in their gaseous atmospheres. The effect is to lengthen the normal radii (*left*) by about 20 percent at the point of contact and to flatten the poles, resulting in a major change of shape (*right*). The change also forces the centers of the two stars apart and lengthens by 25 percent the period in which they rotate around their center of gravity.

short-period systems are known to be only a few million years old. For stars so young, with masses of three solar units or less, very little expansion will have taken place in such a period of time. Probably, then, the short-period systems were produced in their present form.

How would it come about that one in about every 1,000 stars with a mass of less than three solar units was born double-yolked? An obvious possibility is that the cause in each case was fission of a single star. Indeed, this answer was accepted 50 years ago, mainly as a result of considerable work on the subject by the British astrophysicist Sir James Jeans, whose researches were an extension of ideas formulated earlier by the mathematicians Karl Jacobi of Germany, Henri Poincaré of France and Sir George Darwin of Britain.

The fundamental idea was that instabilities in a rotating sphere would lead to a pear-shaped figure that would break apart. Jeans commented that "the masses are at first projected away from one another with considerable velocity but seem likely to settle down finally to describe steady orbits about one another."

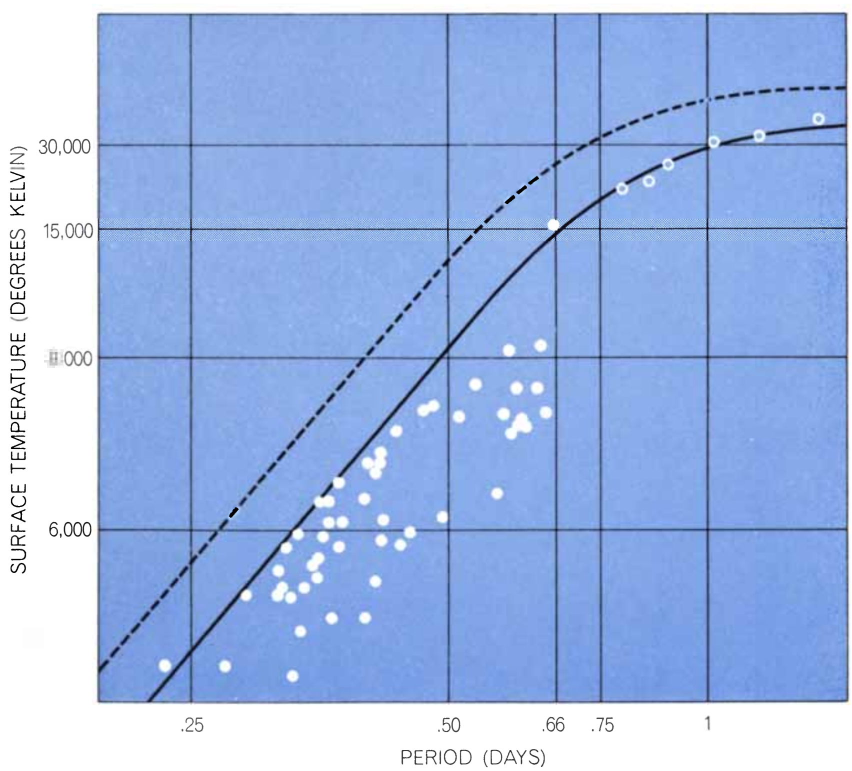
For many years this concept received little attention among astronomers and astrophysicists. One reason was that for the sake of simplicity it was assumed that the pear-shaped figure was an incompressible fluid, which is not what stars are made of. Moreover, most of the investigations of pear-shaped figures were mathematical exercises with no distracting nonsense about real stars.

Interest in the fission theory as applied to real stars has recently been revived by the work of two young British astrophysicists, Ian W. Roxburgh of Queen Mary College and Leon Lucy of Columbia University. To summarize their results requires consideration of stellar evolution before the main sequence, that is, evolution toward the main-sequence curve instead of away from it as with red-giant stars. A star evolving toward the main sequence is contracting. As with expansion, the rate of contraction is directly related to the mass of the star. Contraction, however, takes place over a much shorter period than expansion.

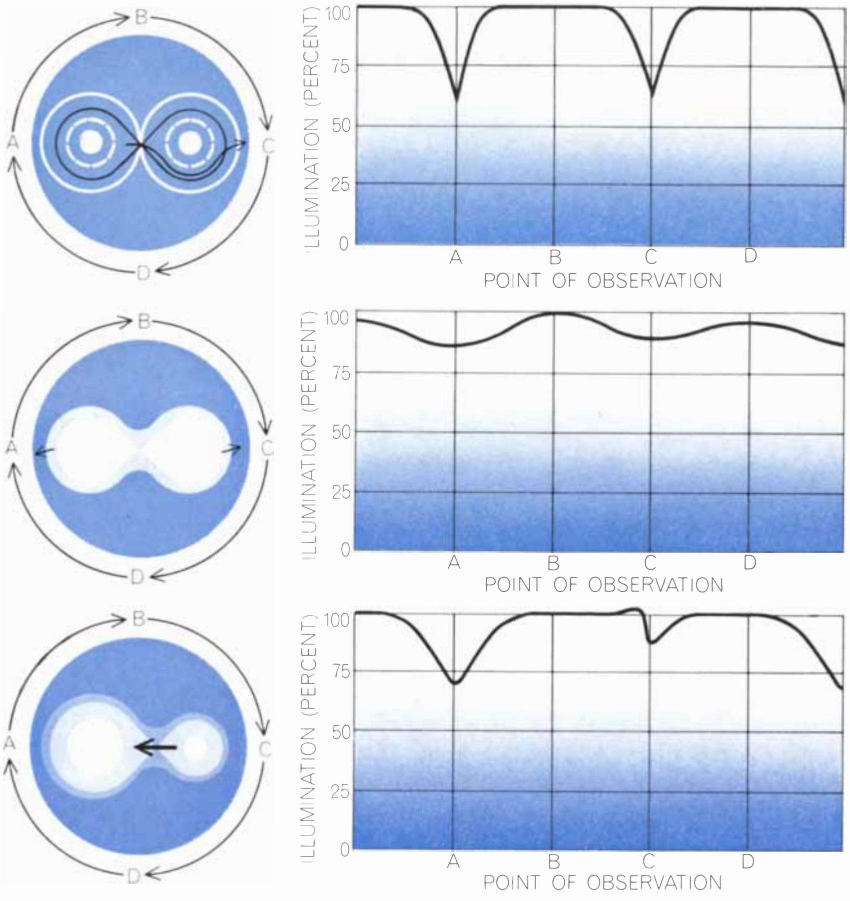
If the star is rotating as it contracts, instabilities can arise that will split the contracting mass and form a contact binary. The appeal of this theory is particularly strong because the theory accounts for two phenomena reflected in the period-temperature curve illustrated at right: the absence of contact binaries with periods of less than a quarter of a day and the sudden cutoff of short-period contact binaries at periods near two-thirds of a day. The absence of the first group is explained by the fact that contracting stars less massive than about 80 percent of the sun's mass do not produce the rotational instabilities necessary for fission. The cutoff at two-thirds of a day is explained by the fact that if fission occurs in a contracting star more massive than about four solar units, the product is not a distorted contact binary but a system of clearly detached stars such as is seen in Y Cygni.

The cross section of a representative contact binary resulting from fission is shown in the bottom illustration on the next page, together with the form of the observed variation in light. The period is half a day, the total mass is four solar units and the temperature is near 8,000 degrees K. One problem that must be explained is that the shape of the system and the manner in which its light varies closely resemble the shape and light variation of the hotter and much more massive AO Cassiopeiae systems. The explanation appears to be that the AO Cassiopeiae systems developed, whereas the short-period contact systems were born as contact systems.

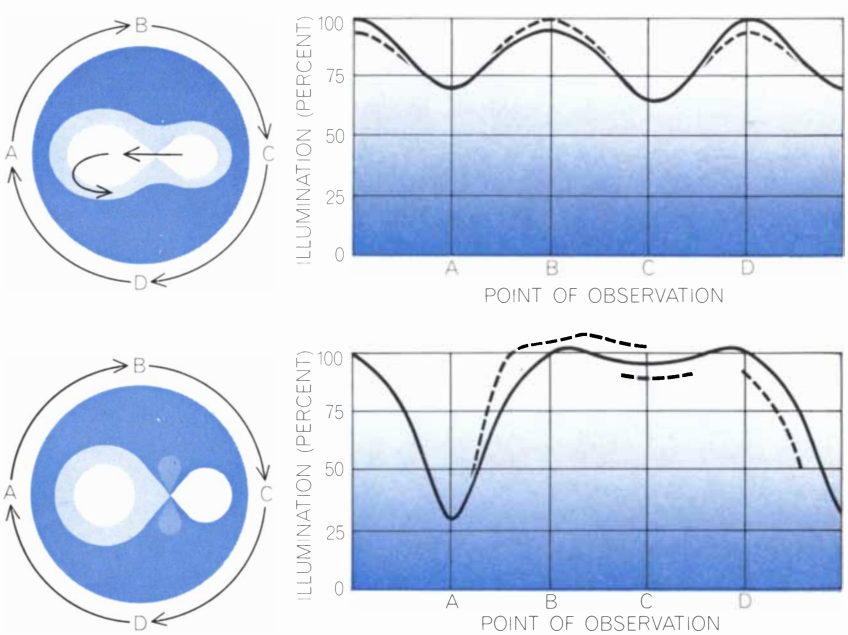
In any case, both kinds of system contain stars in contact. The future development of such systems, which will be outside the mainstream of stellar evolution because of the contact phenom-



PERIOD-TEMPERATURE RELATION of contact-binary stars is predicted for distorted systems (*solid curve*) and undistorted ones (*broken curve*). Solid circles represent real contact binaries within 300 light-years of the sun and show how they compare with the prediction. The open circles represent much more massive systems such as AO Cassiopeiae.



CHANGES OF LIGHT exhibited by Y Cygni, AO Cassiopeiae and V444 Cygni during a full cycle are charted. Points *A* through *D* indicate the perspectives an observer on earth would see; for simplicity they are represented as though he were moving around the systems. Each system has an orbital period of four days but the light varies in distinct ways.



SHORT-PERIOD contact systems, each having a total mass of four solar units or less, are thought to result from instabilities in the rotation of a pear-shaped star. The instabilities eventually lead to a fission. A model of such a contact system soon after birth is depicted at top, together with the variation in light that it would show. At bottom are the characteristics of V Sagittae, which may represent an evolution of such a short-period binary system.

enon, is difficult to predict. The time scale is too long to follow the development of any one system, and so one must consider different systems spread in time over some 10 to 100 million years.

For short-period systems the contact binary in the bottom illustration at left represents the beginning. As to what comes next, the problem is similar to the one affecting AO Cassiopeiae and V444 Cygni systems: the uncertainty in differentiating the age of the two makes it impossible to say with certainty that the one evolves into the other. There is, however, a type of system that seems to fit the requirements for the second stage of short-period contact binaries. The V Sagittae system is an example.

V Sagittae systems, like the first stage of the short-period contact binaries, have a period approximating half a day and a total mass of about four solar units. The comparison of the shapes of the involved stars as well as the observed light variations of the two kinds of system is uncannily similar in almost every detail to the same comparison of AO Cassiopeiae and V444 Cygni. If one could show that the relatively simple short-period systems depicted in the bottom illustration at left develop into the complex V Sagittae systems, that knowledge alone would lend credence to the supposition that the complex V444 systems represent descendants of AO Cassiopeiae systems.

Even more is at stake in solving the problem of how the contact-binary systems evolve. The third and last stage of evolution can be expected to produce a white dwarf—the end that the theory of stellar evolution says must come to every star. Theoretical predictions, which there is no reason to doubt, indicate that before this end can be reached the star must reduce its mass to little more than the mass of the sun.

Many overmassive stars shed their excess mass in spectacular nova explosions [see "Exploding Stars," by Robert P. Kraft; SCIENTIFIC AMERICAN, April, 1962]. The V Sagittae systems may be demonstrating this final stage of evolution. There is strong evidence that the components of these systems are rapidly advancing toward the white-dwarf state. Already the systems are undergoing minor explosions that may be a prelude to the final blowup.

The close study of contact binaries therefore promises to be rewarding in a number of ways. It may provide observational support for assumptions in the theory of stellar evolution. It may also close important gaps in that theory.

STEEL RESEARCH AIDS PRODUCT DESIGN

Special division makes Youngstown's complete research facilities available to the steel customer. It gives direct assistance in the design and methods of using steel in the customer's products.

by R. H. Frazier, Manager, Research Services

Normally, research for the steel industry has two purposes:

(1) To develop new processes within the mills or to improve existing processes. For example, research in this area has led to a 50% rise in blast furnace iron production in the past ten years, and a 30% reduction in coke consumed per ton of iron production. Quality has risen, too. And all this effort has helped maintain stable, nominally low prices for iron and steel.

(2) To develop new steel products to meet more sophisticated requirements in both old and new markets. For example, new petroleum drill pipe with yield strength of more than 100,000 psi has been developed and proven. Increased depth of newer wells has seen pipe used at higher stresses, thus increasing the chance of corrosion fatigue. And the yield strength level is being increased to 135,000 psi and 150,000 psi with the expectation of equally good performance.

But at The Youngstown Sheet and Tube Company, research has a third distinct purpose – perhaps the most important one of all: to be of direct assistance to the customer.

Youngstown Steel has organized a separate division of the Research Department for the specific purpose of providing customer assistance. This division makes available to the customer the complete services of the Youngstown Research facility, not just a part.

A typical example of this service concerned the redesign of a water tank. A customer was manufacturing low-pressure water tanks by welding two drawn heads to a roll-formed body section with a welded side seam. The entire assembly was galvanized by dipping the tank into molten zinc.

The manufacturer decided to try simplifying construction by making two deep drawn sections from galvanized steel sheets and joining two sections with one circumferential weld.

Youngstown's design team played a major role in designing the tank, calculated the size and thickness of the required blank and assured a satisfactory and economical solution. Many thousands of the redesigned tanks have been made, and the customer is getting ready to make another tank, newly designed with aid from Youngstown.

If desired, Youngstown researchers make studies to suggest ways to improve the product's appearance as well as its function. And it is noteworthy that a customer's size and the size of his problems do not necessarily correlate. All companies, large or small, are served on an equal basis.

While remaining in close contact with the customer to insure that all possible assistance is always available, great care is also taken to guard against intrusion. In many cases only the customer himself knows what design characteristics best fit his entire product line. In still other cases, absolute styling secrecy is imperative. The rule is this: Youngstown research facilities are ready when needed. Proof testing or prototype copies of the product are perhaps the best methods of exactly determining the customer's needs.

At the other end of the problem, Youngstown must supply information that can help the customer realize the right forming and fabricating method.

New methods of forming, such as stretch forming, electromagnetic forming, explosive forming and combinations of cold extrusion and cold heading are being used with increased efficiency. Fabrication of a steel product by using new joining methods, such as plasma arc, laser beam, ultrasonic and friction welding, can improve quality and cut cost. Assistance to the customer in the development and application of fabricating methods is given wherever possible.

Another important factor in determining whether or not a product can be produced profitably from steel is material handling. Increasing labor costs make it imperative to handle material mechanically. Using steel's magnetic properties can help reduce handling costs. The steel manufacturer does it in his own plant to transfer large tonnages of steel. The steel user has employed magnetic methods in some of his handling problems, but further economies can often be worked out. Helping improve material handling methods is just one of the Research Services Division's function.

Value Analysis, a method of determining the total cost of putting a product on the market, is used by Youngstown to help the customer reduce overall costs. For often most of the cost of a finished product is contained, not in the raw material, but in the many processes along the line.

Youngstown Steel's Research Services Division is dedicated to establishing a cooperative effort with the customer to maintain a complete exchange of all information helpful in building product quality and efficiency. Its benefits include assistance from Youngstown's Operating and Sales Departments as well.

This article gives a glimpse of what's happening in steel research at Youngstown. It's just a part of the continuing research effort going on 24 hours a day at Youngstown's research center.

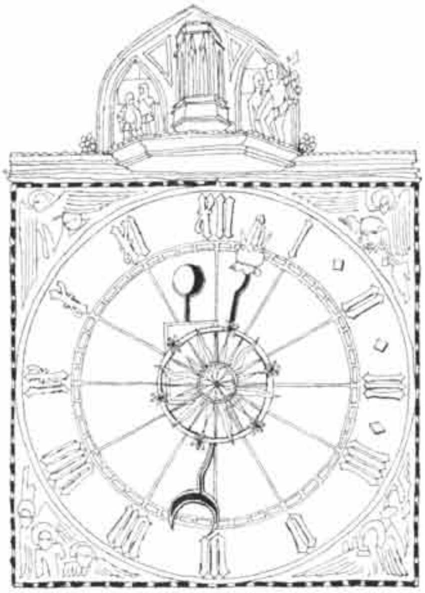
Since the customer's need inspires virtually all of our research, all of our knowledge is available to serve him.

Call if you believe our research staff can help you, or write Dept. 251D8.

Youngstown Steel

THE YOUNGSTOWN SHEET AND TUBE COMPANY · YOUNGSTOWN, OHIO 44501

SCIENCE AND



Riots as Politics

A view of the U.S. urban riots of the past four years as a "pre-political" form of collective action rather than a series of senseless outbreaks of blind rage is beginning to emerge among social scientists. While there is no consensus among investigators, all of whom agree that the riots have varied and complex origins, there is general emphasis on the idea that the disorders represent more than a Negro protest, more than a sudden reaction to years of deprivation. The riots are seen rather as implicitly political demonstrations, although not as organized, conspiratorial political acts. This view is illustrated by a number of papers on urban violence and disorder in a recent issue of *American Behavioral Scientist.*

The riots cannot be explained as pathological outbreaks or even as the inevitable products and symbols of social change, according to Kurt Lang of the State University of New York at Stony Brook and Gladys Engel Lang of the Center for Urban Education. The number of similar outbreaks within a short time suggests that—however spontaneous the individual incidents may be—"the rioting reflects . . . the stirrings of a major social-political movement." Direct action, they point out, is a traditional way to gain recognition; in U.S. labor history, violence has been most common when management refused to bargain. "Rioting evolves as a form of collective pressure or protest where large numbers of people are crowded and alienated together, sharing a common fate that they no longer accept as necessary." The Langs conclude that "conflict needs to be rechanneled into more effective day-to-day negotiations with visible results," by, for example, "the political organization of slum dwellers . . . to provide organizational alternatives to 'collective bargaining by riot.' "

The Langs point out that racial disturbances do not develop as "automatic responses to frustration." In a report on studies of the relation between frustration and aggression Leonard Berkowitz of the University of Wisconsin makes the related point that frustration does not arise automatically from deprivation; much weight must be given to "anticipations of the goal." That is, anticipation and "hope" increase the striving toward a goal, and frustration is most severe when that striving is blocked or made to seem impossible. The politico-social phrase "revolution of rising expectations" expresses this concept, Berkowitz writes. "Privations in themselves are much less likely to breed violence than is the dashing of hopes."

H. L. Nieburg of the University of Wisconsin puts the riots in a still more political context. Any society uses police power to control antisocial acts by individuals or small groups, he writes, and this control of "frictional" violence is generally accepted by the community. The violence of some recent riots is something else again. In response to escalating police action a counterescalation of Negro violence occurs. The possibility of infinite escalation "destroys the efficacy of normal methods of police power." Such violence is not merely frictional but "political," aimed at changing the system the police power is designed to protect. As Nieburg sees it, domestic violence is something like war between nations. "The capability and determination to exact unacceptable cost from the enemy, even at greater cost to oneself, may be the only means available for a small nation or a minority group" to press its demands. In this view the threat of violence is "part of the bargaining process," and the alternatives are escalation of violence or accommodation to change. "Every regime," Nieburg concludes, "must set about building consensus somewhere, and most important among those who themselves retain the capa-

THE CITIZEN

bility of imposing high cost and risks of concerted action if too obtusely neglected."

The Pulsar Industry

The discovery a few months ago of four rapidly pulsating radio sources, nicknamed pulsars, has evoked a steady stream of papers to *Nature, Science* and *The Astrophysical Journal* providing new details about the strange objects and various guesses as to what they are. The most striking characteristic of the pulsars is the very short interval between pulses and the extreme uniformity of the pulse-repetition rate.

The first pulsar, designated *CP*. 1919 (for Cambridge pulsar at right ascension 19 hours 19 minutes), emits a radio pulse every 1.3372795 seconds. Two other pulsars have similar repetition rates; *CP*. 0834 emits a pulse every 1.27379 seconds and *CP*. 1133 a pulse every 1.1880 seconds. However, a fourth pulsar, *CP*. 0950, emits nearly four pulses a second; its interpulse interval is only .253071 second.

CP. 1919 remains the best-studied of the four. Its pulses usually show three peaks compressed within 37 milliseconds. The shape and relative intensity of the peaks usually vary from pulse to pulse. A series of strong pulses is usually followed by a series that is weaker by a factor of five. Moreover, the duration of the active periods varies with frequency, ranging from seconds at low frequencies to an hour or so at higher ones. The low-frequency component of the pulse invariably lags behind the high-frequency component. Electrons in interstellar space probably account for the delay. If the electron density is assumed to be one electron per 10 cubic centimeters, *CP*. 1919 must be about 420 light-years away. *CP*. 0950 may be as close as 50 to 100 light-years. The short pulse length of all the pulsars indicates that their physical dimensions range from 3,000 kilometers to 10,000 kilometers, or something less than the diameter of the earth.

The power radiated in the strong pulses is roughly 10^{22} watts, equivalent per unit area to several times the emission of the sun's surface at all wavelengths. It has been found that the emission of *CP*. 1919 is almost completely linearly polarized. This and the intensity of the pulse indicate that the radiation must be produced by a coherent mechanism of the type found in masers and lasers. A. G. Lyne and F. G. Smith of the University of Manchester, who report the polarization in *Nature,* suggest that "the radiation originates in a region with at least one dimension smaller than 10 centimeters.... This region may travel towards the observer with relativistic velocities." The positions of two of the pulsars, *CP.* 1919 and *CP.* 0950, have been determined with enough accuracy to allow a search for their visible counterparts, if such exist. A faint object that may be *CP.* 1919 appears on Palomar Observatory Sky Survey Plates. A very dim red object lies barely within the error rectangle defining the position of *CP.* 0950. There is no confirmation that either object is the pulsar.

It has been suggested that pulsars represent signals from advanced civilizations (generally rejected); resonant oscillations of white-dwarf stars or neutron stars (stars that have respectively exhausted their nuclear fuel or collapsed to the point where most of their electrons have been fused with protons); emissions from neutron stars that are rotating approximately once a second; emissions from a double star consisting of two white dwarfs or two neutron stars with an orbital period of about a second. It has also been suggested that the pulsation period of about 4/3 seconds corresponds to the time it would take a supernova to collapse to near-disappearance and to bounce back to the radius it had had at the onset of collapse, about 10,000 kilometers. The pulsations would represent a repeated bouncing. Meanwhile there is scarcely a radio telescope that is not tuned in on the pulsars.

Cool Accelerator

The feasibility of operating a full-scale linear particle accelerator continuously at temperatures near absolute zero will be tested within the next few years, using a 500-foot prototype machine that is currently under development at Stanford University. If the tests are successful, the scheme may be adapted for use with the two-mile electron accelerator at the Stanford Linear Accelerator Center (SLAC). At present the SLAC accelerator, the largest of its kind in the world, operates only in a pulsed mode, producing high-energy electrons in bursts that are "on" only about a thousandth of the total operating time.

The decision to go ahead with the 500-foot-long machine followed the successful completion of a series of experiments performed with a five-foot-long model of a supercooled linear accelerator; the tunnel of the five-foot model was completely immersed in a circulating bath of liquid helium at a few degrees above absolute zero. The experiments were carried out by a research team headed by William M. Fairbank and H. Alan Schwettman of the Department of Physics and the Hansen High-Energy Physics Laboratory at Stanford. Development work to date has been financed by the Office of Naval Research.

According to Fairbank and Schwettman, the main advantage of their scheme is that it enables continuous operation by reducing energy losses in the walls of the microwave acceleration cavities used to boost the electrons along the accelerator tunnel. This makes it possible to use lower-power klystron tubes to provide the microwaves; the principal reason the SLAC accelerator is now restricted to pulsed operation is that the klystron tubes would burn out if they were operated continuously at very high energies. By supercooling the tunnel of the five-foot model the Stanford group was able to reduce electrical resistance (and hence energy losses through resistance heating) in the microwave system to a millionth of what it would be at room temperature. They also found that the "superfluid" behavior of liquid helium at low temperatures greatly simplifies the problem of circulating this coolant through the system.

If the SLAC accelerator is supercooled, it is estimated that it could produce a much more homogeneous electron beam at theoretically 10 times its present energy. Continuous operation at such an energy would presumably open up a whole new range of experiments in high-energy-electron physics.

Thorium Power

The nuclear-power industry is entering a period of such rapid growth that the supplies of low-cost uranium ore could be exhausted by the year 2000 unless breeder reactors are introduced on a large scale by 1980 or so. Breeder reactors will be needed to turn nonfissile uranium 238 into fissile plutonium 239 or to turn nonfissile thorium 232 into fissile uranium 233. In both cases naturally fissile uranium 235 is needed to get the cycle started. A symposium recently published by the Atomic Energy Commission suggests that breeders using the uranium-thorium cycle may offer important advantages over those using the uranium-plutonium cycle.

In the past several years four reactors based on the thorium cycle have been placed in operation. New methods of fabricating thorium fuel materials and extracting uranium 233 from them have been developed. And new estimates show that low-cost thorium ores are more plentiful than had been thought.

A study made by Paul R. Kasten of the Oak Ridge National Laboratory, presented at the thorium-cycle symposium, concludes that significantly less uranium ore would be needed by the year 2000 and thereafter if the thorium breeder cycle were given preference over the uranium-plutonium cycle. The total amount of uranium ore (in terms of uranium oxide, U_3O_8) thought to be available at low cost is 800,000 short tons. An AEC study had previously calculated that a nuclear-power industry based initially on uranium thermal reactors to supply plutonium for fast breeders would require more than two million tons of uranium oxide, or more than twice the amount of low-cost ore believed to be available. Under somewhat more favorable assumptions the ore requirement could probably be held to 800,000 tons. Kasten's study indicates that if the thorium cycle were substituted, the same power output could be achieved with the mining of only 500,000 tons of uranium ore. Power costs, moreover, should be at least as low with the thorium cycle as with the uranium-plutonium cycle.

Earliest American?

The discovery of what may be the oldest human remains in the New World at an ancient campsite beside the Palouse River in eastern Washington was announced by investigators from Washington State University at the May meeting of the Society for American Archaeology in Santa Fe, N.M. The human bones, which include fragments of a shattered skull, wristbones, ribs, a vertebra and one split and charred femur, are between 11,000 and 13,000 years old. This makes Marmes man, as the find has been named, clearly older than his nearest rival in the U.S. (the Midland, Tex., skull, estimated to be no more than 8,000 years old) and possibly older than the oldest known remains in the hemisphere (the Tepexpan skull in Mexico, estimated to be between 11,000 and 12,000 years old).

The first of the bones belonging to Marmes man were discovered in 1965 by Roald Fryxell, a geologist and anthropologist at Washington State, during a survey of areas in the river canyon that are to become part of a reservoir. The bones were contained in undisturbed sediments that lay buried under a 13-foot rockfall. Until some 13,000 years ago the sediments had been submerged in a glacial lake; the rockfall occurred some 11,000 years ago. The campsite must therefore have been established at some time during the intervening period. Along with the human remains, the site has yielded bones of elk and deer, some of which are also split and charred, and two bone artifacts: a projectile point and a shaft fragment.

New World archaeologists find it frustrating that the earliest sites they have discovered—perhaps 15,000 years old in Alaska and South America, perhaps 20,000 years old in Mexico—are devoid of human remains, although this is a logical consequence of the nomadic lives led by the hemisphere's earliest inhabitants. The bones of Marmes man too might never have come to light if the hunters camped beside the Palouse had not, as the condition of the femur suggests, eaten him.

Demography and Selection

The intensity of natural selection may have been about the same for primitive man as it is for modern industrial man, two geneticists have proposed. This would imply that "there may be adequate provision in our present population structure for continuing evolution of some sort," they point out. Such a finding is of interest because some people have asked if the advantageous effects of selection are being defeated by the lower death rates that can result from improved health and sanitation. The question therefore arises: How different is the demographic structure today from the structure that existed when man was evolving to his present condition?

In *Proceedings of the National Academy of Sciences* James V. Neel and Napoleon A. Chagnon of the University of Michigan Medical School report on the population structure of two primitive tribes of South American Indians, the Xavante of the Brazilian Mato Grosso and the Yanomama of northern Brazil and southern Venezuela. Acknowledging the difficulty of establishing accurate data, they report a low mean number of live births among women: 4.7 for the Xavante and 2.6 for the Yanomama. The mortality of children before reaching 15, or reproductive age, was estimated at 33 percent among the Xavante and 16 percent among the Yanomama—high by U.S. and European standards but quite low compared with those of many contemporary tropical agricultural societies. Neel and Chagnon propose that man may have passed through three principal demographic stages: a period of intermediate fertility and prereproductive mortality characteristic of primitive hunting-and-gathering societies; a period of high fertility and mortality characteristic of agrarian societies, and a period of low or intermediate fertility and of low mortality characteristic of industrial societies.

An index of "selection intensity," devised by James F. Crow of the University of Wisconsin, depends on variations in fertility among women and on the extent of mortality before reproductive age. Calculating selection intensities for the Indians, for several agrarian societies in Africa and Asia and for U.S. whites and Negroes, Neel and Chagnon find that the values for the "primitive" Indians are of the same magnitude as those for the U.S. populations. If the Indians' demography is at all illustrative of that of ancient men, among whom evolution did occur, the implication is that evolution can still go forward in our society.

When Does the Bystander Help?

The probability that an uninvolved bystander will help someone in trouble is higher when the bystander is alone than when he is in a group, according to a number of experiments conducted by John M. Darley of New York University and Bibb Latané of Columbia University. The experiments also showed that a bystander in a group is more likely to act if he knows the victim or other bystanders than if everyone is a stranger to him. Latané described the work in a talk at Princeton University titled "Bystander Intervention in Emergencies."

In the experiments subjects were confronted with an emergency under various circumstances. Sometimes a subject was alone. Sometimes other people were present; unknown to the subject they had been coached by the experimenter to be indifferent to the emergency. In a third condition several uncoached people were present; sometimes the subject knew one or more of them or the victim and sometimes he did not. The emergencies included the appearance of smoke from a wall vent in a room where the subject had been asked to wait; hearing someone apparently undergoing an epileptic seizure; listening to sounds of a woman accidentally injuring herself; overhearing a fight between two children, and witnessing the theft of money from a pocketbook.

Latané has offered three explanations that he said seemed consistent with the results of the experiments. One is that a subject who is alone knows that he has full responsibility for responding; in a group the responsibility is diffused. "To account for the friends-strangers difference," Latané said, "this theory would have to assume that responsibility is less easily laid off on a friend than on a stranger." A second explanation is that people in a group hold back for fear of appearing to do something foolish—a fear that is evidently stronger among strangers than among friends. The third explanation is that each bystander in a group looks to the others for clues as to how a situation should be interpreted and, seeing the others passive, decides that nothing is really wrong. "All three of these explanations seem plausible to me," Latané said, "and there is no reason why all three could not be jointly operative."

Persistent Plastics

Certain synthetic plastics, unlike natural polymeric materials, resist attack by bacteria and fungi and so present problems in waste disposal. An effort to find organisms that will attack such materials as nylon and synthetic rubber has been started by Walter J. Nickerson of the Institute of Microbiology at Rutgers University. He described the project at a meeting of the Texas branch of the American Society for Microbiology.

Nickerson noted that natural polymeric materials such as feathers and hooves are degraded by natural means once they are no longer associated with a living animal. In contrast, he said, a number of things made of synthetic polymers fail to decay in dumps. "It is conceivable," he continued, "that someday we will have to go to biodegradable polymers just as we have already had to go to biodegradable detergents." Part of Nickerson's technique is to look in dumps for promising organisms. Once he found a decomposing aircraft refueling hose that was covered with a black slime. The slime turned out to be a fungus, not yet identified, that seems to be able to attack synthetic rubber. Nickerson has also found an unidentified pink bacterium that shows similar promise.

Disappearing Stones

Man's capacity for growing stones in various parts of his urinary tract is not the same everywhere in the world nor even the same in a single country from century to century. Dame Kathleen Lonsdale of University College London writes in *Science* that bladder stones, common in the Malagasy Republic, are very scarce on the nearby African mainland. Bladder stones were also once endemic in Sicily, she notes, but have not been found on the island since World War II.

The disappearance of stones is particularly well documented in England. Between 1772 and 1816 one in every 38 patients at the Norfolk and Norwich Hospital was under treatment for bladder stones. In the same period so many of the boys at the Westminster School in London suffered from bladder stones that they had their own hospital ward. The children's bladder stones were usually composed of ammonium acid urate; the adults' were usually uric acid.

No children's stones are encountered in England today; the number of cases began to diminish rapidly after World War I. Adults' stones seem to have persisted longer, and a few are still found today. A factor that may be related to the decline of stones, Dame Kathleen suggests, is that the bread the English ate during the 19th century was heavily adulterated with alum and chalk.

Essence of Bread

What makes bread smell so good while it is being baked and for a short time after it comes out of the oven? A key ingredient in the odor is 1,4,5,6-tetrahydro-2-acetopyridine, report the workers who have isolated the compound at the Western Regional Research Laboratory of the Agricultural Research Service of the U.S. Department of Agriculture. Four members of the group—Irving R. Hunter, Mayo K. Walden, James R. Scherer and Robert E. Lundin—described the work in a paper presented at a meeting of the American Chemical Society.

By itself, they said, the tetrahydropyridine compound "has an overpowering odor" of soda crackers. When it is exposed to air, it quickly undergoes both physical and chemical changes—which suggests why the aroma of freshly baked bread does not last long. Hunter and his colleagues found, however, that easily made derivatives of the compound were relatively stable. They reported that spraying week-old bread with an aqueous solution containing six parts per million of one of the derivatives "returned a desirable fresh-bread odor" to the bread. The workers foresee commercial applications of their technique that will increase the marketability of bread.


Improved information handling
is critical to
medical progress.

STANDARDS OF MEASUREMENT

The goal is to define standards of length, mass, time and temperature that are both precise and reproducible. Of the four only mass still lacks a referent in nature

by Allen V. Astin

The task of finding more accurate ways to measure length, mass, time and temperature never ends. These are the four master measures on which all others depend. They establish the fineness with which man can examine the physical universe and they provide the basis for all technology. The goal in devising standards of measurement is to provide a unit that can be reproduced anywhere with high fidelity by anyone with access to certain technical facilities. Thus the units of length, mass, time and temperature should be referred to basic constants of nature, preferably at the level of atomic behavior. Three of the four units—length, time and temperature—are now defined in terms of natural constants. This still remains to be done for mass.

When man first sought a unit of length, he adopted part of his body—his hand or foot—as a crude but convenient measure. In the 18th century French savants defined a new unit, the meter, as a particular fraction of the earth's dimension. In 1960 the 11th General Conference on Weights and Measures, meeting in Paris, redefined the meter in terms of a particular wavelength of the radiation from the isotope krypton 86 [*see illustration on opposite page*].

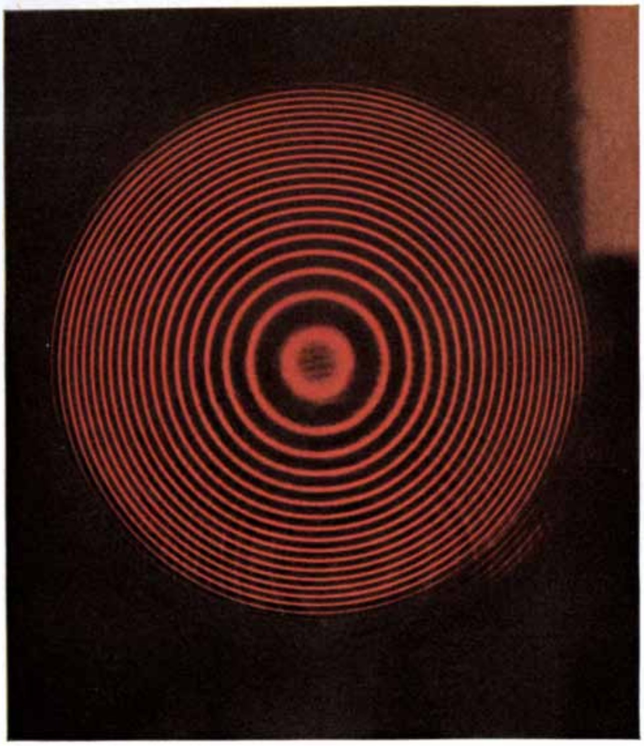
The unit of time, the second, was much earlier specified in terms of the relative positions of the earth and the sun. The second was defined as 1/86,400th part of a day, and more recently as 1/31,556,925.9747th part of the tropical year 1900. At the 13th General Conference on Weights and Measures, held in Paris last October, the second was redefined as 9,192,631,770 cycles of the frequency associated with the transition between two energy levels of the isotope cesium 133. The redefinition was needed because it was found that the rotation of the earth is more erratic than had been thought. The irregularity is probably caused by tides, winds, earthquakes and magnetic fields. If a perfect clock had been running in 1900, it would now show that the rotation of the earth is half a minute behind schedule. With the best atomic clocks it is possible to measure time to about one part in 10^{12}, an accuracy nearly 10,000 times greater than could be achieved by astronomical means.

A hundred and fifty years ago standards were important for only five different kinds of measuring unit: length, volume, weight, time and angle. Today we must have standards for the accurate measurement of temperature, light intensity, color, sound intensity, electric current, X-ray dosage, nuclear radiation and many other phenomena. The assembly of an automobile or a television receiver depends on scores of such measurements. A far greater number of standards is required for the much more complex and exacting task of constructing a space vehicle. If the vehicle is to operate successfully millions of miles from the earth, the physical, electrical and mechanical properties of thousands of individual parts and components must be carefully controlled by reference to accurate standards of measurement.

Although dozens of different units are now needed to express the magnitudes of the many properties routinely measured in science and technology, virtually all can be derived from four, and only four, independent units: the meter for length, the kilogram for mass, the second for time and the kelvin (formerly the degree Kelvin) for temperature. These four quantities, together with two derived quantities (the ampere and the candela) are the building blocks of the International System of Units, or Système International. Only a few important measurements do not depend on the four basic standards. These include angle measurements, which are basically ratios of two lengths and hence independent of particular units of length, and color measurements, which are really schemes of classification related primarily to the properties of the human eye.

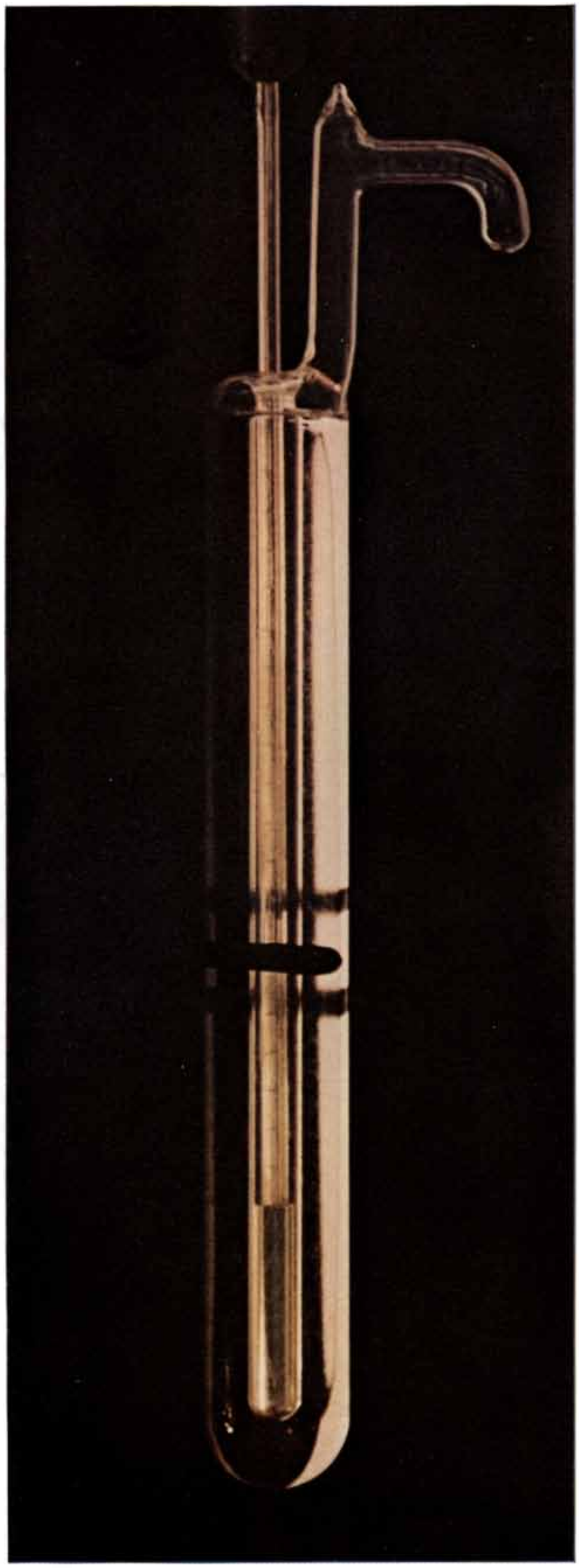
By referring to a high school physics text one can usually see how secondary physical quantities can be related to the basic four [*see illustration on page 62*]. For example, the unit of force, the newton, is obtained from Newton's second law of motion, which states that force equals mass times acceleration ($F = ma$). The newton is defined as the force that gives an acceleration of one meter per second per second to a mass of one kilogram. The ohm, a unit of electrical resistance, can be derived directly from standards of length and time. Most mechanical measurements—such as density, energy and pressure—involve combinations of units of mass, length and time. Thermodynamic measurements involve combinations of mechanical and tem-

UNIT OF LENGTH, the meter, was defined in 1960 as 1,650,763.73 wavelengths in vacuum of a particular emission line of krypton 86. Because the wavelength of the line varies with temperature, the discharge tube containing krypton 86 (*opposite page*) is held at the "triple point" of nitrogen, −210 degrees Celsius (formerly centigrade). At the triple point, liquid, solid and vapor are in equilibrium. The photograph shows the nitrogen-containing vessel from above; bubbles of nitrogen are rising from a mixture of liquid and solid nitrogen. Excited atoms of krypton 86 produced pinkish light with which picture was taken. The length standard is a reddish-orange component whose wavelength is 6,057.8021 angstrom units.



FUTURE LENGTH STANDARD may be provided by monochromatic light from a helium-neon laser, whose waves remain coherent, or in step, over long distances. Used in an interferometer it produces fringes such as these, which remain distinct over an optical path of 200 meters. The fringes produced by krypton 86 cannot be used to measure distances as long as a meter in a single step.

STANDARD OF MASS is the mass of a platinum-iridium cylinder, Prototype No. 1, kept at the International Bureau of Weights and Measures at Sèvres, near Paris. The kilogram shown here is one of several accurate copies kept at the National Bureau of Standards.



TEMPERATURE UNIT, the kelvin, or degree Celsius, is defined as 1/273.16 of the thermodynamic temperature of the triple point of water, which is .01 degree Celsius. It is measured in this apparatus, which brings pure water, ice and water vapor into contact.

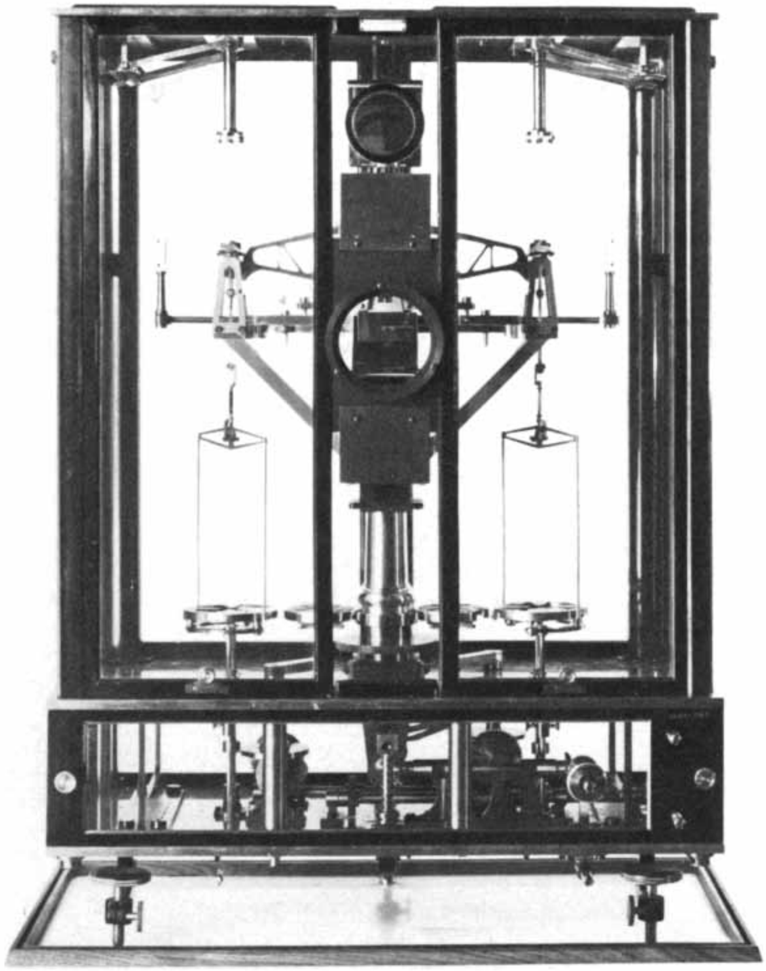
perature units. The roentgen, the unit of radiation exposure, is derived from electric-charge standards and mass standards.

Until the advent of experimental science at the time of Galileo in the 16th century only astronomers were much concerned with standards of measurement. At that time even in a single country there were usually a variety of units of different sizes for the same quantity, for example the grain, the ounce, the pound avoirdupois, the troy pound, the stone and the ton. Galileo's diverse inquiries made it clear that physical measurement was an integral part of studying natural phenomena. Natural philosophers began to realize that common, well-defined units of measurement were essential to the exchange and comparison of experimental results. By the second half of the 18th century a concerted drive had developed among the investigators of several nations to establish a truly international system of measurement resting on a sound scientific basis. The drive culminated at the time of the French Revolution, when the metric system was born.

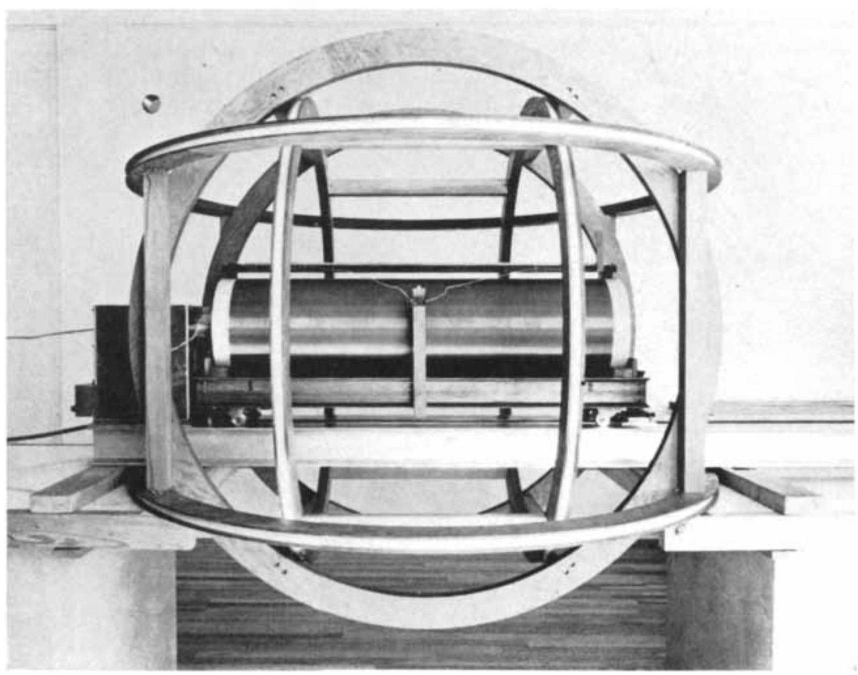
Various standards of length were proposed for the new measuring system. More than 100 years earlier the astronomer Jean Picard had suggested that the unit of length be defined as the length of a pendulum with a natural period of one second at sea level and a latitude of 45 degrees. The proposal had many adherents, including Thomas Jefferson. It was finally rejected as insufficiently precise by a committee appointed in 1790 by the French National Assembly. Another suggestion considered and rejected was to define the standard as some fraction of the Equator.

The winning proposal was to define a new unit of length, the meter, as one ten-millionth of a quadrant of the earth's meridian as carefully measured over that fraction of the quadrant lying between Dunkirk in France and a point close to Barcelona. The measurement was painstakingly carried out by a surveying party under the direction of the astronomer Jean Baptiste Delambre between 1792 and 1799. Astronomical measurements established that the distance between Dunkirk and Barcelona represented a little more than a tenth of the entire quadrant from the North Pole to the Equator. The measured distance from Dunkirk to Barcelona turned out to be 1,075,039 of the units subsequently defined as the meter.

The unit of mass, the kilogram, was taken as the mass of a cubic decimeter (a tenth of a meter) of water at the tem-



SENSITIVE BALANCE at the National Bureau of Standards can compare the Bureau's master kilogram, Prototype No. 20, with various copies with an accuracy of one part in 10^8.



POSSIBLE METHOD of defining a substitute for the mass standard involves the gyromagnetic ratio of the proton: the ratio of the proton's angular momentum to its magnetic moment. Ratio has been measured by the Bureau with an accuracy of a few parts per million.

MEASURE	UNIT		DEFINITION
LENGTH	METER	ORIGINAL:	1/10,000,000th of quadrant of earth's meridian passing through Barcelona and Dunkirk
		PRESENT:	1,650,763.73 wavelengths in vacuum of transition between energy levels $2p_{10}$ and $5d_5$ of krypton-86 atom, excited at triple point of nitrogen (−210 degrees Celsius)
MASS	KILOGRAM	ORIGINAL:	Mass of one cubic decimeter (1,000 cubic centimeters) of water at its maximum density (4 degrees Celsius)
		PRESENT:	Mass of Prototype Kilogram No. 1 kept at International Bureau of Weights and Measures at Sèvres, France
TIME	SECOND	ORIGINAL:	1/86,400th of mean solar day
		PRESENT:	9,192,631,770 cycles of frequency associated with transition between two hyperfine levels of isotope cesium 133
TEMPERATURE	DEGREE CELSIUS (KELVIN)	ORIGINAL:	1/100th interval between freezing point of water (0 degrees Celsius) and boiling point of water (100 degrees Celsius)
		PRESENT:	1/273.16th of the thermodynamic temperature of the triple point of water (.01 degree Celsius)

REFINEMENT OF MEASURING STANDARDS for length, mass, time and temperature is shown by this table. The original definitions of length and mass were those incorporated in the metric system, recommended by the Paris Academy of Sciences in 1791. The unit of time, the second, had been in use for so long and was considered so reproducible that it was not questioned by the founders of the metric system. The Celsius, or centigrade, scale for temperature had been proposed in 1742 by Anders Celsius of Sweden. It is often regarded as part of the metric system. The kelvin, named for Lord Kelvin, is now equivalent to the term "degree Celsius."

perature of its maximum density; this volume was to be called a liter. In this way the units of mass and volume were derived from the standard of length using the most available of all liquids as the medium for the conversion. Key figures in establishing the metric system in addition to Delambre were Charles Maurice de Talleyrand, the French diplomat, and Antoine Laurent Lavoisier, the discoverer of oxygen.

Progress in the adoption of the metric system was slow but steady. It was a major disappointment to its innovators that Jefferson failed to urge its adoption by the U.S. (partly, it seems, because the Dunkirk-Barcelona distance supposedly put France and Spain in a favored position). The metric system was accepted, however, in Italy, Belgium and the Netherlands in the first quarter of the 19th century. And in the mid-1860's it became legal to use metric measures in Great Britain and the U.S.

Meanwhile there had been growing dissatisfaction with the system as it was originally conceived. The whole reason for selecting the earth's meridian as a basis for a length standard had been that the meridian (or some specified fraction of it) would always be available for remeasurement. Experience showed, however, that two meter bars could be compared with each other with much greater accuracy than a meter bar could be related to the earth's meridian. In addition it was proving difficult to reproduce the kilogram in different countries simply by weighing the mass of a liter of water at maximum density.

In response to these concerns the French government arranged for a conference in 1870 to work out standards for a unified measurement system. These efforts led to the signing of the Treaty of the Meter in Paris in 1875. The treaty established an International Bureau of Weights and Measures, which was to be the custodian of the standards for an international system of measurement, and a General Conference on Weights and Measures. The Conference, meeting periodically, would handle problems and adopt new definitions as the need arose.

As provided by the treaty, special commissions began designing prototype standards of the meter and the kilogram so that this time the system could be based on two independent standards. After several years of work the meter was officially defined in 1889 as the distance between two engraved lines on a bar of platinum-iridium alloy at zero degrees centigrade (now Celsius). The international meter bar was to be kept in a vault at Sèvres, near Paris, in the custody of the new International Bureau, and it was to be available for comparison with the length standards of all nations. Copies of the meter bar were furnished to the nations adhering to the treaty. Also in 1889 the kilogram was defined as the mass of a particular platinum-iridium cylinder, and copies of the cylinder were supplied to the treaty nations.

Soon after the new prototype copies were received in the U.S. the Office of Standard Weights and Measures in the Treasury Department, which was given custody of the standards, redefined the yard and the pound as appropriate fractions of the meter and the kilogram. Since that time yards, pounds and gallons in the U.S. have been based on metric standards. Formerly the U.S. standards for these units had been based on copies of English standards.

In the last half of the 19th century there were tremendous advances in the theories of heat, light, electricity and magnetism. Major industries came into being to exploit these developments. It became necessary to invent and build instruments that could measure a completely new set of properties. In addition standards had to be developed for many of the new units of measurement. These pressures led to the establishment in many countries of a central organization for setting and developing standards. Thus the National Physical Laboratory was created in England in 1889 and the National Bureau of Standards was established in Washington in 1901.

Over the past 75 years the General Conference on Weights and Measures has steadily extended and refined the metric system, so that it now goes far beyond the original standards of dimension and mass. In 1960 the Conference officially adopted the International System of Units, which rests on four independent base units for length, mass, time and temperature. The Conference also decided to include as base units the ampere for electric current and the candela for light intensity. These two, however, are not independent of the other four; they were given the status of base units for reasons of convenience.

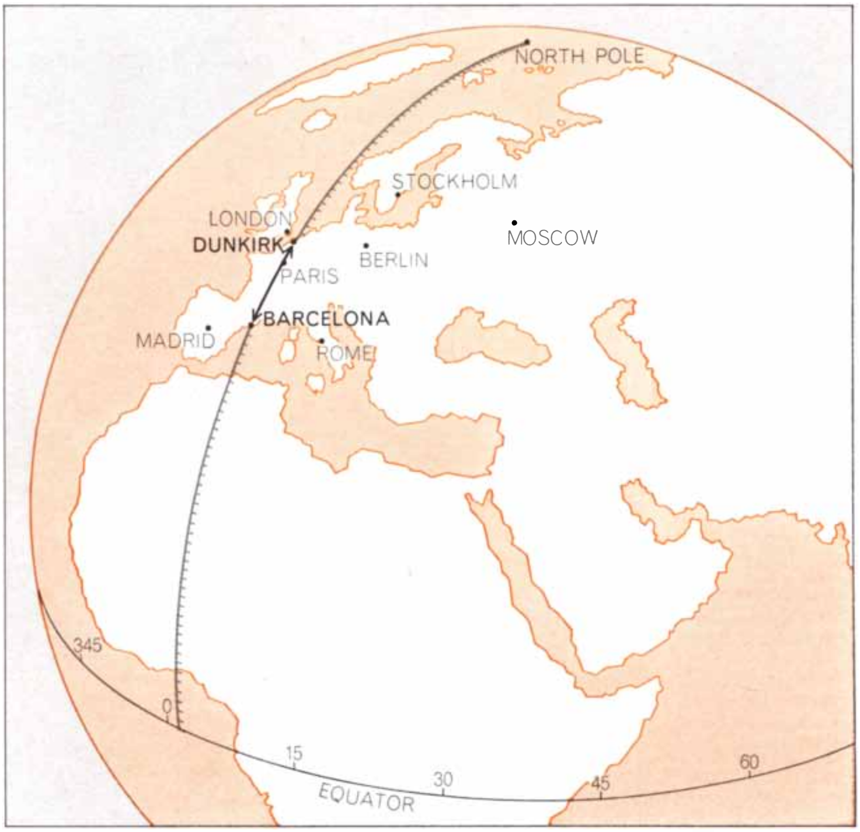
Patterns of Interference

As early as 1827 the French physicist Jacques Babinet had suggested that the wavelength of light had possibilities as a standard for length. The measurement of such a wavelength, however, was far beyond the simple resources of Babinet's day. His proposal could not be realized until much later, when the concept of interferometry had been developed. The idea is simple enough: when the crests of two waves coincide, they reinforce each other; when a crest coincides with a trough, the two waves cancel. In the first case the interference is constructive; in the second case it is destructive.

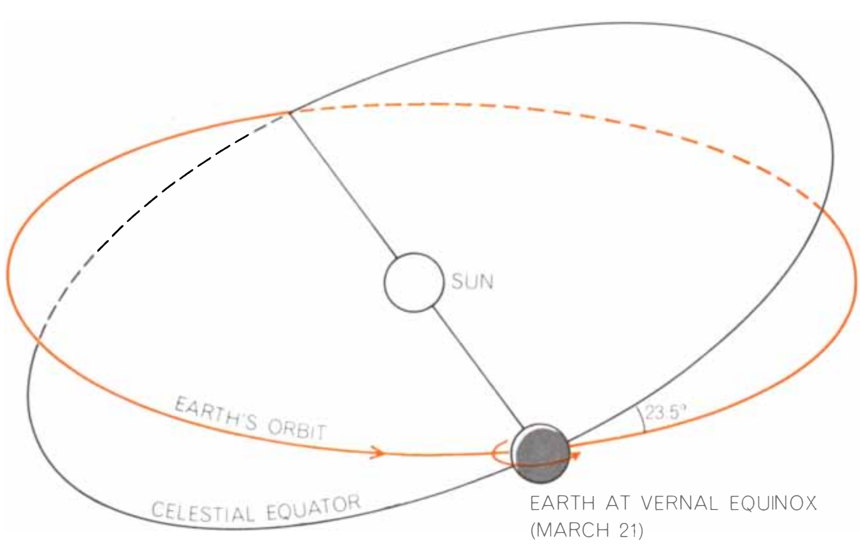
The interferometer makes it possible to see these interference patterns as a series of bright and dark lines. If two similar light beams from a single source travel over separate paths that differ in length by as little as a tenth of a wavelength and are then recombined, some destructive interference will occur and can be detected. The interferometer can be used either to measure wavelengths precisely or to measure distances or thicknesses in terms of known wavelengths.

A simple interferometer can be made by placing one optically flat glass plate on top of another [*see illustration on next page*]. The flats make contact at one edge and are separated at some other point by the object to be measured. Light of a single color, or wavelength, is directed at the upper surface. When this light reaches the lower surface of the upper flat, it is divided into two portions. One portion is reflected upward by the lower surface and the other portion continues downward to be reflected from the upper surface of the lower flat. The two series of reflected rays recombine in the upper flat, where they interfere to form alternate light and dark bands as seen from above.

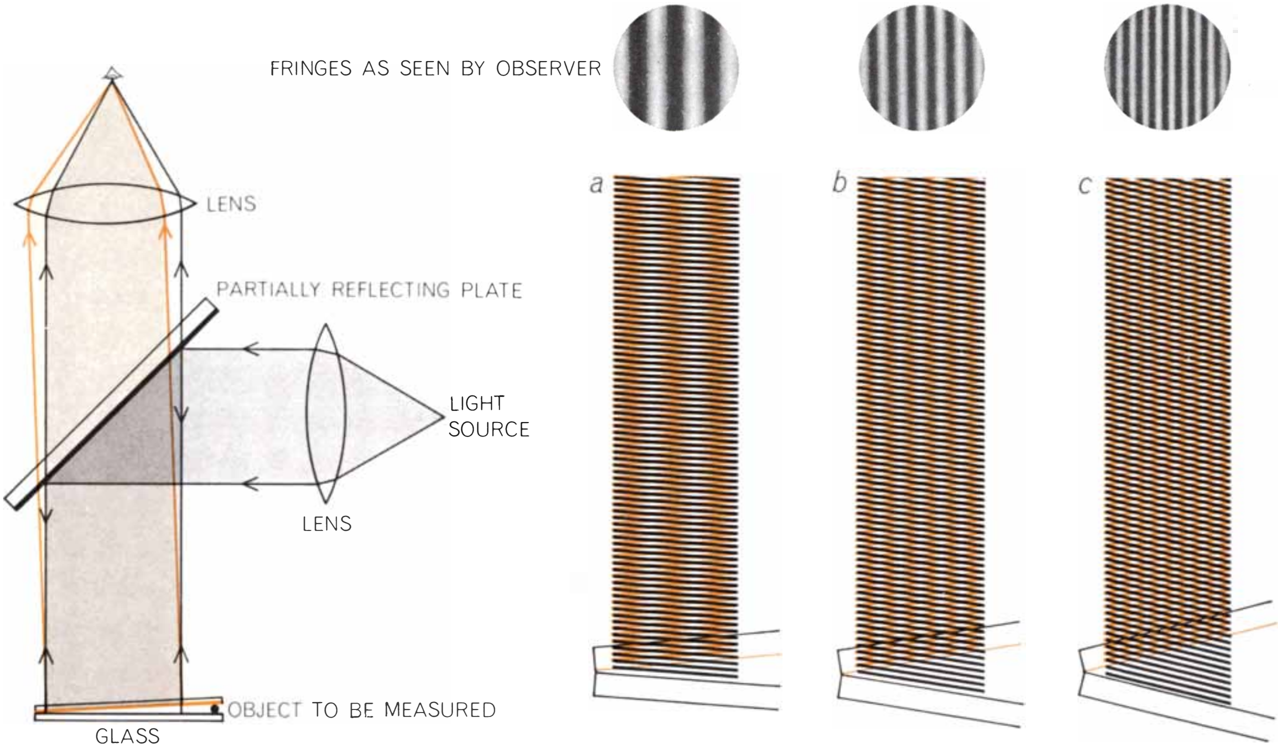
Each fringe, or dark band, of this pattern represents a difference in optical path of the two rays equal to an odd number of half-wavelengths, or a separation of the two flats equal to an odd num-



BASIS OF METER was the quadrant of the earth's meridian passing through Dunkirk, France, and Barcelona. The Dunkirk-Barcelona distance was measured by a French surveying team and extrapolated to the full quadrant using astronomical determinations of latitudes. The meter was defined as one-ten-millionth of the Equator-to-pole quadrant.



BASIS OF SECOND, generally accepted before adoption of the metric system, was the mean solar day, of which the second was 1/86,400th part. The mean solar day, in turn, is 1/365.2422th of the tropical year, measured from vernal equinox to vernal equinox.



CONCEPT OF INTERFEROMETRY for measuring length exploits the wave behavior of light. In the simple interferometer at the left a beam of parallel rays is directed at two optically flat plates of glass that are separated at one edge by the object to be measured. The rays (*color*) striking the bottom of the upper plate are reflected at an angle to the rays (*gray*) that are reflected from the upper surface of the lower plate. When these two families of rays interfere with each other (*a, b, c*), they produce a series of light and dark fringes whose spacing depends on the angle formed by the two flat plates, hence on the thickness of the object being measured. The dark fringes represent "destructive" interference, where the crests of one wave coincide with the troughs of another. This is represented here by three moiré patterns formed when parallel lines intersect at different angles. Wavecrests are represented by colored lines, troughs by black lines. As the angle is doubled from *a* to *b* and tripled from *a* to *c* the number of intersections is similarly multiplied, corresponding to a similar multiplication in the number of fringes. The number of fringes is related to the wavelength of the light and to the size of the object. The photographs of the fringes (*top right*) were made at the National Bureau of Standards.

ber of quarter-wavelengths (since the path difference is twice the separation of the flats). Therefore by counting the number of fringes between the edge of the upper plate and its point of contact with the object to be measured, the object's length can be determined. It is equal to the wavelength of the light used multiplied by one-half the number of dark fringes to the point of contact.

Some 75 years ago A. A. Michelson revived Babinet's suggestion that an optical wavelength be considered for a length standard. He devised a type of interferometer, which bears his name, for comparing linear displacements with wavelengths of light.

At first Michelson thought that a brilliant green line in the spectrum of mercury would be satisfactory as the ultimate standard of length. Closer study showed, however, that the green line of mercury was too broad (that is, its wavelength was spread over too great a range) to provide adequate precision. Michelson then shifted his attention to a prominent red line in the spectrum of cadmium. Even this line proved to be so broad that when the optical path difference was greater than a few centimeters the interference fringes became too blurred to be counted. This meant that a distance as long as a meter had to be measured in several steps, with a consequent loss in precision [*see illustration on pages 58 and 59*]. Nevertheless, Michelson did obtain by this method a value for the meter in terms of the red line of cadmium.

At the end of World War II William F. Meggers of the National Bureau of Standards returned to the problem of finding a wavelength standard for length, acting on a suggestion made in 1940 by Luis W. Alvarez. In 1950 Meggers demonstrated that a practical length standard could be provided by a mercury lamp containing mercury 198, an artificial isotope produced by the transmutation of gold in a nuclear reactor. A single isotope of mercury produces a much sharper green line than does natural mercury, whose green line actually consists of 16 spectral components that are not quite coincident. The single emission line of mercury 198 provided such a substantial improvement in defining the meter in terms of wavelength that the National Bureau of Standards urged the 10th General Conference of Weights and Measures, held in 1954, to give fresh consideration to a wavelength definition. Meanwhile other nations reported results with krypton and cadmium isotopes. The Conference agreed that work should be pressed on various approaches with the goal of setting a wavelength standard in 1960.

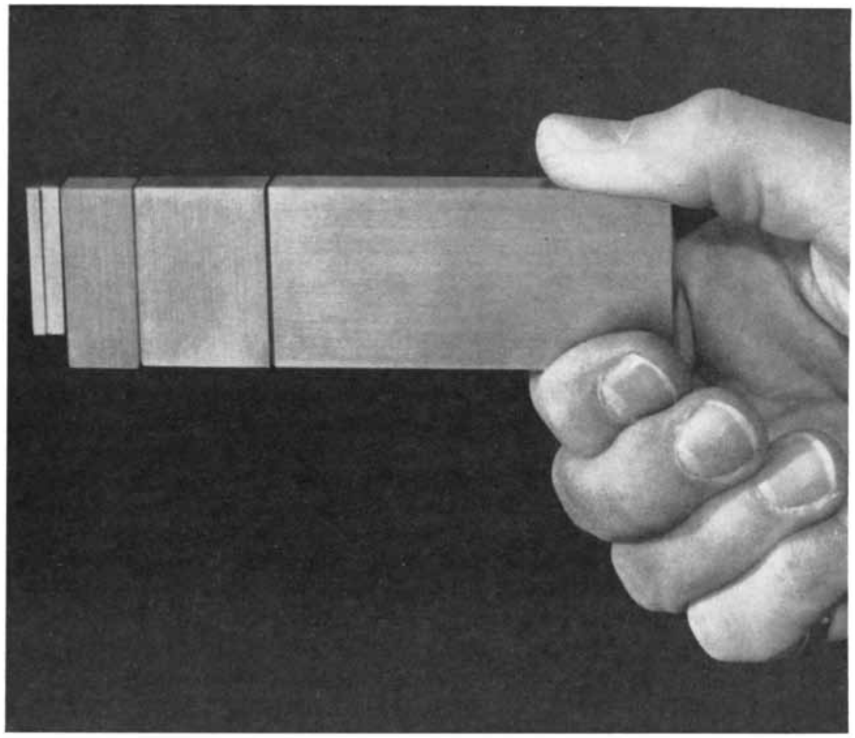
After the comparisons had been carried out it was concluded that a lamp containing the isotope krypton 86, when excited at the temperature of the triple point of nitrogen (−210 degrees Celsius) gave the highest precision. At the triple point the three phases of matter—solid, liquid and vapor—are in equilibrium. When a lamp is excited at a reduced temperature, it produces sharper spectral lines than it does at room temperature because of Doppler broadening. At room temperature the atoms in a lamp move with a wide range of speeds in all directions, and the wavelength of light they emit is shifted to values slightly higher and lower than the mean. By chilling the lamp the spread of values is much reduced. The krypton lamp was selected in part because of its superior operation at low temperatures.

In October, 1960, the 11th General Conference of Weights and Measures redefined the meter as 1,650,763.73 wavelengths in a vacuum of the reddish-orange radiation emitted by the transition between the energy levels $2p_{10}$ and $5d_5$ of the krypton-86 atom. The radiation is emitted when atoms excited to the $5d_5$ level fall to the $2p_{10}$ level. The accuracy of the old standard, in effect since 1889, was limited by the accuracy with which two meter bars could be compared: about one or two parts in 10 million. The krypton-86 standard improves on this accuracy by a factor of 10.

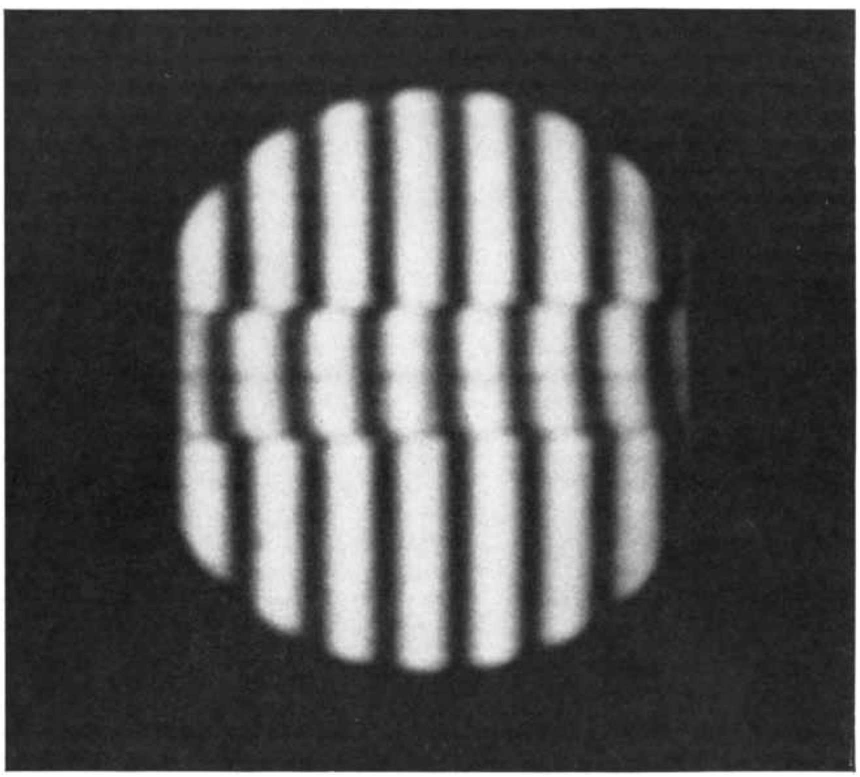
The chief defect of the krypton standard is that it still cannot be used to measure distances as long as a meter in a single step. Although the lamp's wavelength is very precise, the atoms in the lamp radiate more or less independently of one another. As a result the waves from the lamp are not in phase, or in step, and thus do not produce detectable fringes beyond a few tens of centimeters.

The development of the laser now provides a source of illumination that seems to meet all the requirements for measuring path differences of tens or hundreds of meters rather than centimeters. Because the light waves in a laser beam are all in step, they produce extremely sharp fringes. As early as 1963 workers at the National Bureau of Standards were able to obtain interference fringes over an optical path of 200 meters with a helium-neon laser. A year later they succeeded in measuring the length of a meter bar in a single step with an accuracy of seven parts in 100 million. More recently the Bureau has related one laser line—the neon line at a wavelength of 6,328 angstrom units—to the krypton standard with an accuracy of one part in 100 million, which is close to the limit of accuracy inherent in the krypton wavelength. Before a laser wavelength can be accepted as an international standard, however, it will have to be demonstrated that the laser wavelengths are sufficiently stable and reproducible.

Conceivably the laser could extend the limit of interferometric length measurement to hundreds or even thousands of



PRACTICAL LENGTH MEASUREMENT is performed with the aid of gage blocks, steel blocks with two highly polished opposite faces. The distances between the polished faces of the master blocks used by industry are calibrated by the National Bureau of Standards. There are usually 81 blocks of different sizes in the standard industrial set. By "wringing" the polished surfaces together, groups of the blocks can be assembled into measuring rods.



CALIBRATION OF GAGE BLOCKS is done by interferometry using two reference standards: light waves emitted by mercury 198 and by cadmium. In this picture light reflected from one surface of a gage block creates the offset pattern of fringes. The offset shows how much the gage block's dimension differs from an integral number of wavelengths.

kilometers. Such measurements, however, present the difficulty of counting several hundred million interference fringes, a task that could be accomplished only by automatic means.

The Length Standards of Industry

A key link in the chain of measurement that leads from the krypton standard to the industrial production line is the precision gage block. In its simplest form the gage block is a rectangular piece of steel with a square or oblong cross section and two opposite faces that are ground and polished flat and parallel to each other. The length of the block is the perpendicular distance between these two faces, or, for highest precision, the distance between one of the faces and a specified point on the other.

A typical set of gage blocks consists of 81 blocks with sizes ranging from .05 inch to four inches. By carefully sliding the gaging surface of one block over the gaging surface of another, two blocks can be "wrung" together so tightly that they are difficult to separate [*see top illustration on preceding page*]. In this way one can use combinations of blocks to gage a large variety of distances. The dimensions of individual blocks are established by interferometric methods in which light beams are reflected from the gaging surfaces. Methods developed by the National Bureau of Standards make it possible to calibrate industrial gage blocks routinely with an uncertainty as low as one part in a million, enabling industry in turn to calibrate other equipment with only slightly less accuracy.

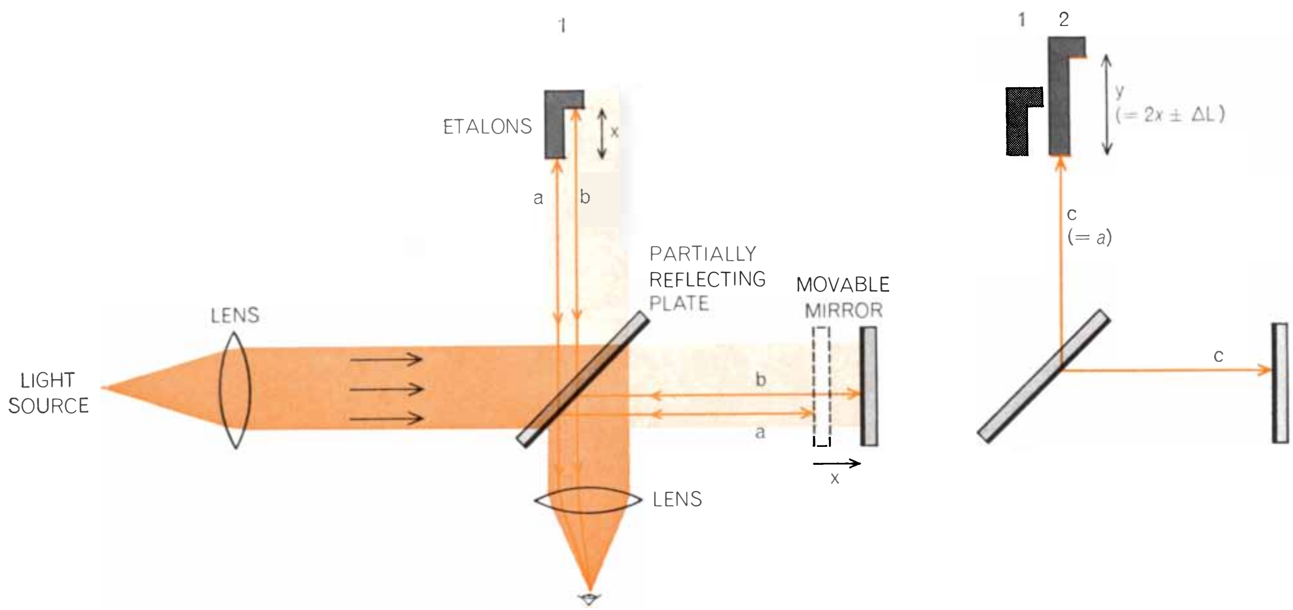
In addition to gage blocks, which provide "end standards," industry also has need for "line standards." These are scales of graduated length that are used to define translation, or travel, distances in many types of precision machine tools and scientific instruments. Until recently the calibration of such scales was a laborious job involving visual microscope comparison with another standard. In 1966 the Bureau developed an automatic fringe-counting interferometer with a laser light source that measures line standards directly in lengths up to a meter with a precision of a few parts in 100 million. The new device has reduced the time needed for calibrating line standards by a factor of 10.

The U.S. copy of the international standard of mass, known as Prototype Kilogram No. 20, is housed in a vault at the Gaithersburg laboratory of the National Bureau of Standards. It is removed no oftener than once a year for checking the values of lesser standards. Since 1889 Prototype No. 20 has been taken to France twice for comparison with the master kilogram. The national standard is never touched by hands. When it is removed from the vault, two people are always present, one to carry the kilogram in a pair of forceps, the second to catch the first if he should fall.

By means of a precision balance the national standard is compared with high-precision copies. The values obtained for the copies are accurate to one part in 100 million. In view of this high accuracy no great effort is currently being made to replace the prototype kilogram with a more permanent or independently reproducible standard. Corrosion or nicks in the platinum-iridium cylinder that would cause a mass change of as little as one part in a billion should be readily detectable by visual inspection.

It would, of course, be intellectually satisfying to have the mass standard defined in terms of a constant of nature, but no one has been able to propose a suitable constant or a way of measuring it that would come close to the precision desired. One constant that has been considered as a substitute for the mass standard is a property of the proton known as the gyromagnetic ratio, which depends on the precession frequency of the proton when spinning in a magnetic field of known strength. Although this ratio has been measured to within a few parts per million, it falls far short of the precision needed for a mass standard.

Recent work in crystallography at the Bureau has suggested another approach to a mass standard: actually counting the number of atoms in a precisely measured volume of a material. If the density of a



MICHELSON INTERFEROMETER, devised by A. A. Michelson in the 1880's, made it possible for the first time to define the meter in terms of the wavelength of monochromatic light. With the light sources then available Michelson could not measure the meter in a single step; therefore he built a series of "etalons," *L*-shapes with two parallel reflecting surfaces (*color*). By adjusting the interferometer's movable mirror to match the two light paths *a* and *b* and counting fringes, Michelson could establish the precise value of *x* in the smallest etalon. He then introduced another etalon with a mirror separation *y* approximately equal to 2*x*. Again by counting

material is accurately known, the mass of an individual atom of the material could conceivably be computed and employed as an invariant standard of mass.

In order to realize such a standard it will first of all be necessary to have perfect crystals. In such a crystal the number of atoms in a unit volume is exactly equal to the cube of the number of crystal planes per unit length. The problem then becomes one of measuring the number of crystal planes in a particular length of the crystal. The Bureau is now working to adapt an X-ray interferometer to the making of such a measurement. An X-ray interferometer is similar in principle to an optical interferometer except that X rays are used instead of visible light rays, and crystals of silicon (or some other material) are used instead of glass plates or mirrors. Quite a few difficulties will have to be overcome before the method can challenge the precision attainable with the platinum-iridium prototype kilogram.

Definitions of the Second

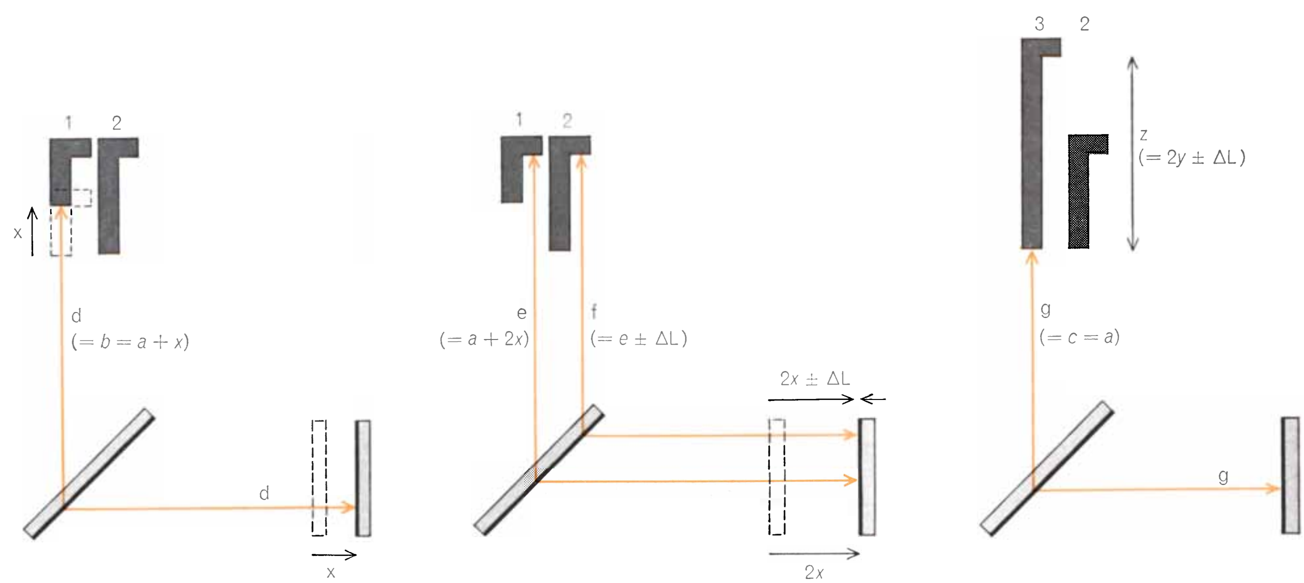
The measurement of time involves concepts and problems very different from those of the measurement of length and mass. We cannot choose a particular sample of time and keep it on hand for reference. Since ancient times the standard of time has been derived from some periodic event or motion.

It is curious that the originators of the metric system did not bother to define a unit of time. For centuries time had been measured in terms of the rotation of the earth, with the day divided into hours, minutes and seconds. The second had long been defined as 1/86,400th of the mean solar day. This definition proved adequate until well into the 20th century, when clocks controlled by the resonance properties of quartz crystals made it clear that the second so defined was constantly changing by small amounts. In some years the length of the day was found to vary by as much as one part in 10 million, or three seconds in a year of 31.5 million seconds.

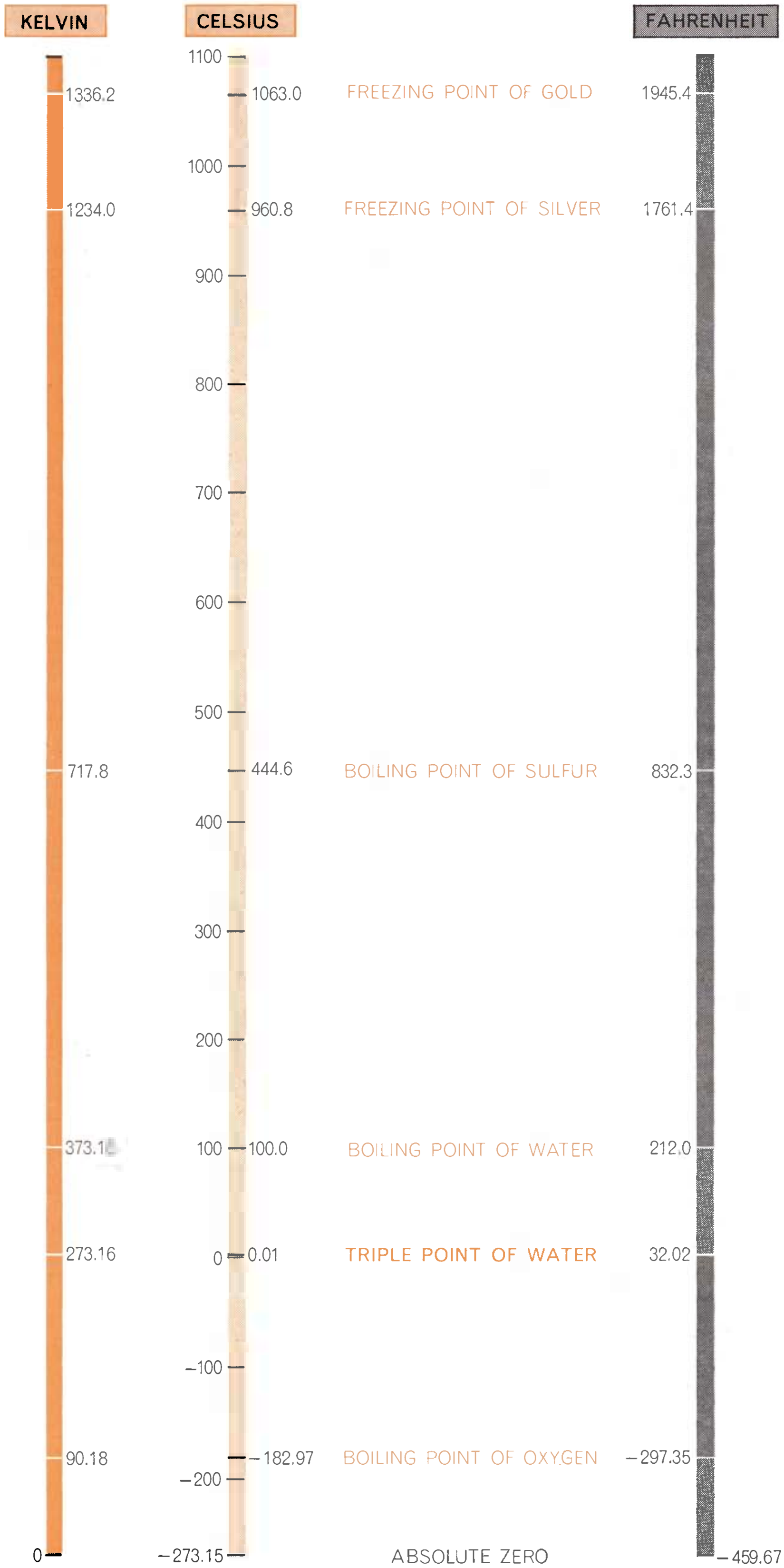
Meanwhile developments in physics and electrical engineering were making it possible to control clocks by using as a pendulum one or another of the natural frequencies associated with transitions between energy states in atoms and molecules. It had long been known, of course, that atoms and molecules, in going from one state to another, emit or absorb microwave energy at the sharply defined frequencies of spectral lines, but there seemed to be no way to use these extremely high frequencies in a clock. With the development of radar in the 1940's it became possible to measure transition frequencies in the microwave region by comparing them with electronic oscillators and so to use them for controlling highly accurate clocks.

These developments suggested the possibility of defining the second once and for all in terms of the invariant frequency associated with an atom or a molecule. It was first necessary to resolve the discrepancy between the scale of time based on the irregularly rotating earth and the more reliable time scale used by astronomers: ephemeris time, based on the motion of the earth around the sun. Accordingly in 1956 the International Committee of Weights and Measures, acting on authority of the 10th (1954) General Conference of Weights and Measures and in cooperation with the International Astronomical Union, redefined the second as "the fraction 1/31,556,925.9747 of the tropical year 1900 January 0 at 12 hours ephemeris time." (The tropical year is the time between successive arrivals of the sun at the vernal equinox.) Four years of observations of the moon, completed in 1958, were needed to relate the solar second to the new second of ephemeris time, with an estimated uncertainty of a few parts in a billion—an uncertainty, incidentally, that far exceeded the exactness implied by the definition. The 11th General Conference ratified the new definition in 1960 and urged that work proceed on an atomic definition.

The first atomic clock built at the National Bureau of Standards in 1948 used a transition frequency of the ammonia molecule. Later good transitions



fringes he could accurately determine the value ΔL by which y differs from $2x$. To do this he lined up the near face of the second etalon so that light path c equals light path a. He then moved the first etalon back by a distance equal to x, so that light path d equals light path b. Light path e then equals path $a+2x$ and can be compared with light path f. The difference between e and f, determined by counting fringes, gives the value of ΔL. The procedure is repeated using an etalon with a mirror spacing of z, about $2y$, and thereafter with longer and longer etalons. Michelson finally measured the meter with 10 successive shifts of an etalon 10 centimeters long.



THREE TEMPERATURE SCALES are in common use. Two of them employ the same unit, the degree Celsius, or kelvin, but differ in the location of their zero point. In the Fahrenheit scale one degree equals 5/9ths of a degree Celsius. The International Practical Temperature Scale defines six "fixed" points (*color*), including the triple point of water, .01 °C.

for timekeeping were found in the elements cesium, hydrogen and thallium. The isotope cesium 133 turned out to be the most suitable. The transition between two hyperfine energy levels of the fundamental state of the cesium-133 atom was adopted in 1967 by the 13th General Conference as the "pendulum" for defining the second. It was defined as 9,192,631,770 cycles of that particular transition in cesium 133.

The Bureau's standard of time is maintained by a cesium clock at its laboratories in Boulder, Colo. [*see illustration on opposite page*]. The clock's accuracy is about one part in 10^{12}. This means that in 6,000 years it would not gain or lose more than a second. The Bureau is now working on still more accurate timepieces, for example the hydrogen maser, which promises to be 100 times more accurate than even the cesium clock.

The cesium clock at Boulder provides the basis for standards of time and radio frequency that are broadcast by four radio stations operated by the National Bureau of Standards. Two of the stations, WWV in Fort Collins, Colo., and WWVH in Maui, Hawaii, broadcast additional information such as standard audio frequencies (including the standard musical pitch, *A* above middle *C*), radio-propagation forecasts and geophysical alerts. The other two stations, WWVB and WWVL, both at Fort Collins, provide standards of higher accuracy for research laboratories, instrument makers and Government installations. By using communication satellites to relay time signals the international synchronization of time has been improved so that it is now accurate to within about a millionth of a second.

Beyond the Triple Point of Water

Although temperature standards have long been based on highly reproducible constants of nature, such as the freezing and boiling points of very pure substances, their accuracy does not go beyond a few decimal places. The current international scale is based on a series of reference points known as fixed points.

The most familiar scale in the English-speaking world is of course the Fahrenheit scale, which was first crudely defined by taking the temperature of the human body as being 100 degrees Fahrenheit and the lowest temperature obtainable with a mixture of ice and salt as zero degrees. The scale is now based on the "ice point" (the temperature at which water and ice are in equilibrium at atmospheric pressure), 32 degrees Fahrenheit, and the temperature of boiling water, 212 degrees Fahrenheit. On the centigrade scale (the scale now called Celsius) as originally established, these two reference points were set at zero degrees and 100 degrees.

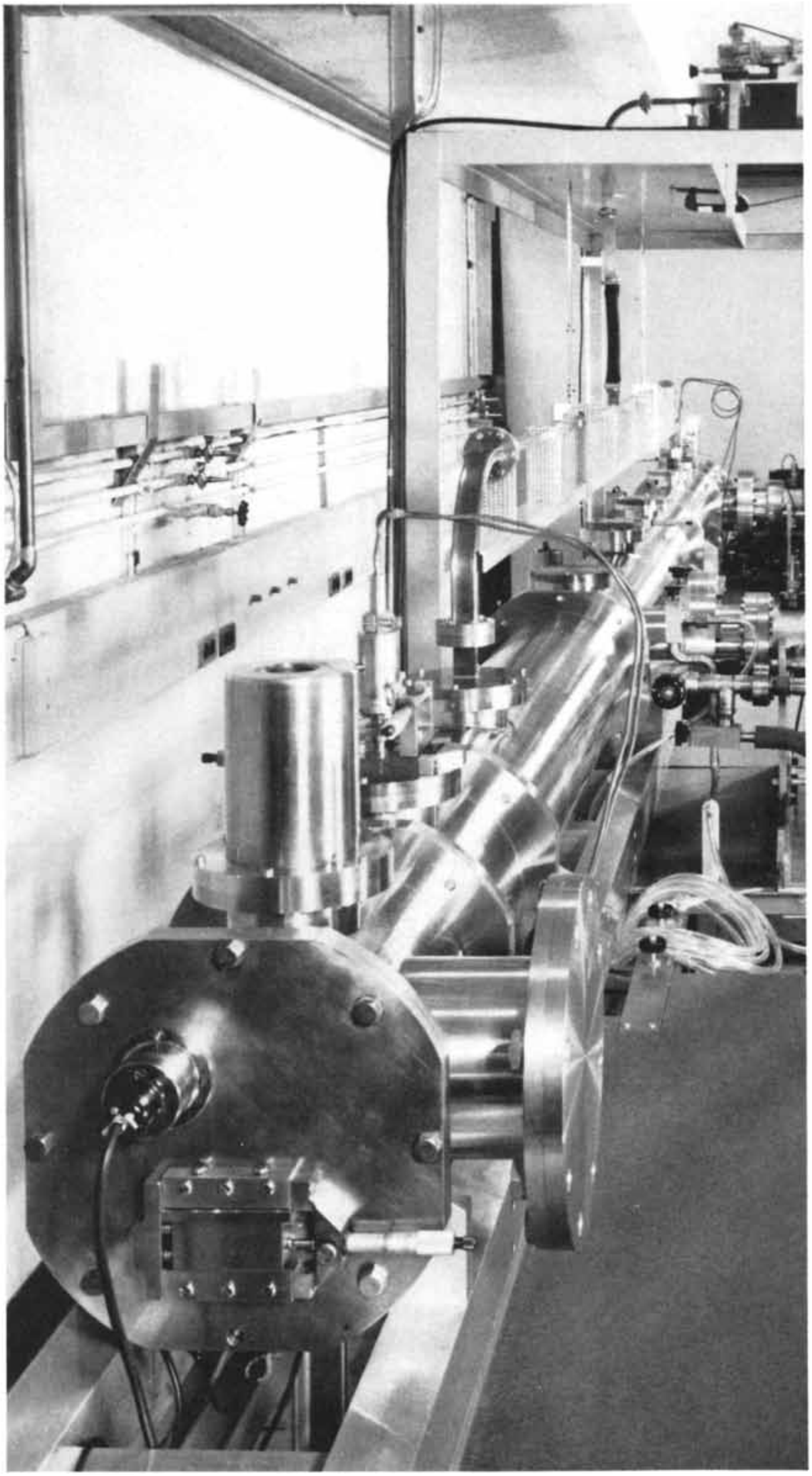
During the 19th century Lord Kelvin proposed a more fundamental scale in which the zero point was to be the point of zero thermal motion for an ideal gas: −273.15 degrees Celsius, or −459.7 degrees Fahrenheit. Each degree on this thermodynamic, or Kelvin, scale is equal to one degree on the Celsius scale. Because temperatures on the Kelvin scale can be determined only by complex experimental procedures, its use is limited to scientific work.

In the 1920's the International Committee of Weights and Measures sought to provide a practical scale compatible with the Kelvin scale by defining the temperature of a number of fixed points, based on the best experimental values available throughout the world. These values were expressed in terms of the Celsius (then centigrade) scale but were related to the Kelvin scale by a constant difference factor.

In 1954 the 10th General Conference redefined the thermodynamic temperature scale with a single fixed point, the triple point of water, and assigned to the temperature of this point the value 273.16 K. (Temperatures on the Kelvin scale now omit the word "degrees.") The triple point of water is the temperature at which the solid, liquid and vapor states of water exist together at equilibrium. It is .01 degree Celsius above the ice point. This single fixed point can be reproduced with greater accuracy (about one part in a million) than either the ice point or the boiling point of water. In 1960 the International Temperature Scale was renamed the International Practical Temperature Scale at the same time that the ice point was replaced by the triple point as the fundamental reference.

The six defining fixed points on the International Practical Temperature Scale, all in degrees Celsius, are now the boiling point of oxygen (−182.97), the triple point of water (.01), the boiling point of water (100.0), the boiling point of sulfur (444.6), the freezing point of silver (960.8) and the freezing point of gold (1,063.0). It will be noted that none of these values is carried beyond the second decimal place, which is an indication of the comparatively low precision with which they can be reproduced.

Measurement of both extremely high and extremely low temperatures has be-

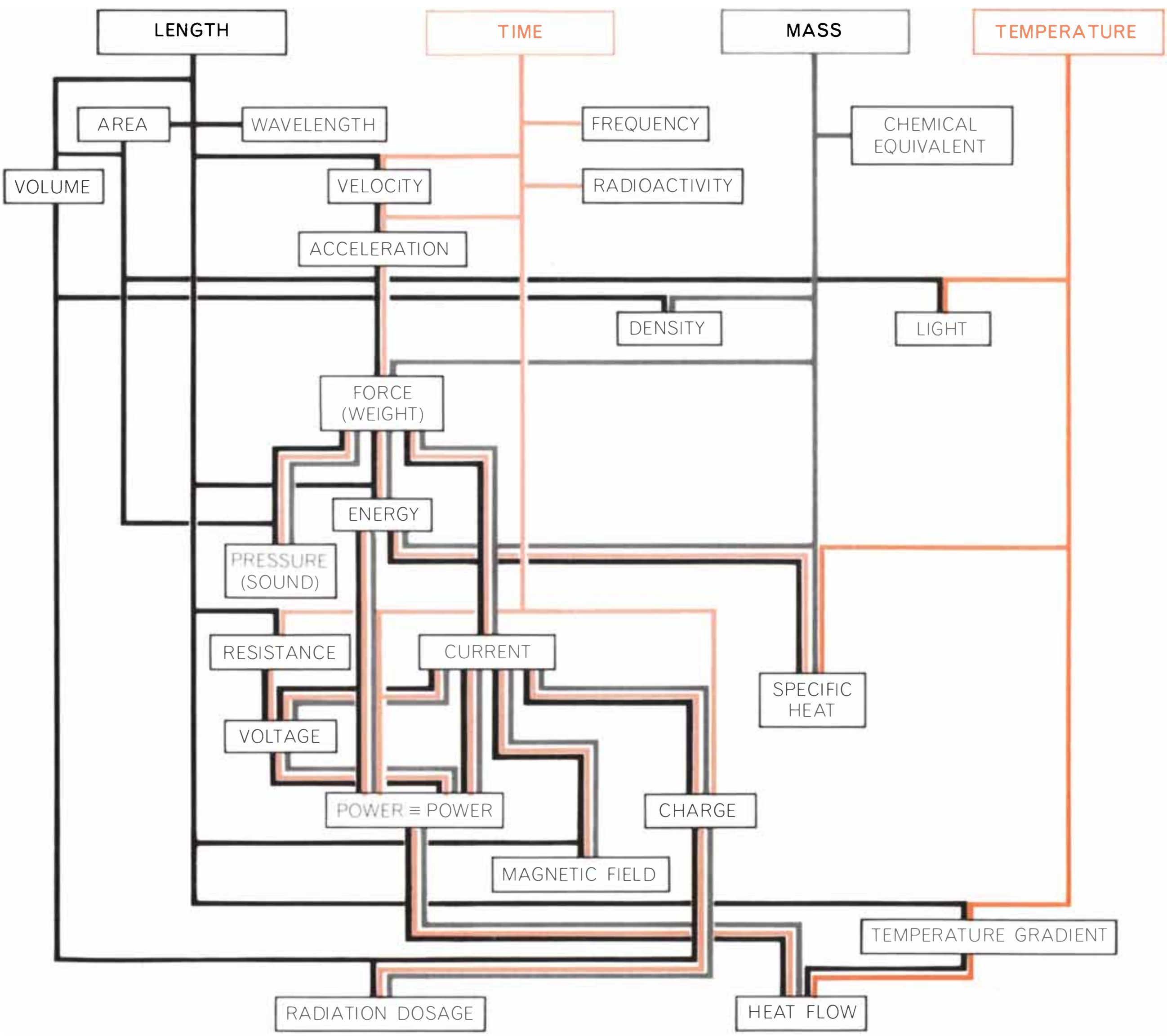


CESIUM CLOCK at the laboratories of the National Bureau of Standards in Boulder, Colo., provides the basis for the frequency and time signals broadcast by the Bureau. Atoms of cesium isotope 133 are boiled out of an oven located behind the end flange at which a micrometer is attached. As they leave the oven the atoms pass through a magnetic field that selects atoms in a certain energy state. The atoms then pass through a section where they are exposed to radio waves whose frequency is maintained at 9,192,631,770 hertz (cycles per second), which exactly matches a natural resonance frequency of the cesium atom. The frequency is maintained by feedback from a detector that records the arrival of cesium atoms at the far end of the clock. If the frequency drifts slightly away from the desired value, the number of cesium atoms reaching the detector falls off sharply, thus leading to a correction.

come increasingly important in many technologies. Extension of the temperature scale to these regions has proved to be most difficult. The National Bureau of Standards has established a scale known as the NBS Provisional Scale of 1955 for use in the range from 90 K down to 12 K. More recently two additional scales, the Helium-4 Vapor Pressure Scale and the Helium-3 Vapor Pressure Scale, have provided provisional scales below 5 K. These are based on the change in the vapor pressure of liquid helium with temperature. In 1965 the gap between 5 K and 12 K was closed by means of a scale based on an acoustical thermometer, developed by the National Bureau of Standards, that measures temperature in terms of the change in the speed of sound in helium gas.

Efforts are now being made to extend the International Practical Temperature Scale downward to about 14 K by use of resistance thermometers. International agreement on this extension is expected within the next year or two, leading to a new international practical scale.

Above the freezing point of gold the values on the International Practical Temperature Scale are obtained with optical pyrometers, whose readings can be converted to temperatures by extrapolation from the freezing point of gold on the basis of heat-radiation theory. A photoelectric pyrometer developed by the National Bureau of Standards provides readings up to 3,500 degrees Celsius with an uncertainty of two degrees at the maximum reading. At higher temperatures, as in plasma arcs (10,000 to 15,000 degrees Celsius), spectroscopic methods must be employed. These are based on a theory that relates the temperature of an incandescent gas to certain characteristics of the resulting spectrum. At the extremely high temperatures associated with hydrogen fusion (10 million degrees Celsius and up) different temperature values are obtained depending on the spectroscopic method used to measure them. Apparently temperature as ordinarily defined has little meaning at the top of the scale. New concepts as well as new measuring methods will have to be developed in order to measure the properties that are relevant in these extreme regions.



INTERRELATION OF MEASURING STANDARDS provides a capsule course in elementary physics. Thus such quantities as velocity and acceleration are functions of distance and time. Force, energy and pressure involve not only distance and time but also a third quantity: mass. Many important quantities such as inductance, capacity and viscosity have been omitted for simplicity.

Move over.

From out of nowhere, a speck appears in your rear-view mirror, grows instantly larger, and you see the famed blue-and-white medallion on the hood. Mister, that's a BMW bearing down on you, and unless you're driving a BMW yourself, you'd best get out of the way.

For this is the car that's overtaking everything else on the road, and taking sportsmen everywhere by storm. This is the car that in Germany, where high-speed driving is a national sport, leads the pack.

What's BMW got? The most advanced high-performance engine in any production car, for a cruising speed of 100 mph. Head-snapping acceleration through the gears. A unique, fully-independent suspension for amazing roadholding that makes the car as safe as it is fast.

What else? Plenty of room for four big adults. Virtual freedom from repairs, and 30 miles to a gallon of gas. All constructed with the everything-fits, everything-works precision craftsmanship that is the pride of Germany.

And all for a remarkable under-$2,600 price.

Go to your BMW dealer, and take the wheel of the sportsman's car. Then kick the throttle hard, and watch the ordinary cars move over.

Suggested retail prices start at **$2,597** P.O.E. New York. U.S. Importer: **Hoffman** Motors Corporation, 375 Park Avenue, New York, N.Y., 1862 S. La Cienega Blvd., Los Angeles, Calif. Dealers coast to coast. Advantageous European Delivery Program. Write for free brochure.

Bavarian Motor Works

BMW

The Sportsman's Car

The Brain of Birds

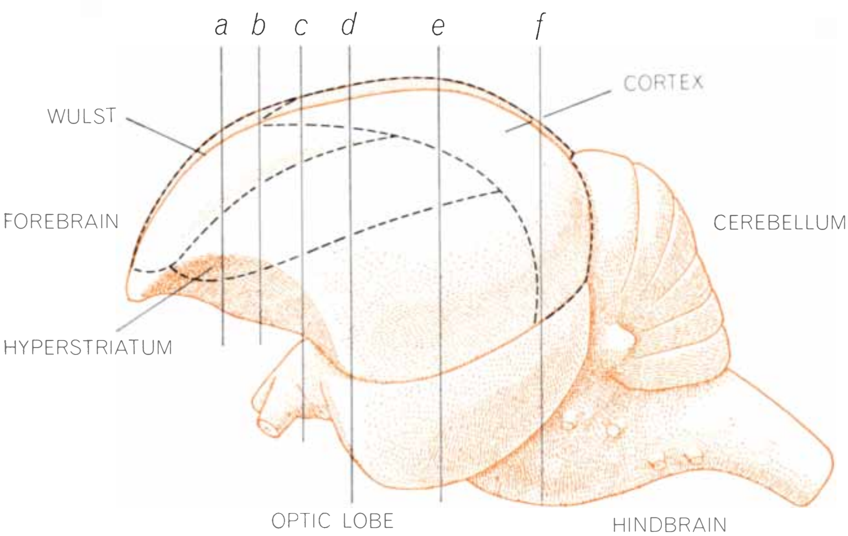
Since birds have a smaller cerebral cortex than mammals, are they less intelligent than mammals? Recent work suggests that they may simply use other parts of the brain to effect intelligent behavior

by Laurence Jay Stettner and Kenneth A. Matyniak

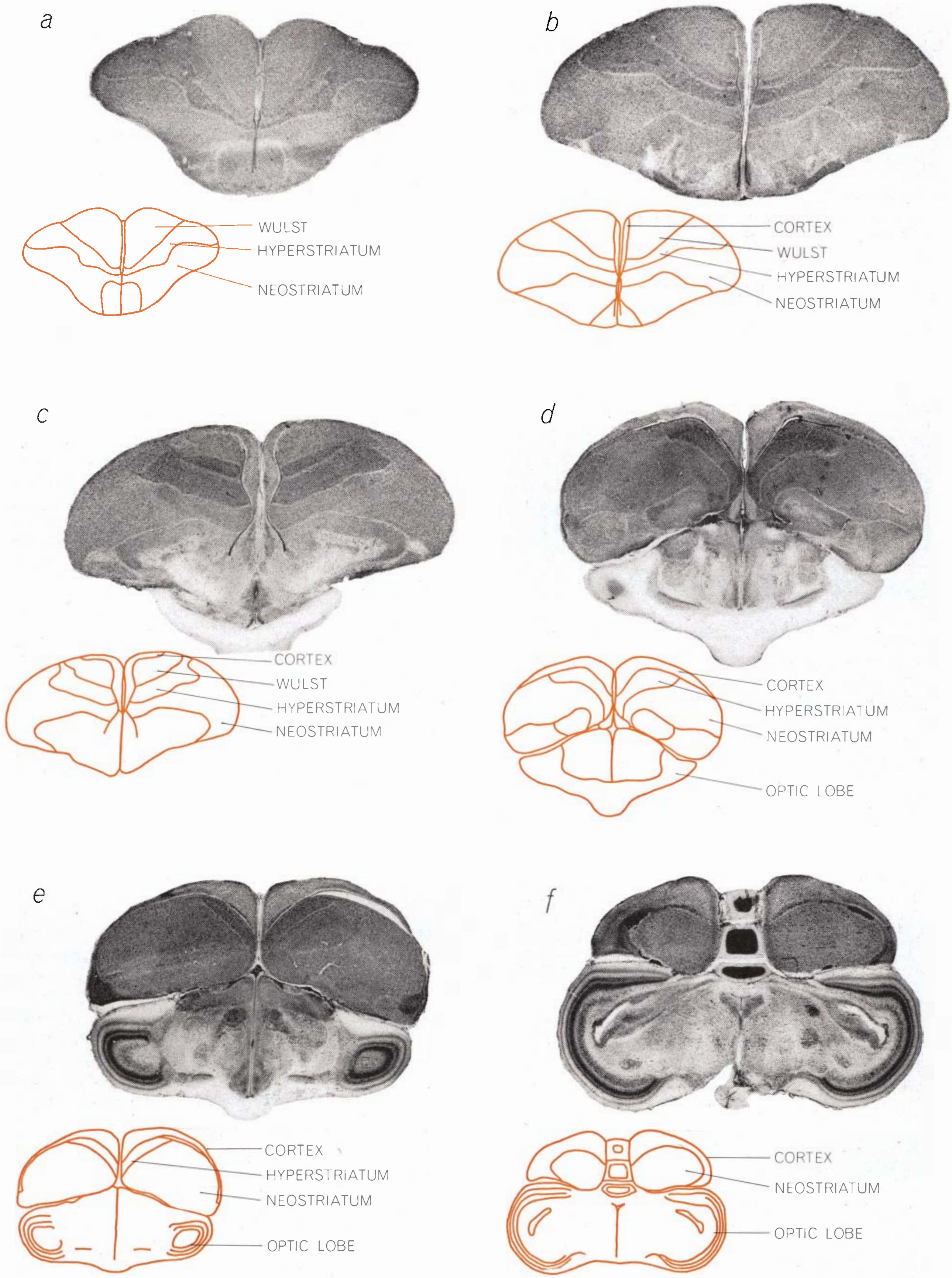
In the lexicon of insult few terms are as disparaging as "bird brain." The derivation of the term is obvious. In comparison with the brains of even the most primitive mammals the avian brain seems a pathetic object. The brain of a bird is not only tiny in size but also notably backward in development of the cerebral cortex, the principal organ of intelligence in the higher animals. Yet investigations of the intelligence of animals have shown that the physical aspect of the bird brain is deceiving. Birds have demonstrated in test after test that they are capable of highly intelligent behavior, sometimes surpassing the abilities of mammals with greatly superior cortical development. These findings indicate that studies of the avian brain could be a revealing guide to the sources and evolution of intelligent behavior.

That birds possess certain remarkable sensibilities has of course been noted ever since bird-watching began. Their uncanny powers of navigation in long migrations, their intricate nest-building and their devoted parental behavior have impressed all students of these animals. Still, these activities could be attributed to inborn, stereotyped patterns of behavior rather than to intelligence. They have generally been regarded as "instinctive" in nature, not involving the flexibility and ability to learn that are the earmarks of intellectual activity. The modern studies of the learning abilities of birds by B. F. Skinner of Harvard University and by other investigators, however, cast a completely new light on avian intelligence. Skinner, who used the pigeon as one of his principal subjects in his experimental studies of learning, found that pigeons were quite flexible in adjusting their behavior to a variety of learning tasks. By now a considerable body of evidence on the learning capacities of birds has been accumulated by a number of investigators, including our group at Wayne State University. Let us review the findings.

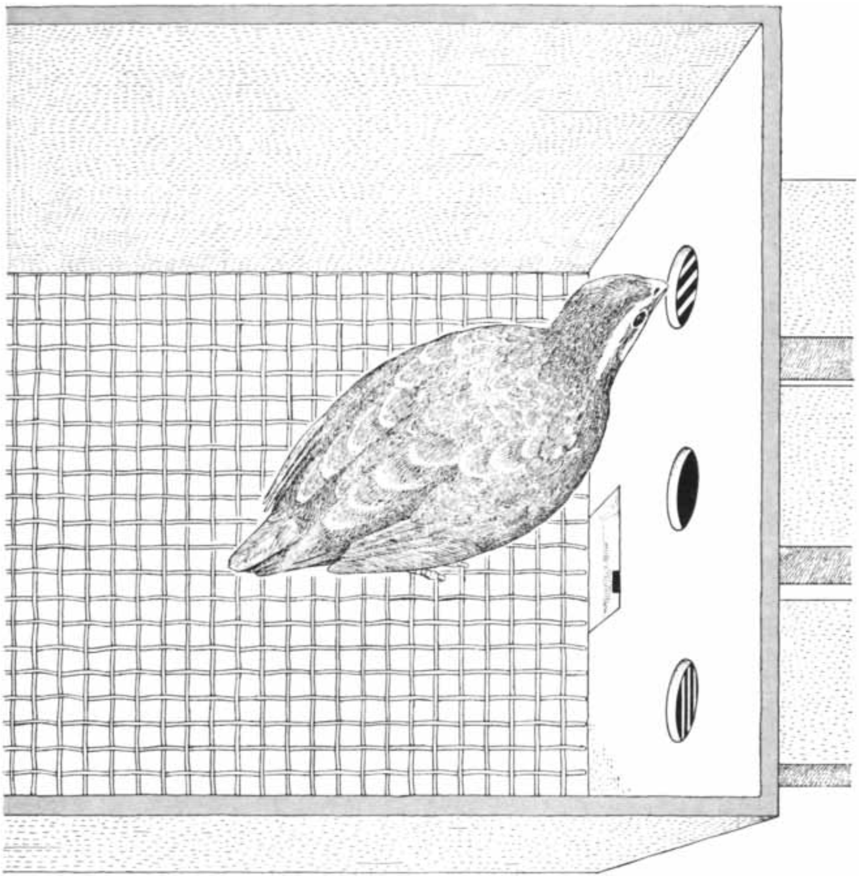
It is not easy to devise an experiment that affords a clear test of animal intelligence, and it is still more difficult to design one that will serve for comparative testing of various animals. The Bryn Mawr College psychologist M. E. Bitterman succeeded in working out a relatively simple type of problem that tests an animal's mental flexibility or, in other words, its ability to solve a problem by repeatedly changing or modifying its behavior to meet new conditions [see "The Evolution of Intelligence," by M. E. Bitterman; Scientific American, January, 1965]. The test is called "multiple reversal." After the animal has learned to choose between two symbols (say a circle rather than a square) in order to obtain a food reward, the "correct" symbol is reversed (from the circle to the square), so that the animal must now switch to choosing the symbol that was previously unrewarded. The experimenter repeats the reversal many times, and the animal's learning is measured by how soon it "catches on" that after the selection of one symbol is no longer rewarded it must switch to the other to gain the reward again. Bitterman found that fishes did not show any improvement in learning such a problem; after each reversal they made about the same number of fruitless selections of the old rewarded symbol before they switched to the new one. Rats, on the other hand, improved as the reversal program proceeded; they made fewer and fewer fruitless trials and eventually learned to switch to



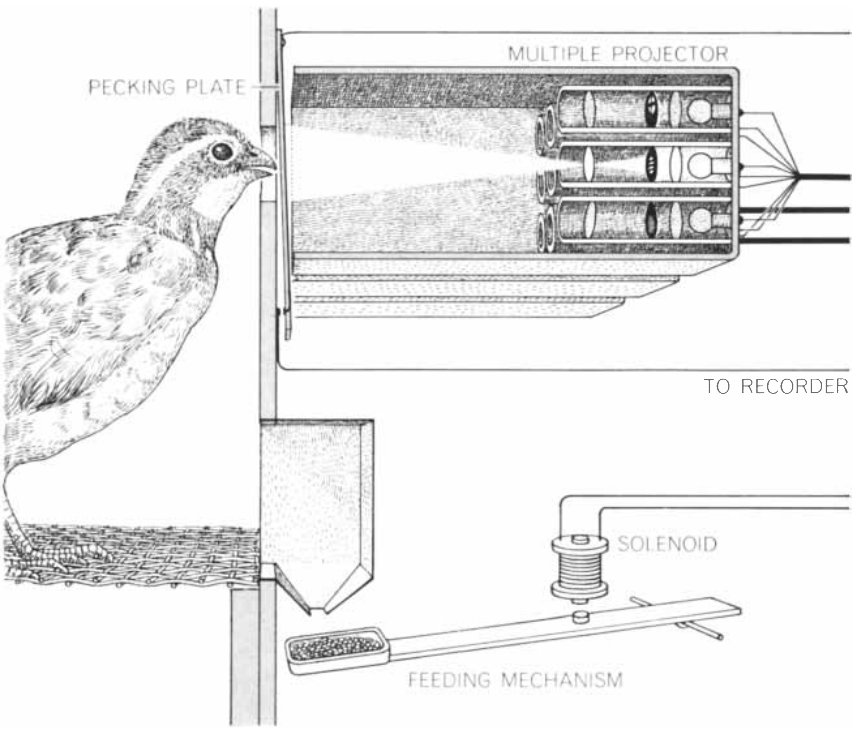
BRAIN OF A BIRD has a small and undeveloped cortex but an extensive striatum that lies above the brain's large optic lobe. The brain illustrated is that of a quail, the bird used in the authors' experiments. Broken lines surround the cortex and two parts of the striatum, the "*Wulst*" and the hyperstriatum. Vertical lines identify the areas seen in transverse section in the illustration on the opposite page, in which the cortex and striatum are contrasted.



TRANSVERSE SECTIONS of a quail's forebrain appear in these six micrographs. The outline drawing below each micrograph shows the salient anatomical features. The smallness and shallowness of the cortex, in contrast to the extensive area occupied by various components of the striatum, is evident in sections *b*, *c* and *d*. The cortex hecomes enlarged only toward the rear of the forebrain.



TESTING CHAMBER is seen from above. The images between which the bird learns to discriminate are projected on translucent "pecking plates" that can be reached through the holes in the chamber wall. When the bird pecks the right image, it is rewarded with food.



CUTAWAY VIEW of testing apparatus shows one of three multiple projectors and part of the circuitry connecting the pecking plate with the solenoid-actuated food lift. The bird's correct and incorrect responses to the various projected stimuli are recorded automatically.

the new symbol after only one or two unsuccessful trials at the old.

How do birds do in this test? Bitterman noted that pigeons showed the same "more intelligent" pattern that rats did. And the pigeon is by no means the most proficient learner among the birds. Experiments in our laboratory and by Robert Gossette of Hofstra University have demonstrated that crows, ravens, magpies, myna birds and parrots surpass the pigeon's performance in reversal learning. On the whole, birds do at least as well as many mammals on this measure of learning capacity.

Let us go on to a somewhat more exacting measure: a sophisticated test designed to measure the learning ability of primates rather than of lower mammals such as the rat. In this test, designed by Harry F. Harlow of the University of Wisconsin, the animal must learn a general approach for successful solution of various problems that involve the same principle but are presented in different physical forms. The animal is required to "learn how to learn" the answer; in technical terminology, the subject must form a learning "set." For instance, the animal may be confronted with a bowl and a shoe and receive a food reward if it touches the bowl rather than the shoe. The objects are then shifted about in further trials, and the animal must learn to choose the bowl every time, regardless of its position. After learning this lesson the animal is presented with a series of pairs of objects that entail the same type of recognition. There are a number of forms of the test; the irrelevant variable may be some factor other than the positions of the objects. Harlow has found that in the first presentation it may take a rhesus monkey, for example, some 50 to 60 trials to learn to touch the correct object regardless of position, but in later presentations the animal eventually is able to identify the rewarded object in only one or two trials. Harlow and other investigators have demonstrated that this type of test provides a measure of differences in intelligence among the various primates. Those with a more highly developed cerebral cortex show a greater capacity for forming learning sets. Thus New World cebid monkeys do better than the more primitive marmosets, rhesus monkeys do better than New World monkeys and chimpanzees in turn do better than rhesus monkeys. Learning set has been regarded as a supertest suitable only for primates; the performance of lower mammals on this test is consistently very poor.

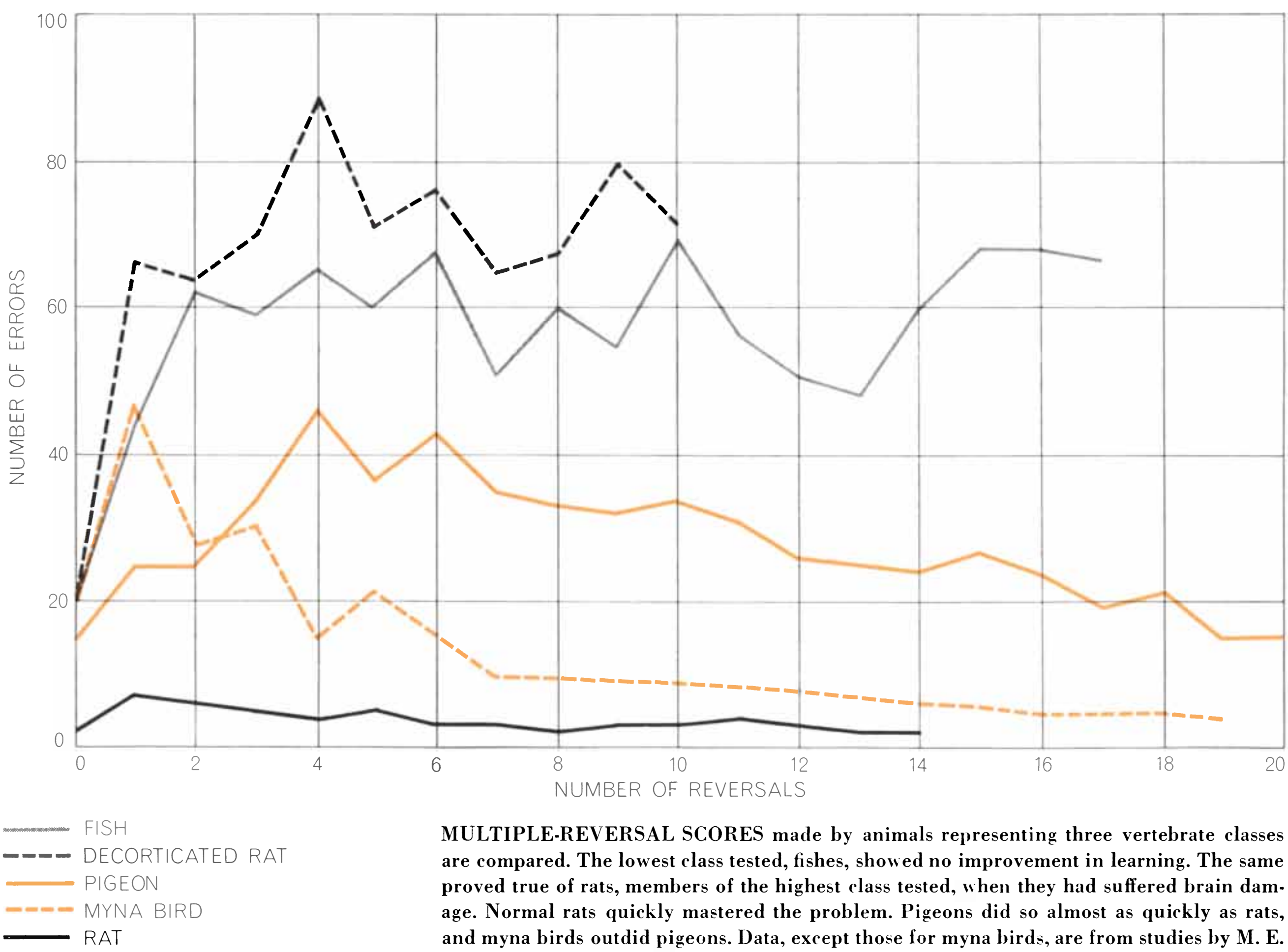
How, then, do birds fare on learning

REVERSAL LEARNING occurs in two steps. At first the animal learns that one visual pattern, in this example horizontal stripes, is rewarded regardless of where it may appear ("*a*" *and* "*b*"). Next the previously unrewarded pattern is made rewarding (*c*) and the number of wrong responses before discovery of the reversal is noted. As tests continue, the higher animals learn to reverse more quickly.

set? So far only two representatives—the pigeon and the chicken—have been tested, and both did better than any nonprimate mammal had done; in fact, the chickens even outperformed the marmoset!

A still more complex learning task for animals is the "oddity" problem: selection of the odd member among three stimuli, two of which are alike. The complexity is introduced by changing the display or the odd stimulus from one trial to the next. For example, in Trial 1 the presentation may be circle, circle, square in a horizontal row; in Trial 2, square, circle, circle; in Trial 3, square, square, circle, so that the odd member is no longer a square but a circle. The animal cannot attach its response to a particular shape or position; it must take the total situation into account and respond to a relationship. Can birds master such a problem? The answer is yes. Monkeys, cats *and* pigeons have shown the ability to learn to pick out the odd member of a given trio of objects.

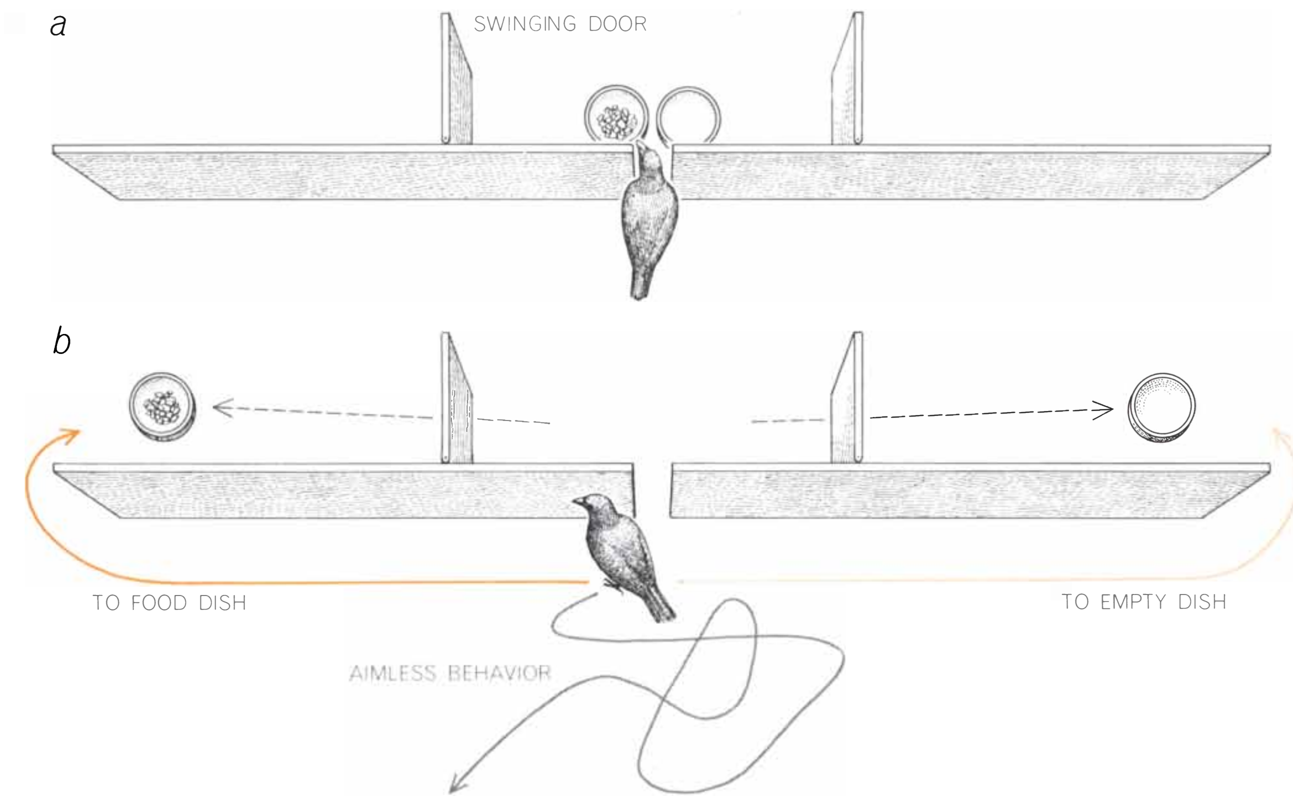
The oddity problem can be carried a step further. Is the animal capable of forming a learning set from such an experience, that is, can it generalize the oddity principle by applying it to various stimuli? Having learned to pick the odd figure out of circles and squares, will it also be able to do so when it is presented with, say, two rectangles and a triangle or two shoes and a bowl? To the human mind such a transfer of learning seems so elementary that one might suppose it should not be at all difficult for any animal that is capable of solving the initial oddity problem. It turns out that such is not the case. Even monkeys have some difficulty with the problem; they learn to generalize the oddity prin-



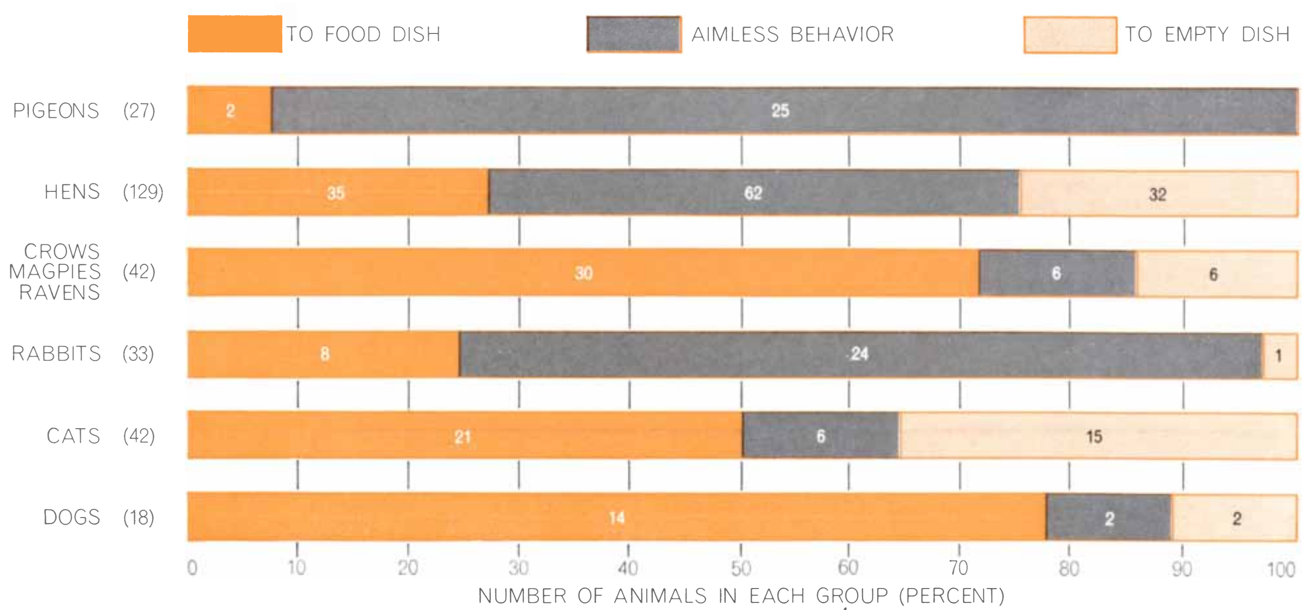
MULTIPLE-REVERSAL SCORES made by animals representing three vertebrate classes are compared. The lowest class tested, fishes, showed no improvement in learning. The same proved true of rats, members of the highest class tested, when they had suffered brain damage. Normal rats quickly mastered the problem. Pigeons did so almost as quickly as rats, and myna birds outdid pigeons. Data, except those for myna birds, are from studies by M. E. Bitterman of Bryn Mawr College. Robert Gossette of Hofstra University ran the myna tests.

ciple only after they have undergone the experience of solving many different oddity problems in succession. On the other hand, cats, as J. M. Warren of Pennsylvania State University has found, do not form the oddity learning set even after mastering 30 individual oddity problems. What the cat cannot accomplish, however, the canary can. Nicholas Pastore of Queens College of the City University of New York presented canaries with an array of nine three-dimensional objects, eight of which were identical. After the birds had learned that selection of the odd object brought a food reward, on later trials with new sets of objects they picked out the odd object in each set at the very first exposure.

Consider next another intellectual capacity: the ability to count or, more precisely, to respond to the property of number. Even primates have considerable difficulty with this task. Herbert Woodrow of the University of Illinois



ANIMAL DILEMMA was devised by L. V. Krushinsky of Moscow State University. An animal feeds from one of two bowls by reaching through a narrow slot in the center of a wide screen (*a*). The bowls are then moved out of sight behind swinging doors. Seeing the bowl with food in motion, the animal may pursue it or not (*b*). Movement in the correct direction allows the feeding to resume.



PERFORMANCE of birds and mammals in solving the Krushinsky problem is compared in this graph. Dogs made the best scores, but crows and their relatives were nearly as good as dogs and better than cats or rabbits. Hens outscored rabbits; pigeons did worst.

Here's why North Carolina became the first State in the Union to use the Polaroid driver's license:

To begin with, they wanted to crack down on the people who drive with stolen or borrowed licenses. Some of these drivers are incapable of passing a driving test. (Some send a friend to take it.) Others have had their own licenses revoked. All of them are a menace to the rest of us. And all of them are easier to spot when the licenses they carry, carry photographs.

North Carolina also wanted to protect its merchants and citizens from thieves who use their victims' licenses for identification in order to cash checks. And they wanted to stop the under-age drinkers who use borrowed licenses to buy beer and whiskey.

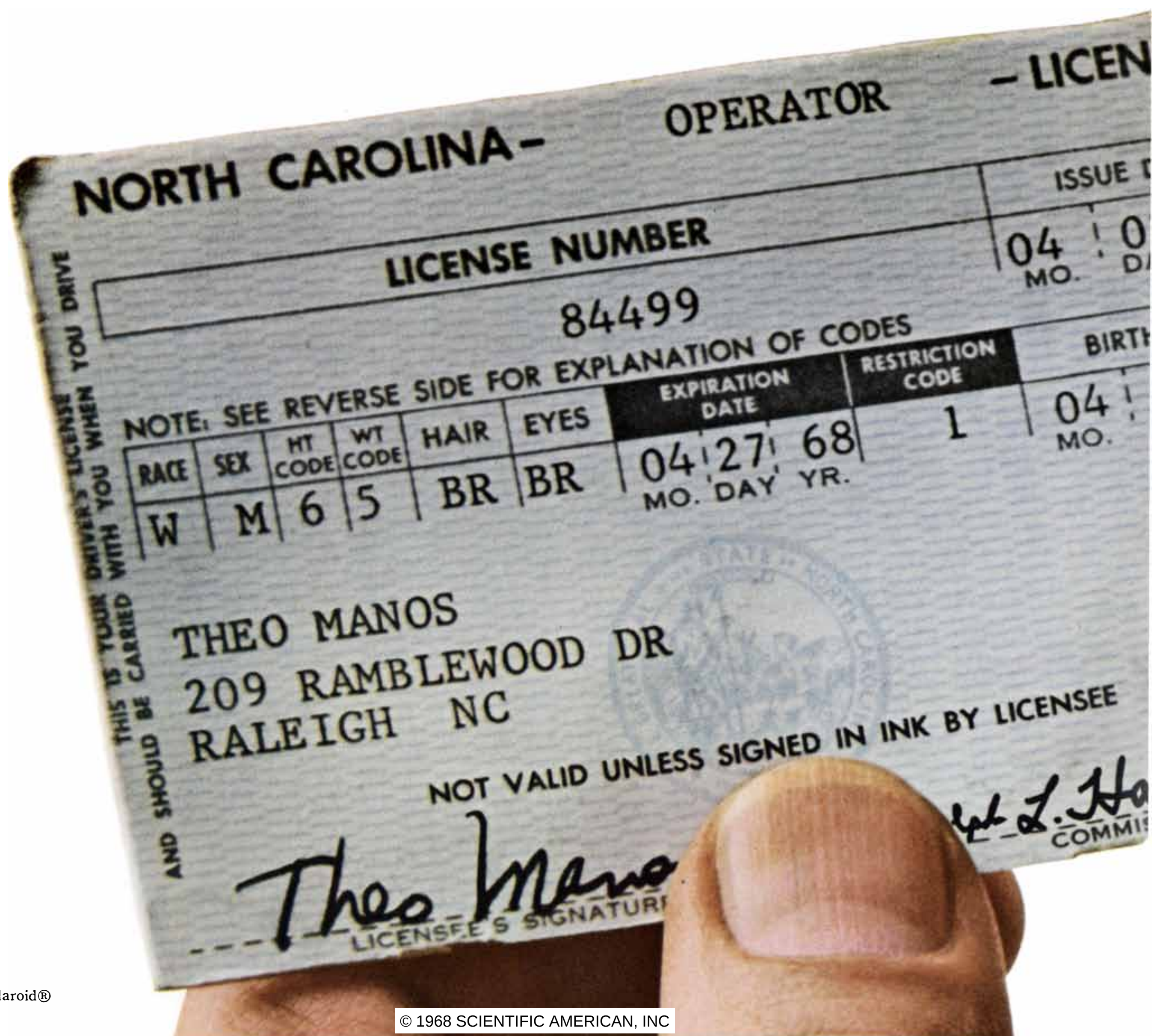
Any photographic license makes these activities difficult. But a Polaroid license makes them virtually impossible. Because the Polaroid license is highly tamper resistant.

The driver's photograph, his personal data, and a superimposed validating signature, are all reproduced simultaneously on a single piece of film. The film is laminated to plastic on the spot, die-cut, and sealed in a protective plastic pouch. (All in 2 minutes.) Any attempt to remove the laminate, in order to alter the picture or data, destroys or damages the license.

But ID security was only *one* reason why North Carolina chose the Polaroid 2-minute license over a conventional photographic license:

The average rate of photographic failure in conventional licenses is close to 3%. So, in an average year, North Carolina would have had to recall 22,000 of its citizens for rephotographing. (And, of this group, 660

North Carolina had a perfectly good driver's license. What made them drop it?



Polaroid®

would have to go back for a *third* time!)

With the Polaroid Land Identification System, if the picture is unsatisfactory, the operator knows it in 60 seconds and reshoots immediately. That saves tempers, time, and money.

The Polaroid System saves money for the State in other ways, too:

No central photo-processing lab to build, and no cans of film to ship to it. (Likewise, no cans containing thousands of negatives to be lost, damaged, or misprocessed.)

No temporary licenses to issue. (Some states take as long as 7 weeks to produce and deliver a photo license.)

No permanent licenses to mail. (The driver gets it on the spot, remember?)

No need to collate photos with their respective data cards after the films have been returned from the processing lab. (And, therefore, no chance to mismatch photos and data.)

The Polaroid System is so simple to operate that 2 office workers can be easily trained to produce as many as 200 finished licenses an hour.

In addition, our System is compatible with most data processing systems so that new-driver applications, license renewals, and driver violations can be handled automatically.

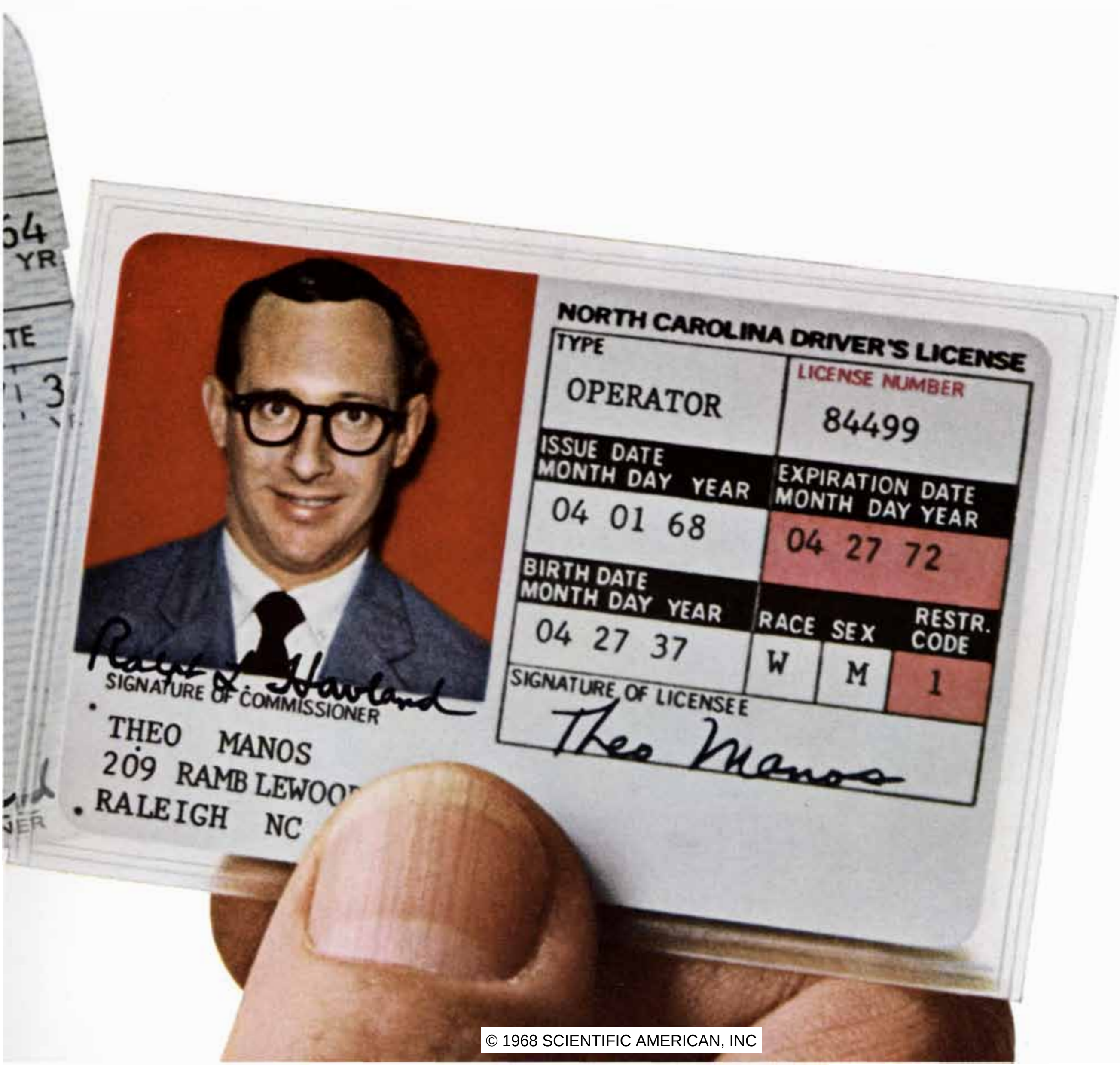
Speaking of violations, the plastic pouch on our driver's license is embossable. So a police officer can print an error-free summons even faster than our System prints the license.

That last feature may not appeal to you as a driver. But if our license appeals to you as a citizen, write to:

Industrial Marketing, Dept. 136, Polaroid Corporation, Cambridge, Mass. 02139.

And we'll drive home the rest of our story.

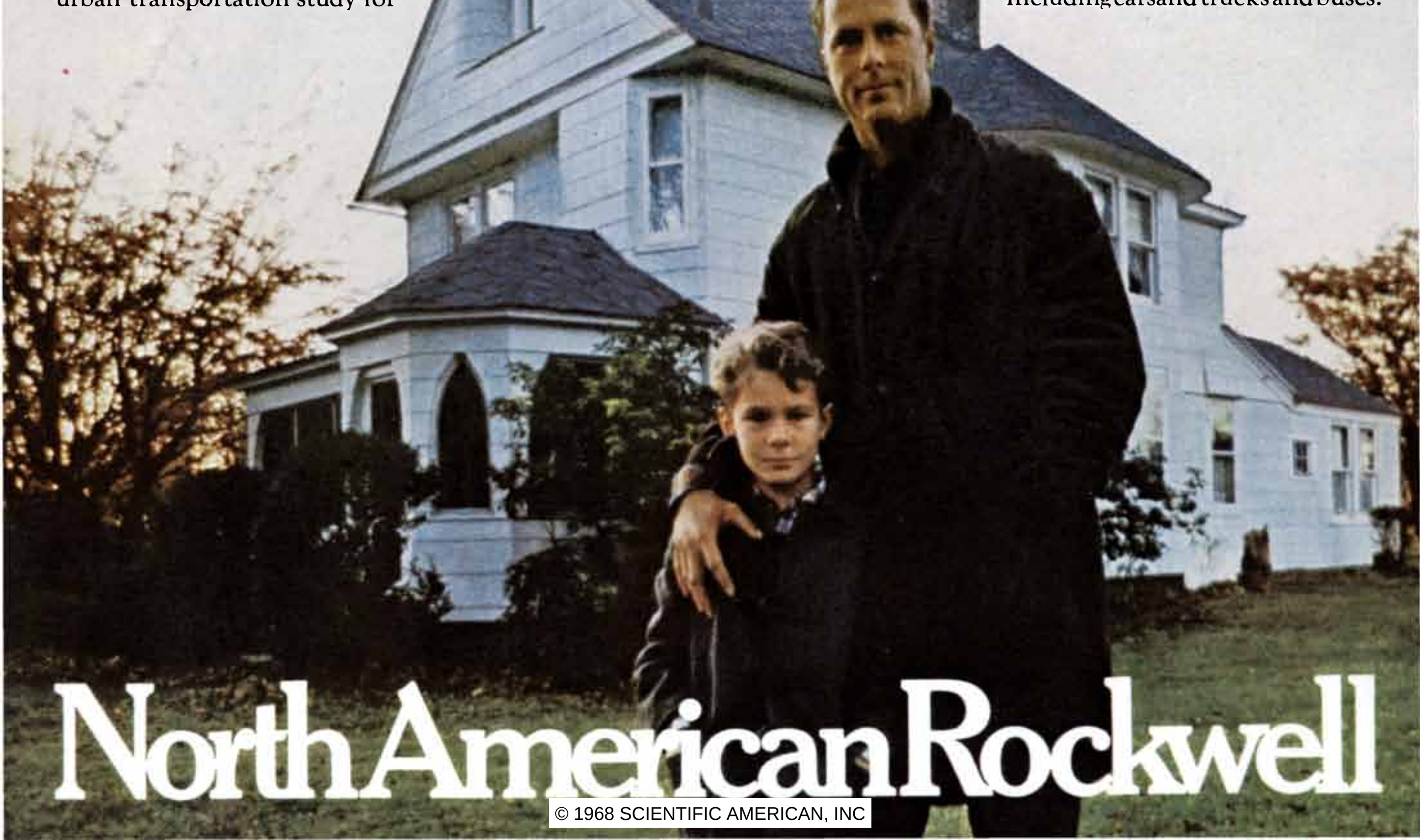
The Polaroid 2-minute driver's license.



When you wake up tomorrow morning, your house won't be as close to the city as it used to be.

American automobiles are multiplying faster than Americans. Freeways turn into parking lots once or twice a day. Parking lots turn into deserts every night. But where would we be without cars and trucks and buses? Right. A lot of people, including us, are taking a fresh look at traffic management. Right now, we're working on an urban transportation study for the Department of Housing and Urban Development. We're interested in traffic management because it's similar to something we know a lot about.

Aerospace systems management. City, state and federal agencies must see the similarity, too. More and more of them are calling on companies like ours to help answer their traffic problems. And nobody wants to find the answers more than we do. Which is understandable. Because we're also one of the world's largest producers of engineered components for a variety of products. Including cars and trucks and buses.



found, for example, that it took 21,000 trials to teach a monkey to distinguish reliably between the sounding of two tones and the sounding of three. For lower mammals such a task is of course a great deal more formidable. Frank Wesley of Portland State College attempted to teach rats to discriminate a single tone from two tones, but after 3,000 trials had produced no observable progress he gave up.

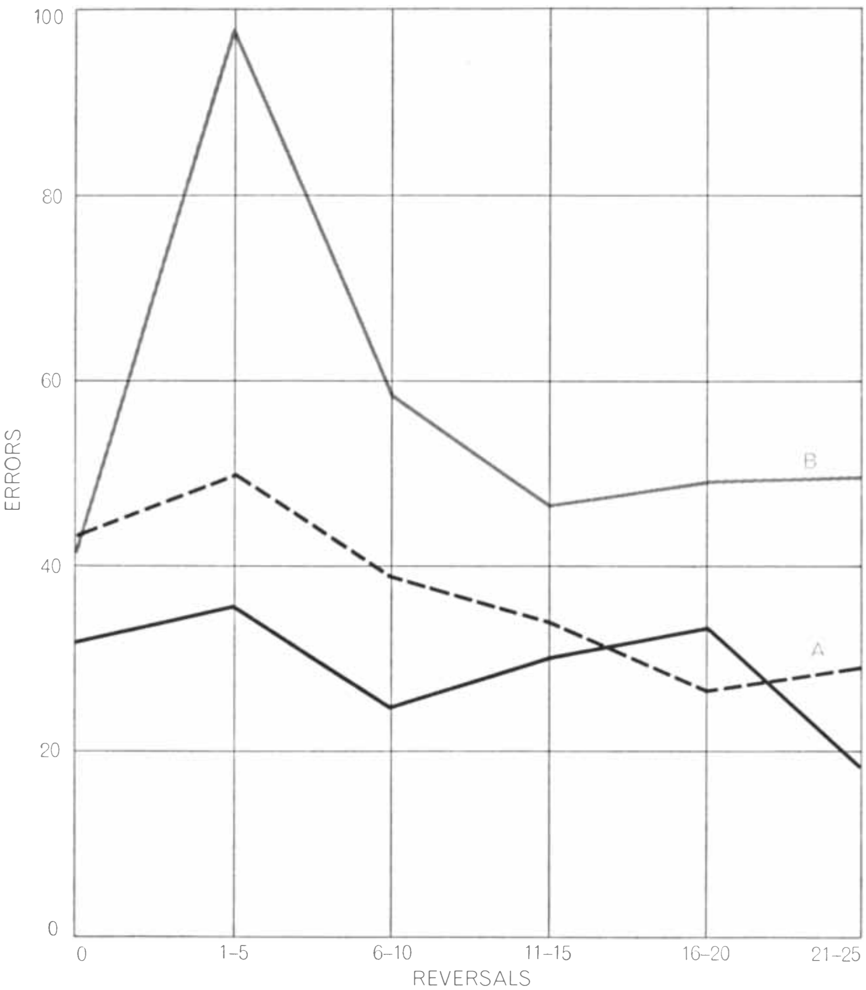
Birds, on the other hand, consistently master counting problems a great deal more complex than these. For example, the German ethologist Otto Koehler and his co-workers trained pigeons to discriminate four "objects" (or stimuli) from five, and they found in various experiments that ravens and parakeets could learn to "count" up to seven. In one form of these tests a raven was shown a key card with a certain number of spots on it and then was presented with an array of containers, each with a different number of spots on the lid; if the raven chose the lid displaying the same number of spots as the key card did, it was rewarded with a worm. The raven learned to find the matching number up to as many as seven spots, regardless of variation in the sizes, shapes or arrangements of the spots. This ability to respond to number per se, without reference to other properties of the stimulus, seems to be very unusual indeed among animals. For instance, the German zoologist Bernhard Rensch found that an elephant (which presumably ranks high in intelligence among mammals), after learning to discriminate a card with three circles on it from one with four circles, failed completely when the symbols were switched from circles to squares, and it took the animal 440 trials to learn this "new" problem [see "The Intelligence of Elephants," by B. Rensch; SCIENTIFIC AMERICAN, February, 1957]. In contrast, the Wayne State University psychologist Leland Swenson showed that a raven, confronted with a similar switch, solved it readily; the bird, having learned to discriminate one circle from two, scored better than 90 percent in trials in which the symbol was changed from the circle to a square, a triangle or an irregular form.

L. V. Krushinsky of the U.S.S.R., in an ingenious series of experiments at Moscow State University, has uncovered still another facet of avian intelligence. He places two bowls behind a slit in the center of a large screen; one bowl contains food and the animal eats from it. Then both bowls are suddenly moved out of sight, one to the left and one to the right. The problem in this case is one not of learning but of making a modest extrapolation from the visual information available to the animal; if the animal goes around the screen on the side toward which the food bowl has disappeared, it regains the food. Krushinsky has tested dogs, cats, rabbits, pigeons, hens, crows, magpies and ravens on this problem. Rabbits, hens and pigeons do poorly; they tend to move around haphazardly after the food disappears, and most of them do not go behind the screen. Cats go around the screen, but they are as likely to go to the wrong side as to the correct one; it takes many repetitions of the experiment for the cat to catch on and move to the correct side each time. Only dogs, crows and crow relatives solve the problem immediately. A majority of them go promptly and directly to the correct side of the screen the first time they are presented with the case of the disappearing bowls.

Here, then, is another demonstration of a bird's capacity for intelligent behavior. Moreover, the test differentiates among the birds, showing that crows and their relatives are superior to the hen and the pigeon (whose performance is the poorest). The fact that these birds best the cat and match the performance of the dog indicates a surprisingly high level of mental power for a bird brain.

The general tenor of all the results reviewed above is unmistakable. It is true that the total volume of evidence so far is not large, and many more comparative studies will have to be made in order to arrive at an accurate and detailed evaluation of the intellectual capacities of birds. Nevertheless, the consistency of the evidence already established cannot be ignored. It points to the conclusion that birds are capable of intelligent achievements equaling or even exceeding those of many mammals. Even if future studies should reestablish mammalian superiority, it cannot be denied that birds show some mental capabilities that have long been thought to belong solely to animals with a well-developed cerebral cortex.

Krushinsky has recently written: "The last decades have markedly changed the previously widespread idea that the behavior of birds is less plastic than the behavior of mammals." It cannot be said that the new view is shared by scientists generally. Many of them are still reluctant to accept the full implications of the experimental evidence, primarily because the avian cerebral cortex is so obviously primitive. It has therefore become essential to take a closer look at the avian brain to see if it has developed



BRAIN DAMAGE resulting from surgical removal of the cortex and of both *Wulst* and cortex produces alterations in the capability of quail to improve reversal learning scores. Solid black line shows improved performance of normal birds over 25 trials. Other lines show performance of birds that were deprived of cortex (*A*) and of both brain tissues (*B*).

some other structure that may account for the birds' apparent intellectual abilities.

There is little question that among mammals the degree of intelligence depends on the size and complexity of the cerebral cortex. The organ shows a clear picture of evolutionary development going up the mammalian order. In the rat the cortex is smooth (without folds or convolutions) and is comparatively undeveloped in the frontal area; in the dog the cortex has a larger surface, some convolutions and greater frontal development; in the monkey it is still further expanded and more convoluted, and in man the cortex has become so extensive and complex that it is plainly distinguishable from that of all other animals. Within any single species (including man) the intelligence of normal individuals cannot be correlated with differences in their cortical development (at least not on the basis of present knowledge), but where there are major differences in cortical development from one species of mammal to another one finds a clear correlation with the degree of intelligence.

In both mammals and birds the cerebrum, or forebrain, contains two major types of structure: the cortex and a lower portion called the striatum. The two structures were inherited from the reptiles. They developed very differently, however, in the mammals and the birds. In the mammals the cortex became dominant, overgrowing and covering the striatum until, in man, the nerve cells of the striatum are deeply buried and intermingled with cortical fibers that have invaded the forebrain interior. In the birds, on the other hand, the main development has taken place in the striatum, while the cortex has become a thin layer of tissue covering only the top and side surfaces of the forebrain. The striatum in birds is a totally integrated, highly organized mass of nerve nuclei and fiber tracts and makes up most of the bulk of the cerebral hemispheres. In particular, the uppermost part of the striatum, called the hyperstriatum, is a well-developed structure that is not present at all in mammals.

A number of years ago the Harvard Medical School neurologist Stanley Cobb, a pioneer in comparative investigations of the brains of birds, suggested that the cortex played little or no part in the mental processes of birds; in fact, he noted that in their case the anatomy indicated a negative correlation between cortical development and intelligence. He deduced that the principal function of the cortex in birds was in relation to the sense of smell, and that as the more advanced avian species came to depend less on this sense the cortex shrank in size and importance. From his many anatomical studies of the brains of birds Cobb concluded that the avian "organ of intelligence" was not the cortex but the hyperstriatum.

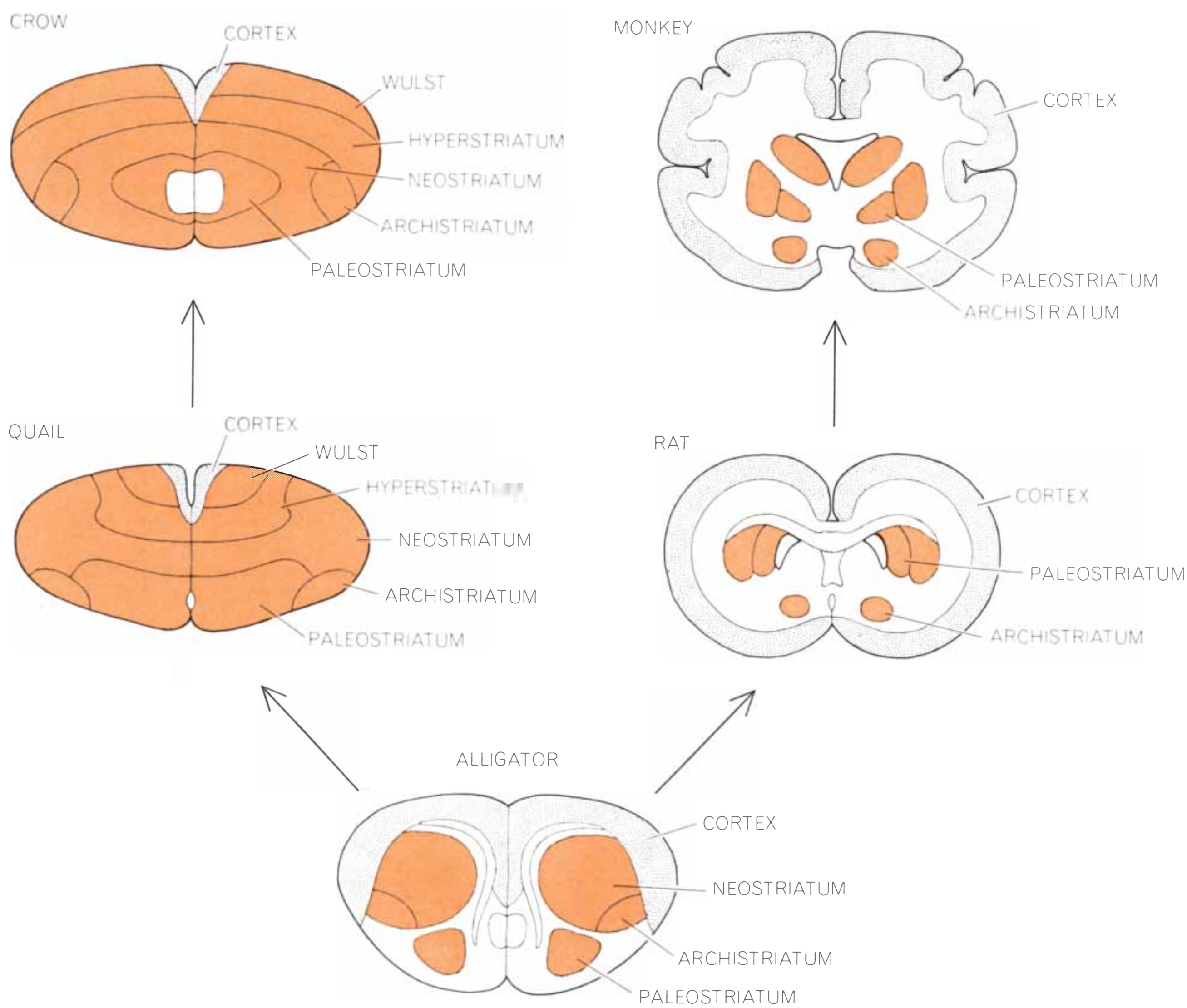
Cobb did this on the grounds that examination of the brains of various birds had shown that species considered to be more intelligent have a more highly developed hyperstriatum; for example, in the crow, the parrot and the canary this organ is more prominent than in the chicken, the quail and the pigeon. More precise anatomical evidence supporting the notion that "hyperstriatum is to birds what cortex is to mammals" has recently come from the detailed work on avian brain structure done by Harvey Karten at the Massachusetts Institute of Technology. Karten has described an area of the hyperstriatum that receives the same type of neural connections in the avian brain as the vision area in the cortex of a mammal's brain.

Various items of evidence involving behavior tend to support these anatomical findings. It has long been known that complete removal of the cortical tissue from a bird's brain does not noticeably impair the animal's motor or sensory abilities, whereas a mammal deprived of its cortex becomes at the least severely handicapped in these respects. Recently H. P. Ziegler of the City University of New York showed that pigeons with extensive damage to their cortex could still perform normally in tests of visual discrimination such as learning to peck at a cross rather than a circle. On the other hand, he found that damage to the hyperstriatum greatly impaired birds' performance in such a test. Krushinsky found in his experiments that the performance of birds on the "around the screen" problem was perfectly correlated with the size of the hyperstriatum; the larger this structure (in proportion to the total size of the cerebrum), the more readily the bird solved the problem. In contrast, the size of a bird's cortex was not at all correlated with ability to solve the problem.

The next inviting step is to explore the hyperstriatum of birds, with a view to finding out what specific structures within that organ are involved in given levels of learning ability. We have begun such experiments in our laboratory. Since Bitterman's multiple-reversal test had proved to be an effective means of differentiating among different species of animals with respect to their learning ability, and these differences in performance presumably reflected some critical difference in their neurological makeup, we selected the multiple-reversal test for our first experiments. As the initial structure for study we chose a bump on the top of the hyperstriatum called the *Wulst*. (It was so named by German investigators.)

Using bobwhite quail as our subjects, we removed the *Wulst* surgically and proceeded to examine the birds' capabilities. They recovered from the operation very quickly and appeared perfectly normal in their movements, eating and drinking behavior, reactions to people and so on. We first submitted the birds to tests involving only a simple form of learning. They learned to peck at a lighted window for food and to choose between vertical and horizontal stripes. Their behavior in these trials was so normal that we came to the conclusion they would certainly pass the multiple-reversal learning test. On the very first reversal problem, however, the birds showed in dramatic fashion that the operation had indeed seriously impaired some aspect of their intellectual functioning. Every bird that had had its *Wulst* removed displayed tremendous difficulty in learning to reverse its choice; this was true even of two birds that before the operation had been trained to a high level of proficiency in reversal. Evidently the *Wulst* not only contained neurological machinery involved in the reversal learning process but also was involved in the function of memory.

Clearly the birds' difficulties with the reversal test were not due to any impairment of their basic motor, sensory or motivational functions. The brain-damaged birds did not differ from normal ones in their movements, their pecking speed and persistence, their pecking accuracy, their responses to food or their ability to learn to make a simple choice between two different visual stimuli. In fact, in the reversal test they continued to peck consistently at the stimulus that



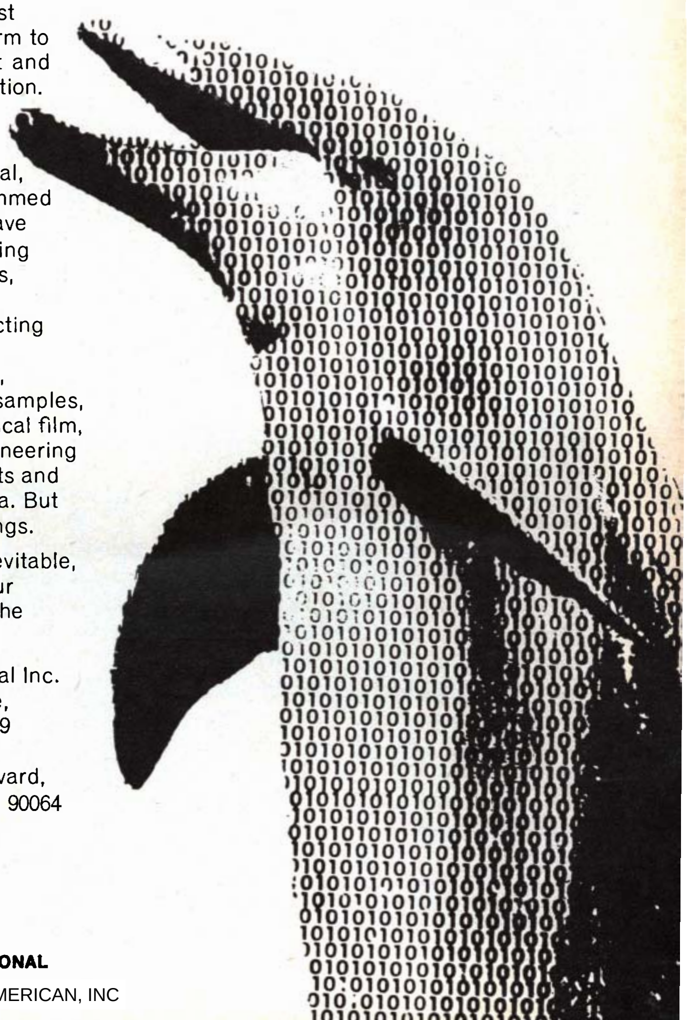
FOREBRAIN EVOLUTION followed separate lines among birds and mammals. Both groups stem from reptilian ancestors, represented here by an alligator's brain seen in transverse section. In it striatal tissue is more abundant than cortical tissue. The trend climaxes in the great enlargement of the hyperstriatum among the birds noted for highly intelligent behavior, such as crows. Among mammals the evolutionary trend progressed in the opposite direction, fostering development of a larger and more complex cortex.

had previously represented a food reward, which convincingly demonstrates that they were able to see the differences between the stimuli.

There are indications that some parts of the avian cortex, as well as the *Wulst*, may be involved in reversal learning. In our original experiments we removed much of the overlying cortical tissue along with the *Wulst*. Later, in order to pin down what tissues were actually involved, we tested birds with only the *Wulst* removed and others with only cortical tissue removed. All the birds that lacked only the *Wulst* showed deficiencies in reversal learning, confirming that it is an important structure in avian learning capacity. Removal of parts of the cortex, on the other hand, left this ability unimpaired in most cases. In some instances, however, cortical excision did impair the ability, although not as much as excision of the *Wulst* did. We are now investigating the possibility that some part or parts of the cortex are functionally involved with the *Wulst* in the higher learning processes.

The discovery of the intellectual capabilities of the avian hyperstriatum has given us a fascinating new avenue for the investigation of brain processes. As a "thinking machine" that is now found to possess many of the capacities of the mammalian cortex, the hyperstriatum is much more accessible to study than the cortex, and its basic operations should be simpler to unravel. Indeed, the hyperstriatum may turn out to be a kind of Rosetta stone for brain researchers. Investigators of the neurology of higher mental processes have been struggling for many years to decipher the message written in the almost impenetrable code of the extraordinarily complex mammalian cerebral cortex. In the hyperstriatum we now have another message that says almost the same thing but in a simpler code. By analyzing the simpler code and comparing the two codes, which obviously are related to each other, it should be possible to speed up progress toward understanding the basis of intelligence.

It was the lowly fruit fly that provided the key that opened the door to the modern study of heredity and the eventual decipherment of the genetic code, and the giant axon of the squid similarly has made large contributions to our understanding of the transmission of messages by the nervous system. Perhaps the much maligned bird brain will eventually make a key contribution to the understanding of how the brain works to produce intelligent behavior.



The Discovery of DNA

In 1869 Friedrich Miescher found a substance in white blood cells that he called "nuclein." Cell biologists saw that it was a constituent of chromosomes and hence must play a major role in heredity

by Alfred E. Mirsky

Deoxyribonucleic acid was discovered in 1869 by Friedrich Miescher. The reader may find it surprising that DNA, which has been the focus of so much recent work in biology, was isolated almost a century ago. If so, he will find it even more surprising that the function of DNA as the substance in chromosomes that transmits hereditary characteristics was recognized only a few years later by a number of biologists (not, however, by Miescher). Here I shall recall how it happened that Miescher discovered "nuclein" (as he called it) and what it meant to him and his contemporaries, and tell something of the investigative history of DNA until, some 25 years ago, it was conclusively shown to be the genetic material.

Miescher was the son of a Swiss physician who practiced in Basel and taught at the university there, and he followed his father into medicine. As a medical student he came under the influence of his uncle Wilhelm His, professor of anatomy and one of the outstanding investigators and teachers of his time. That influence was profound and lifelong. Miescher's later views on biology are often best understood in the light of His's attitudes and ideas; Miescher's writings are available today largely because His gathered and published the younger man's letters and papers after Miescher's death in 1895 at the age of 51.

His urged Miescher to go into histochemistry, the study of the chemical composition of tissues, because in "my own histological investigations I was constantly reminded that the ultimate problems of tissue development would be solved on the basis of chemistry." Miescher took the advice, and after receiving his degree in 1868 he went to the University of Tübingen first to learn organic chemistry and then to work in the laboratory of the biochemist F. Hoppe-Seyler. (The first laboratory devoted entirely to biochemistry, it was located incongruously in an ancient castle overlooking the Neckar River. In later years Miescher liked to tell his students how the narrow, deep-set windows and the dark vault of his room reminded him of a medieval alchemist's laboratory.) Within a few months, in the course of experiments on cells in pus, he discovered DNA.

Pus may seem an unlikely material for a study of cell composition, but Miescher considered the white blood cells present in pus to be among the simplest of animal cells, and there was a fresh supply of pus every day in the Tübingen surgical clinic. He was given the bandages removed from postoperative wounds, and he washed the white cells from the bandages for experiments. If the bandages were washed with ordinary saline solution, the cells swelled to form a gelatinous mass. In a dilute sodium sulfate solution, on the other hand, the cells were preserved and sedimented rapidly, making it easy to separate them from the blood serum and other material in pus.

Miescher undertook a general study of the chemical composition of the white cells. First he extracted them in various ways—with salt solutions, acid, alkali and alcohol. Earlier workers, including Hoppe-Seyler, had extracted pus cells with concentrated salt solutions and had obtained a gelatinous material that reminded them of myosin, the protein of muscle. Miescher got the same result. What is of interest to us is that the gelatinous substance consists largely of DNA! This did not become known until 1942, when it was demonstrated that concentrated neutral salt solutions are an exceedingly useful medium for the extraction of polymerized (and therefore gelatinous) DNA. To extract DNA under these conditions, however, one needs a centrifuge. If Miescher had had a centrifuge, it is quite possible that he would have obtained DNA in its natural form instead of in the depolymerized form he eventually discovered.

Miescher's route to DNA was necessarily more indirect, as is frequently the case for the pathfinder. When he extracted pus cells with dilute alkali, he obtained a substance that precipitated on the addition of acid and redissolved when a trace of alkali was added. At this point Miescher noted: "According to recognized histochemical data I had to ascribe such material to the nuclei... and I therefore tried to isolate the nuclei." The isolation of the nucleus—or of any other cell organelle—had not been attempted before, as far as we know, although the nucleus had been identified in 1831. Miescher's primary observation, on which the isolation of nuclei depended, was that dilute hydrochloric acid dissolves most of the materials of a cell, leaving the nuclei behind. (This observation is the basis of what is still a valuable procedure for isolating nuclei.)

When Miescher examined the isolated nuclei under his microscope, he could still see contamination, which he suspected was cell protein. To obtain clean nuclei he therefore added the protein-digesting enzyme pepsin to the dilute hydrochloric acid he was using. More precisely (since this was in 1868), he made a hydrochloric acid extract of pig's stomach and applied it to pus cells. The isolated nuclei so prepared were somewhat shrunken but were clean enough for chemical study. The next step was to extract the isolated nuclei (rather than the whole cells) with dilute alkali. The extracted material precipitated on the addition of acid and redissolved readily in alkali. Miescher analyzed this material into its elements (finding, for example, 14 percent nitrogen and 2.5 percent phosphorus) and studied some of its other properties. He came to the conclusion that it did not fit into any known group of substances: it was a substance "*sui generis*" and he called it nuclein. The analytical data indicate that somewhat less than 30 percent of Miescher's first nuclein preparation consisted of DNA.

The year with Hoppe-Seyler was now ended. Hoppe-Seyler, who agreed that a new substance had been discovered, was sufficiently interested to repeat the preparation of nuclein after Miescher's departure, and sufficiently cautious to delay the publication of Miescher's paper until he had satisfied himself that the work was sound. The paper was published in 1871.

Miescher left Tübingen in the fall of 1869 to spend his vacation at home in Basel. He decided that during the two-month vacation he would broaden his study of nuclein by looking for it in various cells. The first material he chose was the hen's egg, because His had recently claimed that the microscopic particles called yolk platelets were genuine cells of connective-tissue origin. This was a controversial claim, and Miescher believed a biochemical approach—the search for nuclein in the platelets—would help to establish its validity. Following the procedure he had worked out for pus cells, he soon isolated from yolk platelets what he took to be nuclein. The phosphorus content and some other properties of platelet nuclein did differ somewhat from those of pus nuclein, but Miescher (like many another investigator!) was determined to find what he was looking for, and he was convinced that this was nuclein. In spite of the curious appearance of the platelets, he wrote, "nobody would any longer deny that they have genuine nuclei, because it is not in the optical properties but in the chemical nature of a structure that its role in the molecular events of a cell's life is rooted."

Miescher wrote up his new work and sent it off to Hoppe-Seyler; it was published along with the Tübingen research. The paper on pus cells remains a classic but the one on yolk platelets is forgotten. It was wrong. The microscopists, considering what Miescher called the "optical properties" of platelets, never did accept the idea that they were cells, and in time detailed chemical analysis showed (and Miescher had to agree) that what he had taken for platelet nuclein in fact had a very different composition. It is only recently that careful microscopic observation has demonstrated that yolk platelets are derived from the subcellular particles called mitochondria; they contain only a trace of DNA, whereas Miescher thought they contained a large amount of nuclein.

Having learned biochemistry at Tübingen, Miescher next spent a year at the University of Leipzig in Carl Lud-

CASTLE ON THE NECKAR RIVER in Germany was where nuclein, or deoxyribonucleic acid (DNA), was discovered. The castle housed F. Hoppe-Seyler's biochemical laboratory at the University of Tübingen, where Friedrich Miescher was a postdoctoral student.

wig's laboratory, a world center of physiology. Here he became convinced of the central role of the physical sciences in biology and in particular learned the importance of developing new instrumentation for research.

Miescher returned to Basel in 1870 and soon began the investigation on which he did his finest work: an analysis of the nuclein and other components of salmon spermatozoa. Wilhelm His introduced him to the salmon fishery then flourishing along the banks of the Rhine at Basel. The salmon, having swum all the way up from the North Sea to spawn, were sexually mature, so that huge quantities of ripe sperm were available. The nucleus is extremely large in any sperm cell, and among spermatozoa the salmon's is remarkable: its nucleus accounts for more than 90 percent of its mass. For a young investigator who had recently discovered nuclein in pus cells washed out of bandages, the sperm of the Rhine salmon must have seemed to present a God-given opportunity, and Miescher seized it. He was an intense and rapid worker. Within a year and a half he had completed most of his investigation—in spite of the fact that his laboratory was so crowded with medical students that he could only do his chemical analyses, an essential part of the job, at night and on Sundays. His classic paper on the sperm cell of the salmon was published in 1874.

FRIEDRICH MIESCHER, the discoverer of DNA, was born in 1844 and died in 1895. This portrait is the frontispiece of a collection of his letters and papers published posthumously.

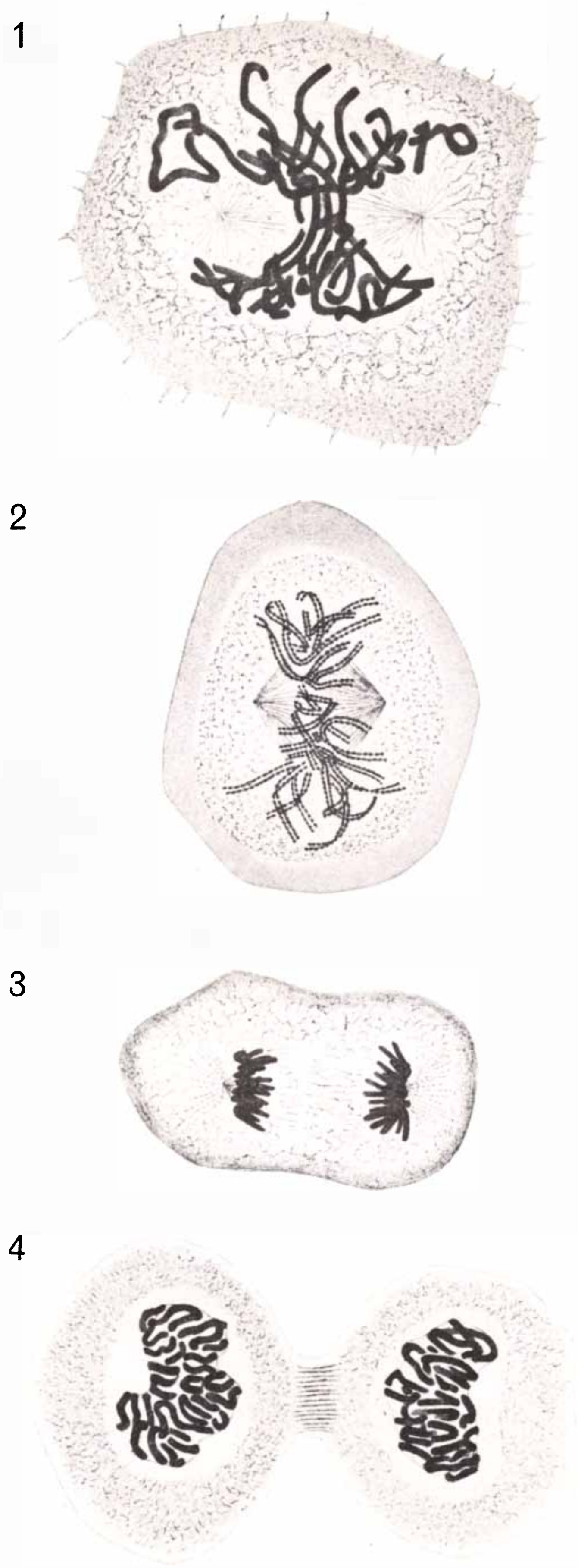
By acidifying a suspension of sperm cells, Miescher first caused the cells to aggregate and settle. Then he treated them with hydrochloric acid (omitting the pepsin he had used with pus cells) and extracted from the sperm an organic base with a high content of nitrogen. It accounted for 27 percent of the mass of the sperm, and he called it "protamine." Then he treated the residue of the sperm with dilute alkali. This extracted the nuclein, which accounted for 49 percent of the sperm's mass.

Miescher saw that nuclein was an acid containing a number of acid groups (a "polybasic" acid) and that it combined with protamine, a base, to form an insoluble salt in the nucleus. He experimented with modifying the chemical equilibrium of the nuclein-protamine combination, a problem that still interests biochemists today. He found, for example, that if sperm washed with acetic acid and alcohol were treated with a sodium chloride solution, much of the protamine was released from combination and passed into solution. If *fresh* sperm were treated with the same salt solution, however, the material became a lumpy gel that could almost be cut with a pair of scissors, as in the case of the pus cells treated with salt solution. The reason was that the DNA in the preparation was present as an extremely long linear polymer. Miescher, as I have mentioned, never did isolate DNA in its natural state and learn the importance of its fibrous structure. He did, however, get some idea that nuclein consisted of large molecules because he found that it would not pass through a parchment filter, whereas protamine would do so readily.

Although most of Miescher's work was done on salmon sperm, he also investigated the sperm of other species, notably the carp and the bull. He was disappointed not to find protamine in either, or even in unripe salmon sperm, and in a letter to His he referred to its presence in ripe salmon sperm as a "miserable special case." Ten years later, however, the biochemist Albrecht Kossel discovered histone, a base analogous to protamine, in the nucleus of red blood cells, and soon it was found also in the nucleus of lymphocytes, white cells from the thymus gland. Today it is known that either histones or protamines are present in saltlike combination with nuclein in the nuclei of all plant and animal cells.

Miescher's analyses of protamine and nuclein into their constituent elements were done with great care, and his results for nuclein are very close to those of later workers for what came to be called nucleic acid. (That term was introduced by the biochemist Richard Altmann in 1899. Altmann's method of preparation was different, but Miescher recognized that the substance was the same, and he did not object to the new name because he had been aware that nuclein was an acid.) To obtain good analytical results Miescher considered it essential to isolate his nuclein at low temperatures. He analyzed nuclein in the fall and winter, sometimes working from five in the morning until late at night in unheated rooms. (Later in his life, when he again took up his study of salmon sperm, he went back to spending long hours in the cold. His health, which had always been delicate, gave way and he died of a chest ailment.)

The process of elementary analysis was particularly important for Miescher because it was his main guide to the composition and identification of a substance. He could not know, for example, that protamine is a protein, and that it is basic and has a nitrogen content because it contains large amounts of the basic amino acid arginine. He knew that phosphoric acid was responsible for the acidity of sperm nuclein, and that nuclein was a substance *sui generis* quite distinct from proteins, but he did not know that nucleic acids had two kinds of subunit: purines and pyrimidines. The detailed chemistry of nucleic acids and the

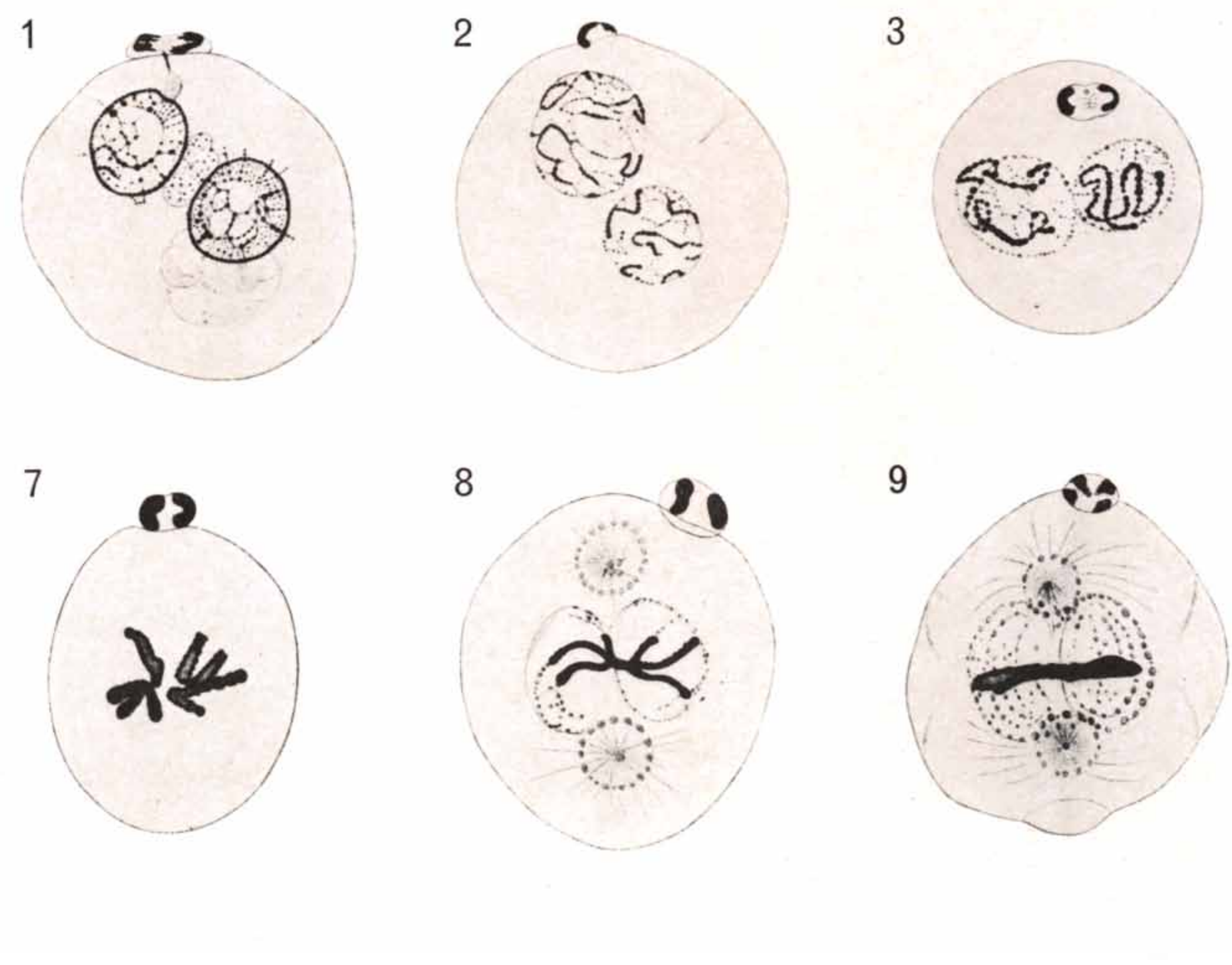


IN CELL DIVISION it is the chromosomes that provide continuity, as is shown in these drawings of salamander epithelial cells published in 1882 by Walther Flemming. In an early stage of cell division the chromosomes (which were known to contain nuclein) are ribbon-like and a "spindle" (two rayed structures) is beginning to form (*1*). The chromosomes seem to split (*2*); actually each has replicated lengthwise and the members of each resulting pair are separating. Each member goes to a different pole of the cell, so that two equal complements of chromosomes are established (*3*). Nuclear membranes surround each complement and the cell divides into two identical daughter cells (*4*).

proteins associated with them in the cell nucleus was worked out by later biochemists, beginning with Kossel in 1884. It took longer still, as we shall see, to understand the biological function of these substances.

Miescher's work on nuclein led him to a deep interest in the life of the Rhine salmon. In conducting what he called his "sperm campaign" almost every year he was witness to one of the most impressive events of animal life: the migration of the salmon 500 miles from the sea on their way to spawn in the headwaters of the Rhine. Between 1874 and 1880 Miescher devoted himself to the physiology of the salmon, examining more than 2,000 fish. He learned that the salmon spent eight to 10 months in fresh water, and that during this period, although they were extremely active, they did not feed; they did not, indeed, secrete any digestive juices. And yet during this time an extraordinary metabolic rearrangement occurred: a massive increase in the size of the sex organs. Miescher found that when female salmon left the sea, their ovaries accounted for .5 percent of their body weight; by the time the fish reached Basel the ovaries represented 26 percent of their weight. The growth, he discovered, was at the expense of the large "lateral trunk" muscle; the loss of protein and phosphate by this muscle was sufficient to account for the growth of the ovaries. From physiology Miescher moved on to ecology, making a number of suggestions for the conservation of the Rhine salmon.

In 1872, at the age of 28, Miescher had been appointed professor of physiology at Basel, succeeding His, who had moved to Leipzig. Miescher became a leading figure at the university. In time he built a new physiological institute (which he named the Vesalianum in honor of Andreas Vesalius, the 16th-century Belgian anatomist who had spent six months in Basel while his *De humani corporis fabrica* was being printed there), stocked it with new precision instruments as they became available and guided it in researches on such classical problems of physiology as respiration, the circulation and the effects of high altitude. From time to time he undertook public service projects. The canton of Basel asked his advice on the nutrition of inmates of prisons and other institutions, and he also gave a series of public lectures on nutrition and home economics. Living in a country that produced milk but did not consume much of it, he was aware of milk's nutritional value, and in one lecture he heaped scorn on the "sordid avarice" of peasants who

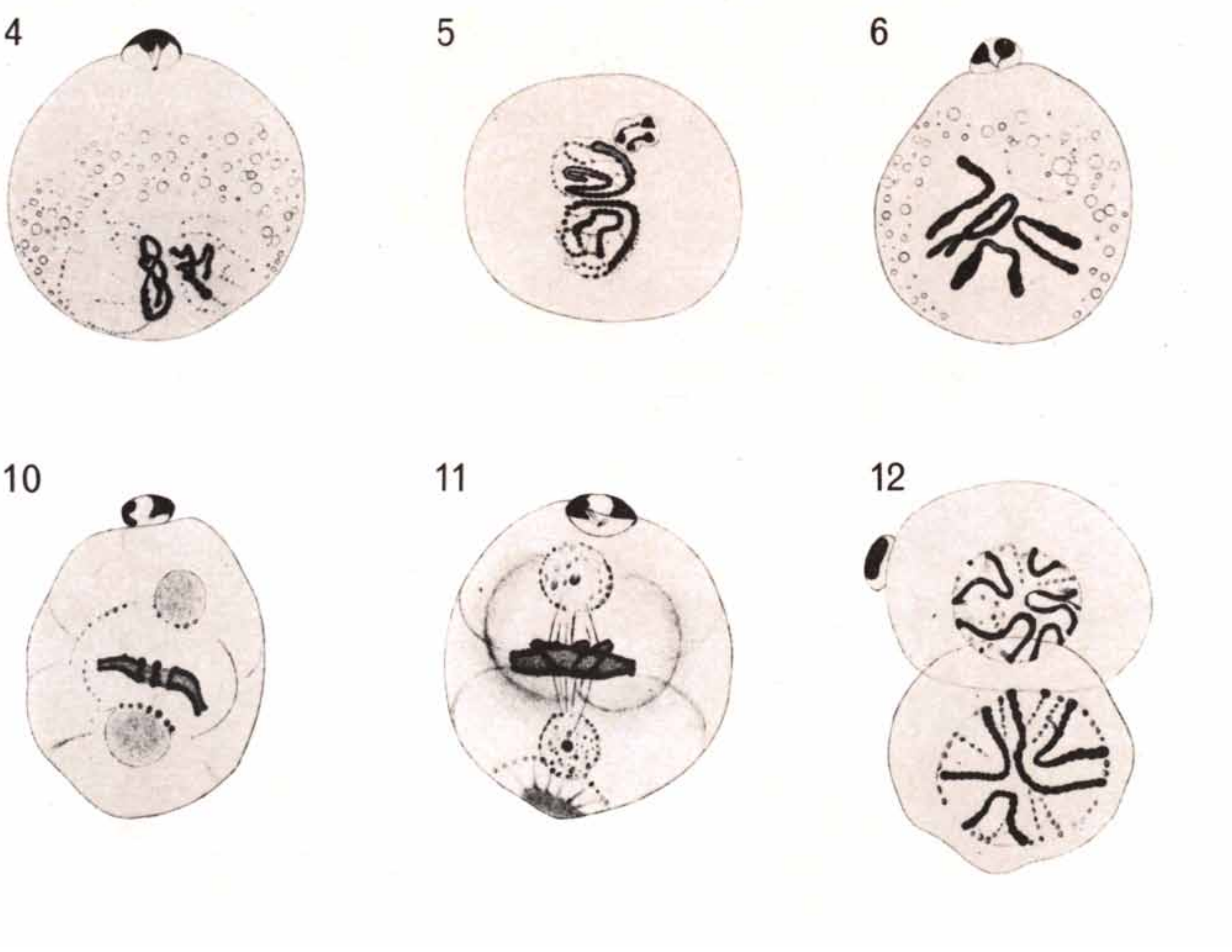


IN FERTILIZATION TOO chromosomes provide the continuity, as shown in drawings of the fertilized egg of *Ascaris*, a parasitic worm, published in 1883 by Edouard van Beneden. Sperm and egg nuclei approach each other (*1*). The nuclear membrane breaks down and the chromosomes become clearly visible; there are two chromosomes in each nucleus, half the normal "diploid" number in

withheld milk from their children in order to make "the last drop" into salable cheese. "If you ask these pale and feeble people what they eat," he said, "they reply: potatoes, coffee, more potatoes and schnapps to keep down hunger." Miescher's social concern led a colleague to comment that he would surely have been active in politics had he not been hard of hearing.

All his life Miescher's primary and absorbing interest was nuclein. From time to time he went back to investigating its chemistry; he was also preoccupied with the question of its biological function. During his work on the white cells of pus he had made no mention, either in his letters or in the paper published in 1871, of the possible function of the nucleus. This is hardly surprising, since at that time and for some years to come the role of the nucleus in the life of the cell was simply not understood. As late as 1882 the leading cell biologist Walther Flemming, describing the latest work on the nucleus, conceded that "concerning the biological significance of the nucleus we remain completely in the dark."

When Miescher came to the investigation of sperm, however, he began to ask questions about the role of nuclein in fertilization and about the nature of fertilization. Does the sperm contain certain special substances that are effective in fertilization? Willy Kühne, the Heidelberg biochemist who had just introduced the word "enzyme," suggested that there might be enzymes in sperm. Since salmon sperm seemed to be a clean and uncontaminated material, Miescher looked in it for enzymes, but he failed to find anything that appeared to be promising. Then he went on to say: "If one wants to assume that a single substance ... is the specific cause of fertilization, then one should undoubtedly first of all think of nuclein." Coming on this passage written in 1874, the reader holds his breath for a moment—but only for a moment, because Miescher turned away from the idea. He supposed, one must remember, that the egg contained a rich supply of nuclein in its yolk granules. And in his opinion there was no special characteristic that distinguished sperm nuclein from the great mass of egg nuclein. Indeed, he believed "the riddle of fertilization is not hidden in a particular substance"; the sperm is acting as a whole through the cooperation of all its parts, and if one considers the magnitude of the sperm's contribution to heredity, it must work in a most complex way. This line of thought led



an *Ascaris* cell (*2, 3, 4*). The four chromosomes come together (*5, 6*). Each of the chromosomes has previously doubled; the replicated pairs separate slightly (*7*). Two "centrioles" appear and a spindle forms between them, and cell division begins (*8, 9, 10, 11*). Two cells are finally formed, each with a nucleus containing four chromosomes, two derived from the sperm and two from egg (*12*).

Miescher to think of fertilization as a physical procedure in which a certain movement (*Bewegung*) of the sperm is transmitted to the egg. In casting about for the nature of the movement, Miescher pointed to the "molecular process" that occurs when a nerve stimulates a muscle as perhaps being analogous to the effect of the sperm on the egg.

When Miescher invoked physical motion to explain fertilization, it is clear that he was thinking of kinetic theory, which at that time was in its formative period. By 1892 another physicochemical approach to fertilization appealed to him and he wrote: "The key to sexuality lies for me in stereochemistry," that is, in the varying positions of the asymmetric carbon atoms in molecules. Miescher's desire to find explanations in physical science did not lead him to an understanding of the biological role of nuclein. At about the same time, however, another group of biologists—who were not interested in kinetic theory or stereochemistry—succeeded in laying some of the foundations of biology and at the same time recognizing the fundamental role of nuclein.

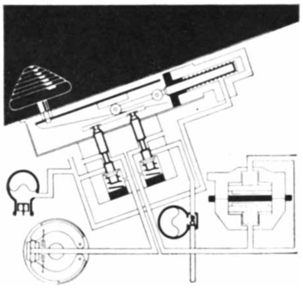
Miescher was nurtured in the great 19th-century school of "molecular biology." Both His and Carl Ludwig (in whose laboratory Miescher had spent a year) were leaders of the movement to analyze vital phenomena on the basis of physical science. Other outstanding figures in the movement were Claude Bernard and the neurophysiologists Emil du Bois-Reymond and Hermann von Helmholtz. The contributions of these men taken together constitute the foundation of modern physiology. Ludwig's work on kidney function, to take an example, is the basis of modern kidney physiology. In 1885 Michael Foster, professor of physiology at the University of Cambridge, spoke of "a new molecular physiology," maintaining that "the more these molecular problems of physiology ... are studied, the stronger becomes the conviction that the consideration of what we call 'structure' and 'composition' must, in harmony with the modern teachings of physics, be approached under the dominant conception of modes of motion.... The phenomena in question are the result not of properties of kinds of matter, in the vulgar sense of these words, but of kinds of motion." It was from this point of view that His considered fertilization to be a process in which the sperm communicates a mode of motion to the egg—a view that, as we have seen, Miescher accepted.

The biologists who at this time succeeded in discovering what actually happens in fertilization, and thereupon recognized the role of Miescher's nuclein, were (with several notable exceptions) not interested in physical science and in modes of motion. They were the founders of cell biology. The essential step taken by these biologists was the minute observation of what actually happens when a sperm fertilizes an egg. Although salmon sperm was an ideal material for Miescher's experiments on the chemistry of the sperm nucleus, it was of little value for observing the act of fertilization. For this purpose Oskar Hertwig of the University of Berlin and the Swiss biologist Hermann Fol chose the sea urchin and the starfish. In their classic experiments in the late 1870's they observed that the sperm cell penetrates the egg and that the sperm nucleus then fuses with the egg nucleus. At the same time these experiments were being done Flemming, in another series of observations, described the changes that occur in the nucleus during cell division [*see illustration on page 81*]. He was able to show that chromosomes provide the continuing elements from one generation of cells to the next and that they do so by replicating during cell division.

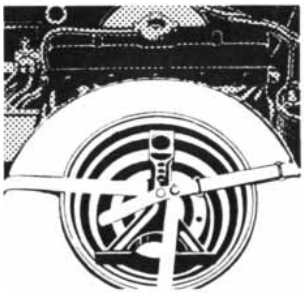
The observations on fertilization by Hertwig and Fol and those on cell division by Flemming were brought together by Edouard van Beneden of the University of Liège in a wonderful series of observations on fertilization in the threadworm *Ascaris,* a parasite of horses. *Ascaris,* unlike most other animals, has nuclei that break down before the egg and sperm nuclei fuse, so that its chromosomes can be seen with unusual clarity. Chromosome behavior can be followed readily because there are only two chromosomes in each nucleus. The male and female chromosomes, indistinguishable from each other, are brought together but do not fuse. Each chromosome replicates and soon there are two cells, formed in the way Flemming described for cell division. Van Beneden saw that in fertilization, as in cell division, continuity depends on chromosomes: the sperm's contribution to fertilization is a set of chromosomes homologous with those present in the egg [*see illustration on preceding two pages*]. (In the course of this work, which was published in 1883, van Beneden discovered meiosis, the halving of chromosome number that precedes the bringing together of egg and sperm chromosomes in fertilization.)

Two years earlier Miescher's nuclein

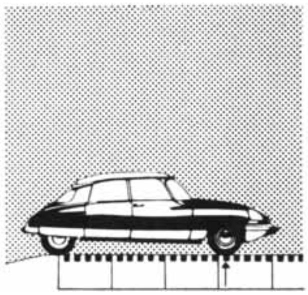
These are 12 important safety details. There are more than 50 of them in a Citroën. Some you may never see (or need). They all work together. This is Citroën's Total Safety Concept



This is a brake pressure distributor. It is part of Citroën's dual circuit braking system. All variations in loading automatically adjust the braking pressure between front and rear wheels. Rear wheel locking is eliminated.

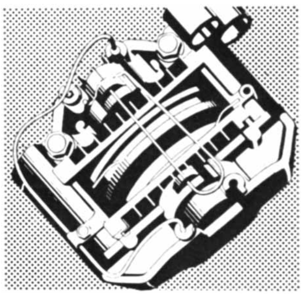


This is the spare wheel in a Citroën. It is stowed forward of the engine, under the hood. Together with the front section of the chassis and the bumper it acts as an additional shock-absorbing element in the event of a head-on collision.



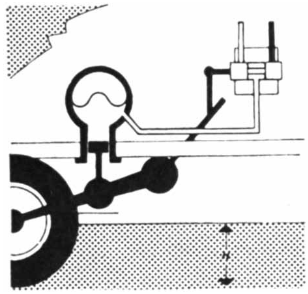
This is the Citroën wheelbase. 123" long. It is the world's longest wheelbase compared to overall length of the car (190"). It increases stability, gives a smoother ride. Road holding is improved, too, with less body overhang.

This is a suspension spring. A hydropneumatic spring in Citroën's exclusive suspension system. In each of 4 spheres, the interplay between a fluid and a gas provides superior roadholding and comfort over all road conditions.



This is a Citroën disc brake which is mounted inboard to the front wheels (where the load is greatest). Disc brakes are better cooled and do not fade. In 1955, Citroën was the first to fit disc brakes on production cars.

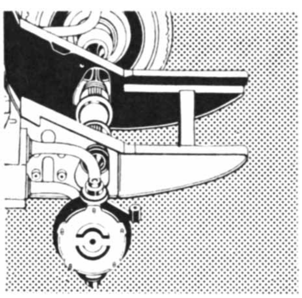
This is the Citroën shape. Another safety detail: it offers the lowest coefficient of air resistance of any production car for high speed stability and better fuel economy. The full length body underpan is even curved to reduce air "lift." In a Citroën safety is far more than a matter of detail. It is a matter of total concept in which comfort, safety and speed are constantly coordinated. That's why Citroën is one of the safest cars in the world, and one of the world's greatest road cars. A test drive will prove it.



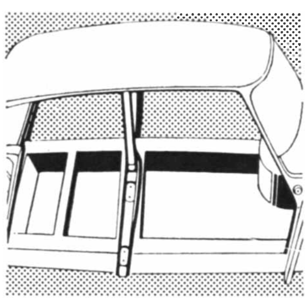
This is the Citroën automatic height corrector. It reacts to any variation of loading maintaining normal ground clearance regardless of weight distribution. Ground clearance can be adjusted manually from 6½" to 10" for driving over any terrain.

This wheel is exclusive with Citroën. Its steering axis meets the ground at the point of tire contact. Thus any unevenness of the ground, badly adjusted brakes or front tire blow-out have no effect on the steering control.

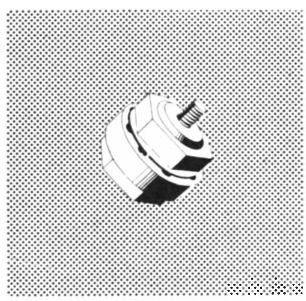
This is the Citroën "No Spoke" steering wheel. It is called the safety steering wheel. In the event of a head-on collision, it collapses, and the driver slides over the curved spoke. Injury is minimized. On Citroëns since 1955.



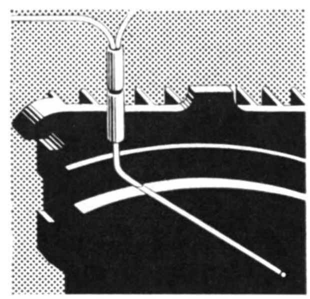
This is the Citroën front axle assembly. In a front wheel drive vehicle (pioneered by Citroën in 1934) the front wheels both drive and steer the car, thus increasing traction, cornering ability, and directional stability.



This is the Citroën chassis. The box platform design is based on aircraft construction principles. Rigid side members protect passengers from lateral impact. Energy absorbing front and rear sections minimize collision impact.



This is a shock absorber. It is the Citroën hydropneumatic suspension shock absorber fitted between the suspension sphere and cylinder. Shocks are absorbed by lamination of the fluid flowing through calibrated holes.



This is a Citroën brake lining pad fitted on the DS-21 which is moulded in the lining. It incorporates an electrical wire. When a certain degree of wear is reached, it activates a warning light on the dashboard. A Citroën exclusive.

Sales and Service throughout the U.S.A. Check the Yellow Pages. For National Dealer List and free brochures: "50 Safety Features," "Factory Direct European Delivery," write: Citroen Cars Corporation, East: 641 Lexington Ave., New York, N.Y. 10022. **West:** 8423 Wilshire Blvd., Beverly Hills, Calif. 90211 had been brought into the picture, not by Miescher but by an obscure young botanist named E. Zacharias. He showed that the characteristic material of chromosomes either was nuclein or was intimately associated with it. In his work on cell division Flemming had relied extensively on stains to make the nucleus and chromosomes readily visible. In the nucleus of cells that were not in the process of division there was a somewhat formless structure that took up certain stains; the same stains were taken up by the rod-shaped chromosomes as they emerged from the nucleus during mitosis. The material that took the stain was called chromatin, and Zacharias identified it as nuclein by following the same procedure that had led Miescher to the discovery of nuclein. He found that when a cell was digested with pepsin–hydrochloric acid its nucleus remained and retained its ability to be stained. If, however, the digested cell was extracted with dilute alkali (which, as Miescher had shown, removes nuclein), then no stainable material remained. Zacharias carried out these tests on an exceedingly wide range of cells, both plant and animal, with essentially uniform results. He tested cells in the process of division and found that chromatin could be stained after pepsin-digestion but not after extraction in alkali. Moreover, the spindle that forms during mitosis did not stain, and it was removed by pepsin–hydrochloric acid digestion. All of this pointed to the coupling of nuclein and chromatin. Zacharias' conclusions were quickly accepted by Flemming and many others.

In 1884 and 1885 four biologists published papers that summarized and interpreted the work of the preceding decade, which had been so crowded with discoveries that those who participated felt the swift movement of events in much the same way that biologists do nowadays. Of the four summarizing accounts, three were by zoologists (Hertwig, Albrecht Kölliker and August Weismann) and one by a botanist (Eduard Strasburger). It was clear that an understanding of fertilization was at the same time an understanding of heredity. Continuity from one generation of an organism to the next was accomplished by the chromosomes in the nuclei of egg and sperm; continuity from one cell generation to the next was also accomplished by chromosomes in mitosis. At this point (in 1884) we suddenly come very close to what is one of the cornerstones of current biology: "I believe that I have at least made it highly probable," Hertwig said, "that nuclein is the substance that is responsible not only for fertilization but also for the transmission of hereditary characteristics.... Furthermore, nuclein is in an organized state before, during and after fertilization, so that fertilization is at the same time both a morphological and a physicochemical event."

Even before Hertwig recognized nuclein as the genetic material, the botanist Julius von Sachs had (in 1882) not only suggested this role for nuclein but also gone a step further in pointing out that the nucleins of egg and sperm could hardly be identical—that the nuclein brought into the egg by the sperm must be different from the nuclein already there. And so by 1885, only a decade after Miescher's paper on salmon sperm and 14 years after his first publication on nuclein, a number of biologists had reached a point of view that is at the heart of our present conception of DNA.

What was the attitude of the discoverer of nuclein? As far as we can tell from Miescher's letters (and those to His freely express his views on many problems of biology), he did not accept the new ideas. He doubted the association of nuclein with chromatin, which was an essential element in the ideas expressed by Hertwig and the others. Miescher had a rather low estimate of the value of staining. He wrote in a letter of 1890, "Here once again I must defend my skin against the guild of dyers who suppose there is nothing else [in the sperm head] but chromatin," and in a paper published posthumously he referred disparagingly to Zacharias' work on chromatin. Miescher's attitude was also conditioned by his belief (expressed in several letters in 1892 and 1893) that he had discovered a new substance in the sperm head, which he proposed calling "karyogen." It was this phosphorus-free substance (the nature of which is a mystery today), and not nuclein, that in his opinion was responsible for the special chromatin stain.

In a letter of 1893 Miescher wrote: "The speculations of Weismann and others are afflicted with half-chemical concepts, which are partly unclear and partly derived from an outmoded kind of chemistry. When, as is quite possible, a protein molecule has 40 asymmetric carbon atoms so that there can be a billion isomers,...my [stereochemical] theory is better suited than any other to account for the unimaginable diversity required by our knowledge of heredity." Weismann's speculations were based on the most advanced biology of the time; Miescher preferred to base his specula-

There are only a few hundred people in this country working on gravity gradient stabilization. They're assaulting basic principles, analysis, hardware and total system requirements. But seldom all four.

Dr. Vladimir Chobotov has a rare assignment. He has to know who's doing what, where, why and when. He's a Staff Engineer at Aerospace.

The Aerospace Corporation performs systems engineering and provides technical direction for the U.S. Government on military space and missile programs. For information about technical positions, contact the Aerospace Corporation, an equal opportunity employer. Write to Stephen B. Robinson, P.O. Box 95085, Los Angeles, California 90045.

THE AEROSPACE CORPORATION

tions on recent advances in chemistry and paid relatively little attention to advances in biology. Time—and the rediscovery of Mendel's "units" of heredity and their identification with genes by Thomas Hunt Morgan—vindicated the idea, forcefully expressed by Weismann, that chromosomes transmit heredity.

Time did not, however, deal so consistently with the idea that nuclein is the material in chromosomes that transmits heredity. That idea appeared in the 1880's, as we have seen, and was widely held in the 1890's. As late as 1895 the American cytologist E. B. Wilson wrote: "Now, chromatin is known to be closely similar to, if not identical with, a substance known as nuclein.... And thus we reach the remarkable conclusion that inheritance may, perhaps, be effected by the physical transmission of a particular chemical compound from parent to offspring." In the next few years doubts arose concerning this conclusion because the amount of chromatin in the nucleus seemed too unstable to provide continuity; the amount varied considerably with the cycle of cell division and with changes in the physiological state of the cell. In the second edition of his book *The Cell in Development and Heredity,* published in 1900, Wilson described this fluctuation in staining but was able to explain it: "We may infer that the original chromosomes contain a high percentage of nucleinic acid; that their growth and loss of staining power is due to a combination with a large amount of albuminous substance...; that their final diminution in size and resumption of staining power is caused by a giving up of the albuminous constituent."

This analysis corresponds exactly with our present understanding, but it was soon to succumb to the apparent evidence of staining. When the large "lampbrush" chromosomes present in certain egg-cell precursors came under intensive study in the 1890's, there seemed to be no chromatin in them at all, and surely if chromatin (or nuclein) was the hereditary material, it must be present in an unbroken line from one cell generation to the next. In 1909 Strasburger wrote: "Chromatin cannot itself be the hereditary substance [because] the amount of it is subject to considerable variation in the nucleus, according to its stage of development." Strasburger was an eminent authority. So was Wilson, and the third edition of his book, which was published in 1925 and influenced a generation of biologists, took the Strasburger view: that the loss of staining in the enlarged chromosomes indicates "a progressive accumulation of protein components and a giving up, or even a complete loss, of nuclein." Wilson emphasized, using italics, "These facts afford conclusive proof that *the individuality and genetic continuity of chromosomes does not depend upon a persistence of chromatin.*" Biologists maintained this position for a generation.

Then, in 1948 and 1949, groups at the Rockefeller Institute and in France independently measured the quantity of DNA in cell nuclei. They found that the amount of DNA per set of chromosomes is in general constant in the different cell types of any organism, even when there are striking differences in the intensity of staining, and that the amount of protein associated with a fixed quantity of DNA may vary considerably and so account for variations in staining capacity. Moreover, the DNA content per chromosome set is a characteristic of each particular species. The doubts and questions concerning staining that had been raised by Miescher and many others were essentially resolved by these measurements. Now the biological role of DNA, proposed in 1884 and 1885 when the chromosome theory of heredity was formulated, received solid support: It was demonstrated that the chromosome complements of egg and sperm carry identical amounts of DNA, which are combined at fertilization and then carried by successive replications to all cells of the organism. The continuity of chromosomes at fertilization and cell division has always been an essential element in the chromosome theory of heredity; the associated continuity of DNA (Miescher's nuclein) points to it as providing the molecular basis for heredity in the chromosomes.

Several years before this point was finally established investigators at the Rockefeller Institute—following a line of investigation with a different historical background—found that hereditary traits could be transmitted from one strain of bacteria to another by the transfer of DNA. Nucleic acid was thus shown to be the genetic material. It should be pointed out that if this substance had been discovered in bacteria, it would never have been called nucleic acid, because a bacterial cell does not have a formed nucleus. The use of such words as "nucleic acid" and "chromosome" in work on bacteria is a constant reminder that the contributions of Friedrich Miescher and his contemporaries form the background for the study of heredity in all living cells.


Think of her as your mother.
She only wants what's best for you.
A cool drink. A good dinner. A soft pillow and a warm blanket.
This is not just maternal instinct. It's the result of the longest Stewardess training in the industry.
Training in service, not just a beauty course.
Service, after all, is what makes professional travellers prefer American.
And makes new travellers want to keep on flying with us.
So we see that every passenger gets the same professional treatment.
That's the American Way.
Fly the American Way
American Airlines

POLISHING

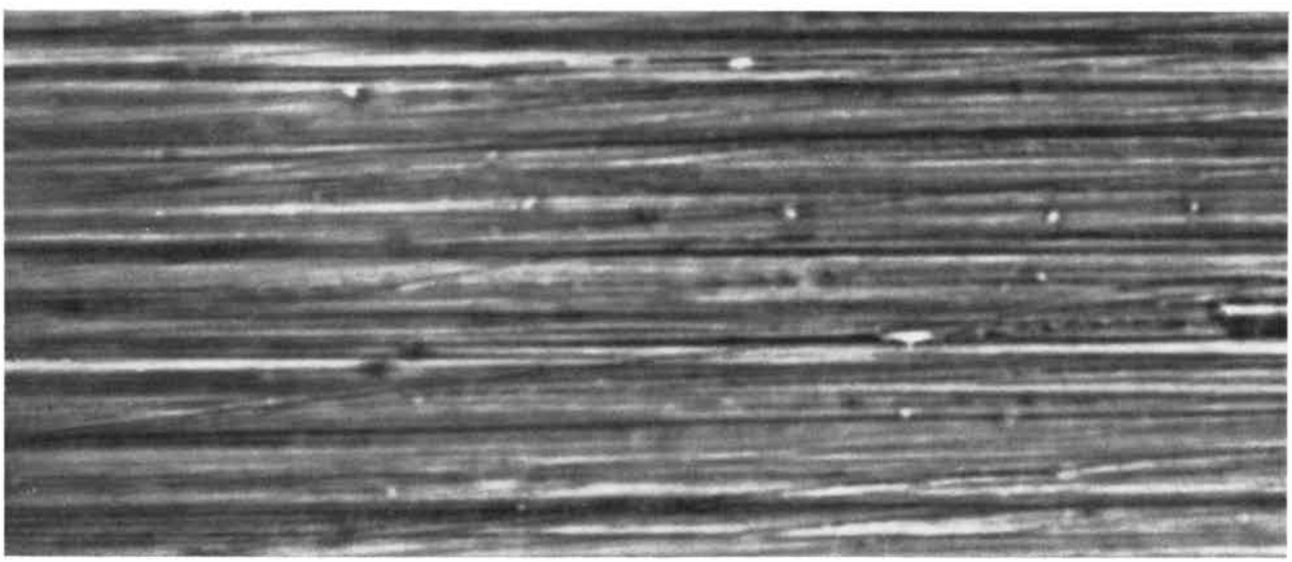
Is polishing simply fine-scale abrasion or is it more akin to melting? Recent findings suggest that neither of these two old rival hypotheses is entirely correct

by Ernest Rabinowicz

What happens to a surface when it is polished? *Webster's Third New International Dictionary* defines polishing as follows: "to make smooth and glossy by a mechanical process usu. by friction." In venturing to describe the process this definition attempts too much and falls into the error of saying too little. The fact is that a surface can be polished by nonmechanical processes having nothing to do with friction. Although the usual procedure for producing a smooth, lustrous finish seems simple enough, the basic events that occur in the smoothing of the surface are actually complex. The nature of the polishing process has been an unsettled question ever since Isaac Newton attempted to explain the physics of the process three centuries ago.

There are important reasons, of course, for wanting to understand exactly what is involved in refining surfaces to specified degrees of smoothness. In present technology new uses are being developed for polished surfaces. Traditionally the polishing art has been employed almost exclusively in the fields of optics and visual effects: the making of optical instruments such as mirrors, the preparation of specimens of metals and minerals for microscopic examination and the imparting of luster to a great variety of objects, from jewelry and automobiles to tombstones. Within recent years polishing has been applied increasingly to purposes that are not visual. For example, polished surfaces are used to provide precise control of mechanical instruments such as the gyroscope, in which the rotor is supported on a film of air between bearing surfaces that are smoothed to a high degree of regularity. The many potential applications of polishing in science and industry make it worthwhile to search for new techniques for producing precision-polished surfaces with maximum efficiency and at minimum cost.

The common methods of polishing an object (such as a telescope mirror) to a high finish generally involve rubbing the surface with a resilient polisher that is coated with very fine abrasive particles. In preparing a metal specimen metallurgists commonly employ a rotating wheel covered with a cloth in which the particles are embedded. A polishing operation of this kind of course resembles the lapping technique, in which the surface of a solid is ground down by rubbing with an abrasive such as sandpaper. In polishing, however, the action is re-



EVIDENCE FOR ABRASION HYPOTHESIS of polishing is contained in this phase-contrast micrograph of a polished silver crystal enlarged about 5,000 diameters. Under ordinary illumination at the same magnification the surface would look perfectly smooth and featureless. Under phase-contrast illumination, a technique that highlights very slight irregularities of the surface, a pattern of fine scratches is visible. The micrograph was made by Leonard E. Samuels of the Defence Standards Laboratories in Australia.

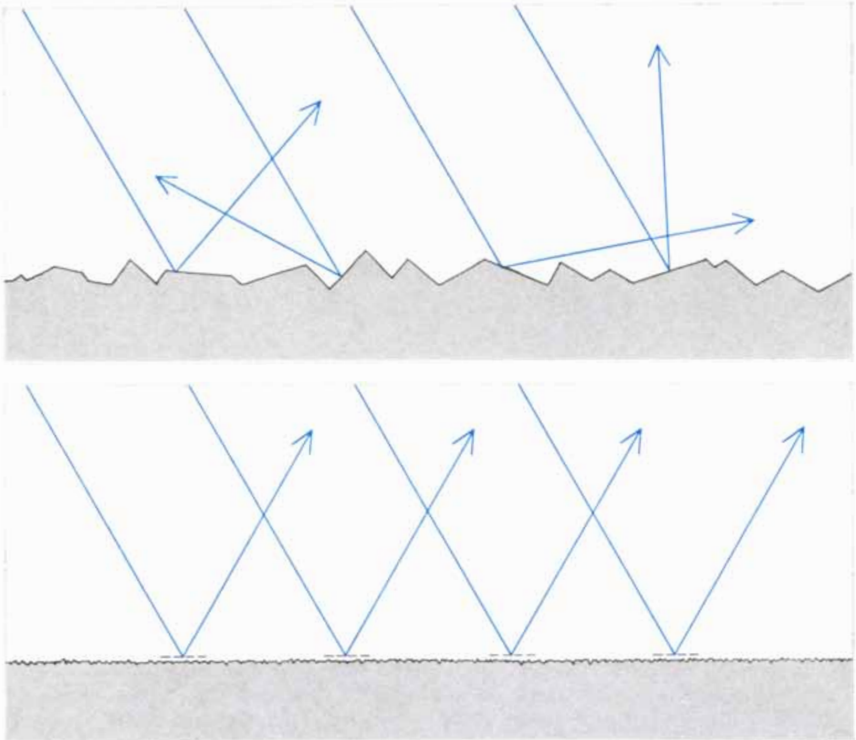
fined by using finer particles in a yielding carrier and introducing water or a lubricating oil at the interface to make the rubbing gentler. Nonetheless, it seems reasonable to suppose that polishing depends simply on fine-scale abrasion.

Newton, who produced the first reflecting telescope exactly 300 years ago (in 1668), developed considerable skill in polishing and proposed a hypothesis about the nature of the process in his famous treatise *Opticks:*

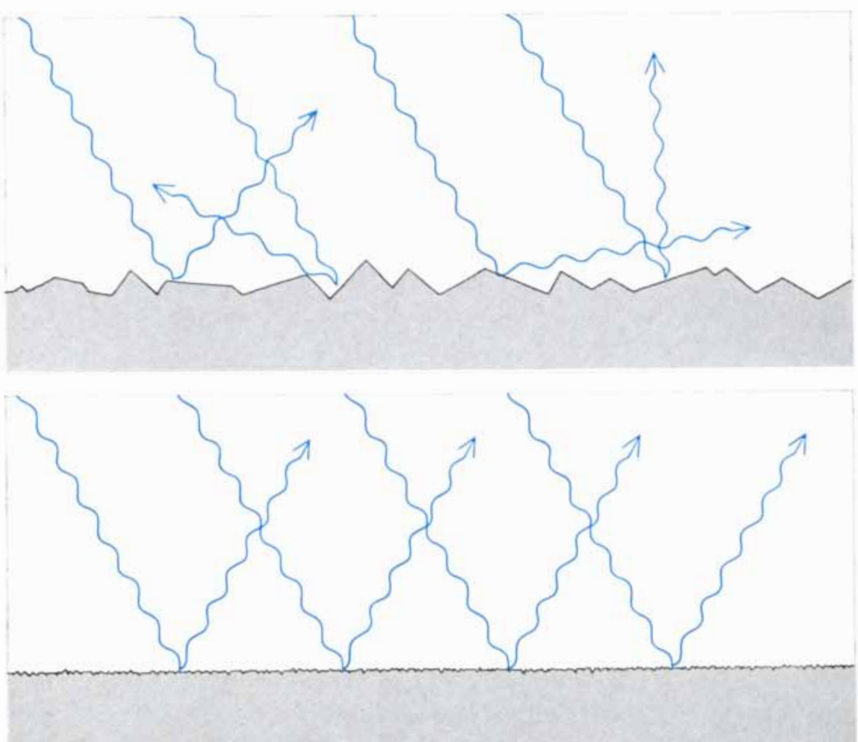
"In polishing glass with sand, putty or tripoli [a diatomaceous earth composed mainly of silica] it is not to be imagined that these substances can, by grating and fretting the glass, bring all its least particles to an accurate polish; so that all their surfaces shall be truly plain or truly spherical, and look all the same way, so together to compose one even surface. The smaller the particles of these substances are, the smaller will be the scratches by which they continually fret and wear away the glass till it be polished; but, be they never so small, they can wear away the glass no otherwise than by grating and scratching it, and breaking the protuberances; and therefore, polish it no otherwise, than by bringing its roughness to a very fine grain, so that the scratches and frettings of the surface become too small to be visible."

This hypothesis of Newton's was somewhat embarrassing to him, because it could be considered to conflict with his theory that light was composed of particles; if the corpuscular theory of light was correct, the particles of light should be reflected from a surface in the same way regardless of whether the protuberances they encountered were large or small. Newton tried to resolve the dilemma by suggesting that the reflection of a particle of light was determined not by the particular spot it hit but by the spot and its surroundings. The wave theory of light later eliminated the need for this tortured reasoning and came to the rescue of Newton's hypothesis of polishing by fine scratching. If the scratches are closer together than the wavelength of light, or are shallower than half the wavelength of light, then light will be reflected from the surface as if it were perfectly smooth.

Newton's description of polishing as fine-scale abrasion went unchallenged for two centuries, and the art was refined in practice by the use of better abrasives, such as diamond, aluminum oxide and magnesium oxide. Early in the 20th century, however, investigators began to



CORPUSCULAR THEORY OF LIGHT advocated by Isaac Newton conflicted with his view of polishing by fine scratching. According to the corpuscular theory, the particles of light should be reflected from the small protuberances in a finely abraded surface (*bottom*) in the same way that they are from the large protuberances in a coarsely abraded surface (*top*). To resolve this dilemma for a polished surface, which obviously reflects light uniformly, Newton suggested that the angle of reflection of a particle of light was determined not by the particular spot it hit but by the average slope of the surface over a finite distance.



WAVE THEORY OF LIGHT eliminated the need for Newton's corollary to his hypothesis of polishing by fine scratching. If the scratches are large (*top*), the light will be reflected from each protuberance individually, but if the scratches are closer together than the wavelength of the light, or if they are shallower than half the wavelength of light (*bottom*), then the light will be reflected from the finely abraded surface as if it were perfectly smooth.

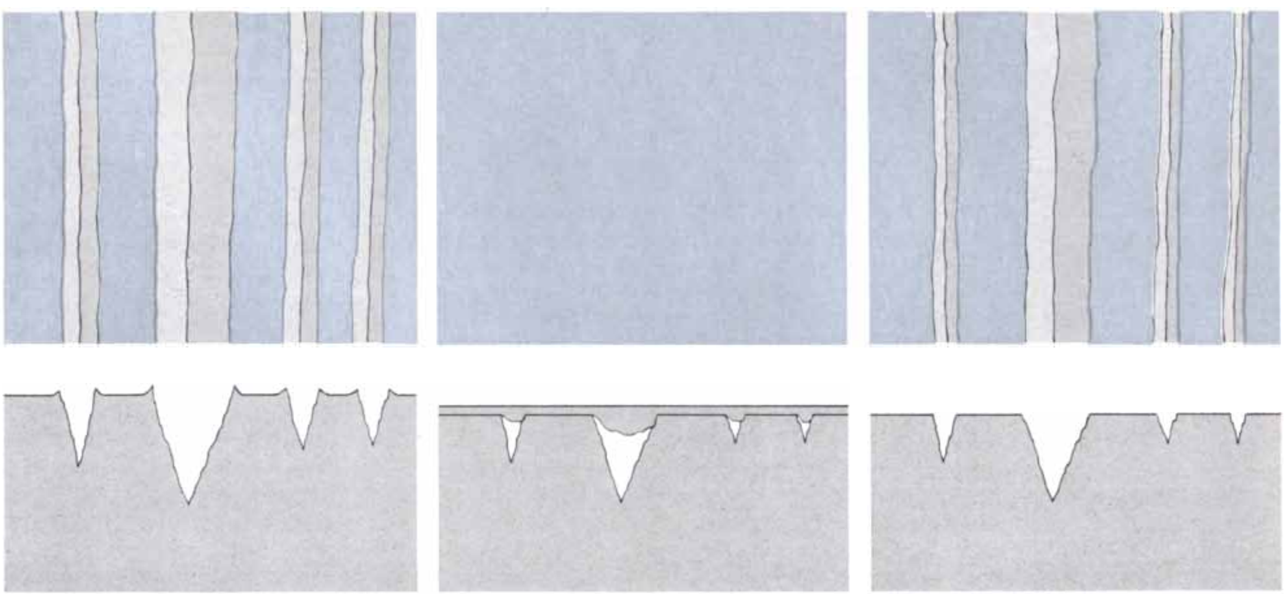
make a close study of polished surfaces with new instruments that for the first time made it possible to examine them in fine detail. In 1901 the British physicist Lord Rayleigh, using a compound microscope, found that a polished surface looked considerably different from one that had been ground down by a rigid lapping tool. He concluded that there was a substantial difference between the grinding and polishing operations. Whereas the force applied to a surface by a rigid grinder would abrade away comparatively large particles of material, the much weaker force applied by a polishing cloth, in which the abrasive grains are held in a soft, yielding medium, could be expected to remove particles on a much finer scale, perhaps almost on the scale of individual molecules.

Rayleigh's suggestions put a new complexion on the polishing phenomenon. If polishing did indeed smooth out a surface on the molecular scale, then the surface of a polished solid would be analogous to the surface of a liquid, which is smooth in the same sense. The liquid analogy was soon carried a step further by another investigator, the British chemist Sir George Beilby.

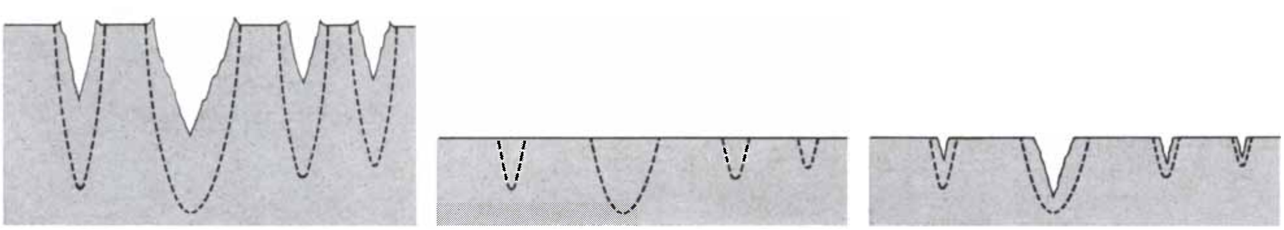
Beilby was studying the effects of a chemical etchant on polished surfaces. After polishing a surface quite smooth he would apply an etchant to dissolve away the topmost layer of the surface. He found, rather surprisingly, that scratches that had been present in the surface before the polishing now reappeared. Beilby took this to mean that the polishing operation had smeared material from high spots over the depressions and thus bridged them with a thin, smooth skin that covered the entire surface. The etchant, he suggested, dissolved this skin and thereby exposed the original scratches and depressions [*see upper illustration below*].

Beilby's findings argued strongly against the abrasion hypothesis of polishing, which supposes that the polishing operation rubs away features such as scratches (so that they should not reappear). The findings suggested a basically different hypothesis of polishing: that the rubbing produces a molecular fluidity akin to melting, with the result that the surface acquires a smooth coat. Investigations since then have focused on versions of the two rival hypotheses—abrasion and melting.

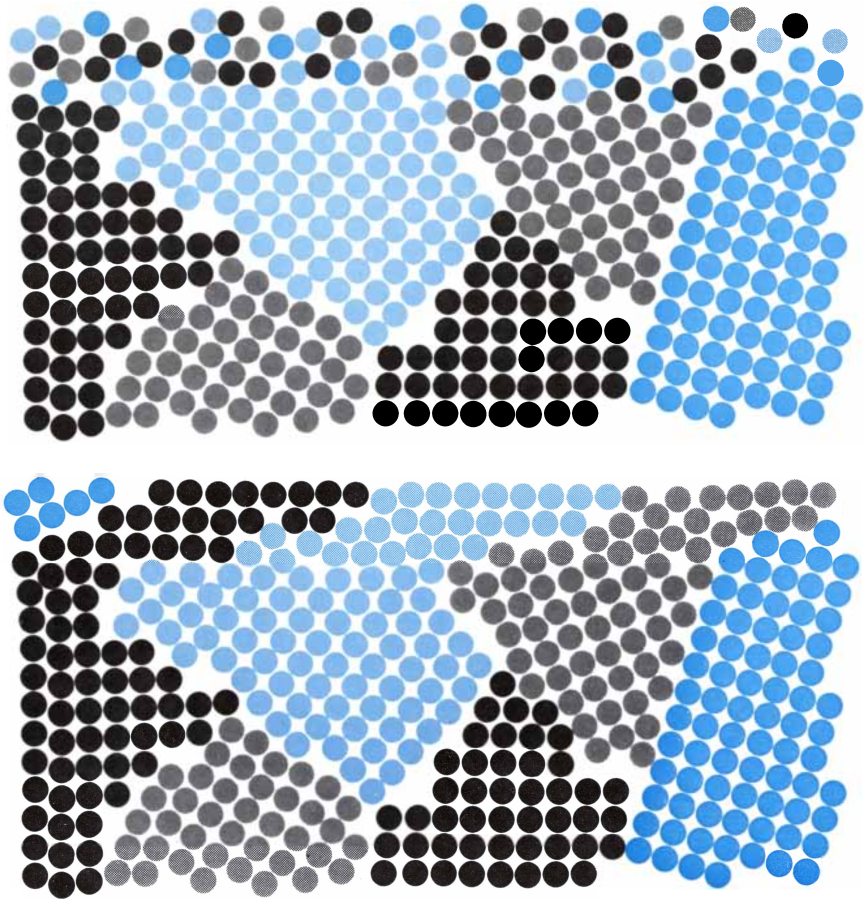
The first question requiring investigation was: Does a polished surface actually have a coat, or "Beilby layer"? This question could not be answered until the discovery of electron-diffraction effects. Examination of polished metal surfaces with this technique eventually showed that the surfaces were indeed capped with a thin film, about 50 angstrom units thick, that was structurally



EVIDENCE FOR MELTING HYPOTHESIS was put forward early in this century by the British chemist Sir George Beilby. Beginning with an abraded surface (*top left*), Beilby polished it quite smooth (*top center*) and then applied an etchant to dissolve away the topmost layer of the surface (*top right*). He found that scratches that had been present in the original surface now reappeared. He interpreted this to mean that the polishing operation had smeared material from high spots over the depressions and thus bridged them with a thin, smooth skin (called a Beilby layer), which was in turn dissolved away by the etchant, thereby exposing the original scratches. Cross-sectional views of the three stages of his experiment are below the corresponding plan views.



ALTERNATIVE EXPLANATION of Beilby's findings was proposed by Samuels in 1956. He observed that the metal under the grooves of the scratches appeared to be deformed (*left*). Polishing removed the scratches from visibility (*center*), but the application of an etchant redisclosed the location of the grooves (*right*), presumably by preferentially attacking the underlying distorted metal.



DIFFERENT INTERPRETATIONS of the nature of the Beilby layer, found to be a thin film about 50 angstrom units thick on the surface of a polished material, were put forward by advocates of the conflicting theories of polishing. Advocates of the melting theory argued that the film appeared to consist of an amorphous array of atoms like that in a quickly cooled liquid (*top*), whereas those in favor of the abrasion theory concluded that the film material was actually crystalline, although in a highly deformed state (*bottom*).

quite different from the underlying metal. This finding did not, however, settle the issue between the melting and abrasion theories. Advocates of the melting hypothesis argued that the film appeared to consist of an amorphous array of atoms like that in a liquid, which would suggest that the film had been molten and had cooled too rapidly to crystallize. Other investigators, however, concluded that the film material was actually crystalline, although in a highly deformed state, and that the deformation could have been produced by abrasion.

In the 1930's the chemist F. P. Bowden and his colleague T. P. Hughes at the University of Cambridge undertook a systematic investigation that apparently resolved the debate. They started with the premise that if the abrasion hypothesis was correct, a given polishing powder should be able to polish any solid softer than itself. Using powders such as the organic substances camphor and oxamide, they polished various fairly soft metals, including lead, tin and the alloy known as Wood's metal. Their experiments indicated that hardness was not in fact the criterion of polishing ability. For example, camphor proved to be capable of polishing Wood's metal but could not polish tin, a much softer metal. On the other hand, they did find a striking correlation between polishing ability and the melting point of the substance involved. Camphor has a higher melting point than Wood's metal and a lower melting point than tin, which correlated with the fact that it could polish Wood's metal but not tin. The same rule held for many other materials they tested.

Bowden and Hughes deduced from their tests that melting rather than abrasion was the mechanism responsible for the polishing of a surface. Their experiments were so comprehensive, and the deductions from the experiments so simple and apparently conclusive, that the basic question seemed to be answered, and for nearly 20 years there was little further research interest in the problem.

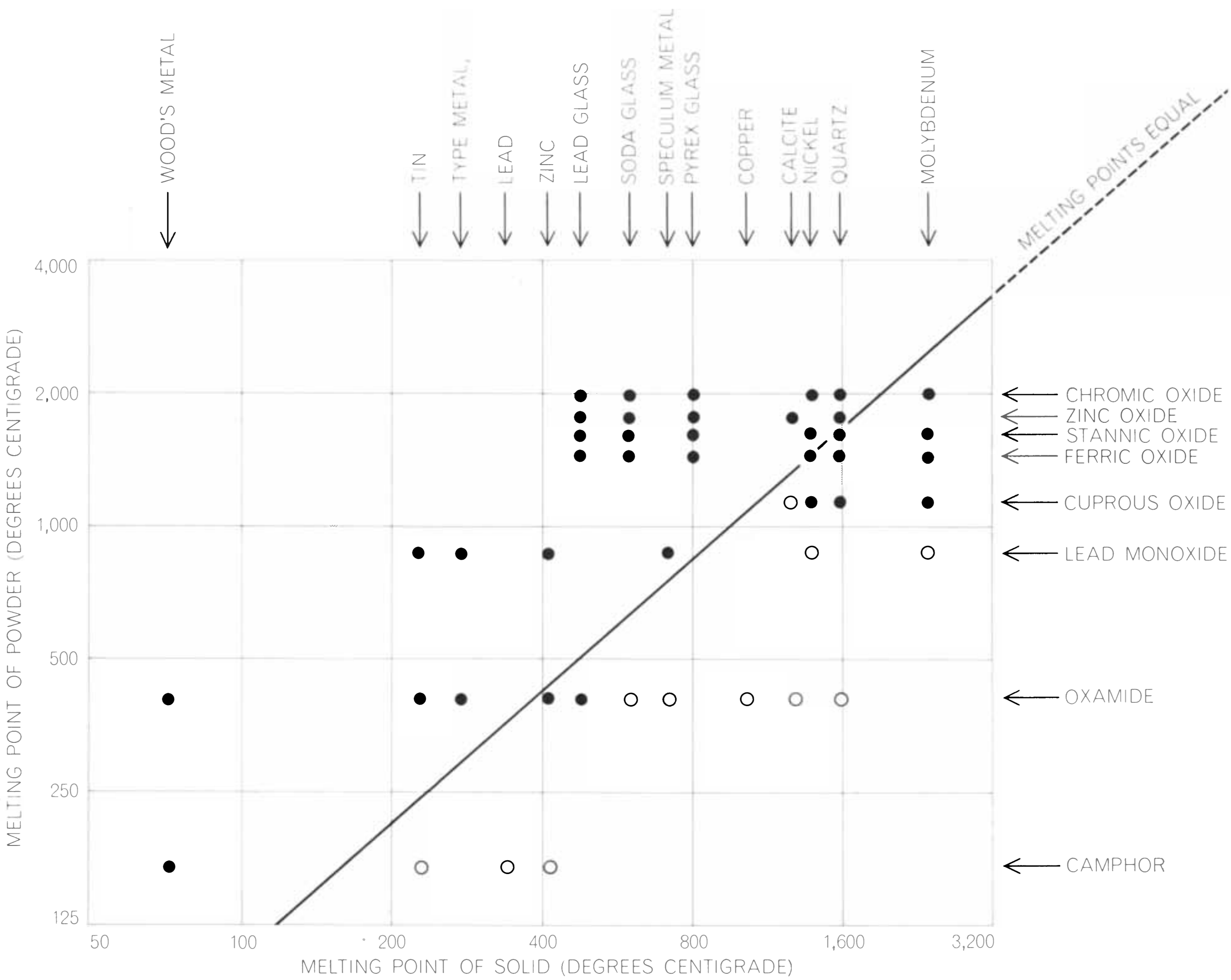
Actually a detailed analysis now shows that Bowden and Hughes's experimental results were not as conclusive as they seemed at the time. The correlation between melting temperature and polishing ability did not hold for materials with a high melting point. From this fact it can be surmised that their experiments did not rule out relative hardness, or abrasion, as the main factor in polishing. One can assume that their polishing operation raised the surface temperature of the materials by only a few hundred degrees centigrade. Such a rise would be sufficient to soften the low-melting metals, so that the metal would become softer than a polishing agent with a higher melting point. On the other hand, a metal with a high melting point would not be softened at the temperatures involved, and the decisive factor would be the relative hardness of the unsoftened metal and the polishing powder. In short, it can be supposed that in all cases a powder's polishing ability depends on the relative hardness of the materials at the temperature produced at the rubbed surface, which implies that the polishing mechanism is abrasion.

Recently the abrasion hypothesis was in fact revived by new studies conducted by Leonard E. Samuels of the Defence Standards Laboratories in Australia. Samuels obtained a sharper view of polished surfaces by using techniques such as phase-contrast illumination, which highlights very slight irregularities in a specimen. The phase-contrast method showed that even surfaces that looked perfectly smooth under ordinary light nevertheless had fine scratches, indicating that the polishing operation had abraded the surface. Moreover, Samuels' experiments brought to light a new explanation of the etching experiments by Beilby that had seemed to argue against the abrasion theory. Consider again Beilby's finding that underlying scratches reappeared after the film formed on the surface by polishing was etched away. One can suppose that the structure of the metal under the groove of a scratch is deformed. Now it is known that deformed metal is most susceptible to attack by an etchant. (Because of this property coin collectors commonly use an etchant to recover the worn-off date on a coin; the metal where the date was stamped is of course deformed.) Samuels observed by sectioning and etching the surfaces that the metal below the grooves of scratches was indeed deformed. Polishing removed these scratches from visibility, but the application of an etchant redisclosed the location of the grooves, presumably because the chemical preferentially attacked the underlying distorted metal [*see lower illustration on page 93*].

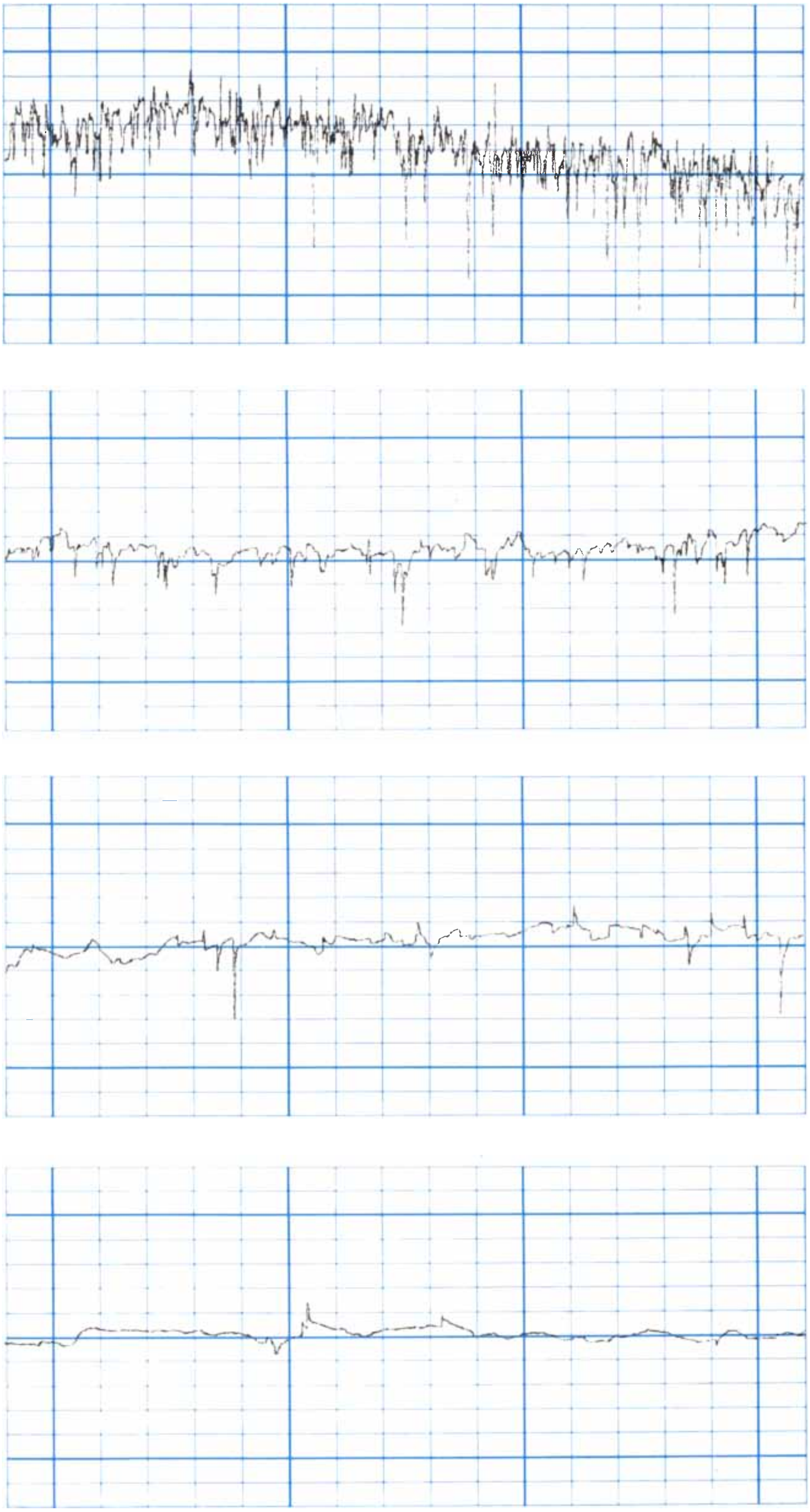
The evidence for the abrasion hypothesis, then, looked convincing, but there were more chapters to come. Several years ago we undertook a new approach to the problem in our laboratory at the Massachusetts Institute of Technology. We decided to explore the characteristics of polished surfaces in quantitative terms. Since microscopic measurement by optical methods is difficult and at best is limited in resolution to about 300 angstroms, we chose the profile meter as our measuring instrument. This device, a first cousin to the phonograph mechanism, moves a diamond needle across a surface in a straight line to trace a profile of its up-and-down undulations. A transducer translates the needle displacements into an electrical signal, which is amplified and fed into an electromagnetic recording instrument that writes the profile on a chart. The profile meter differs from a phonograph system in that the needle movements are vertical to the surface instead of tangential, the needle is much finer and the force pressing the needle to the surface is very small (only a tenth of a gram as against several grams in the case of a record player).

The profile meter can measure distances as small as 100 angstroms (a millionth of a centimeter), and it records the measurement in a readily readable form. Because the up-and-down undulations of a polished surface are very slight, if they were shown in scale with the horizontal distance the needle travels over the surface, they would be almost undetectable on the chart, just as a profile of the earth's surface on a relief globe would look almost perfectly smooth if the height of irregularities (such as mountains) were in true proportion to the transverse distance instead of being exaggerated. As is done on a relief globe of the earth, the profile meter magnifies the relative height or depth of the irregularities, such as scratches, in a surface.

Examining surfaces with the profile meter, we have found that the polishing process does not act on the surface in the way one would expect of abrasion. Instead of wearing down the original hills and valleys to leave smaller hills and valleys, polishing produces a featureless landscape, with a few minor undulations, that is quite different in shape from any abraded surface [*see illustrations on next page*]. Our measurements disclose another interesting fact. Weigh-



CORRELATION between polishing ability and the relative melting points of the polishing powder and the solid was apparently established by a series of experiments that were conducted in the 1930's by F. P. Bowden and T. P. Hughes at the University of Cambridge. In this chart the black dots signify that polishing occurs; the open circles signify that no polishing occurs. Bowden and Hughes deduced from their tests that melting, not abrasion, was the mechanism responsible for the polishing of a surface. A more recent analysis has shown that the correlation between melting temperature and polishing ability does not hold for materials with a high melting point (*top right*). Hence such experiments do not rule out relative hardness, or abrasion, as the main factor in polishing.



PROFILES OF A COPPER SURFACE at various stages in going from an abraded appearance (*top*) to a polished appearance (*bottom*) were made in the author's laboratory with a profile meter, a device that moves a tiny diamond needle across a surface and translates the up-and-down displacements of the needle electrically into a written profile on a chart. The horizontal magnification is about 50 times, the vertical magnification about 20,000 times. Tests with the profile meter show that instead of wearing down the original hills and valleys to form smaller hills and valleys, polishing produces a featureless landscape, with a few minor undulations, that is quite different in shape from any abraded surface.

ing a polished object before and after the polishing, we find that it loses weight by an amount that corresponds closely to our calculated estimate of the amount of material originally present above the level of the lowest valley in the surface. This indicates that the polishing process has smoothed the surface not by smearing material from the high spots into the valleys but by removing material from the surface.

Now comes a crucial question: Does the surface reach the melting point of the metal that is being polished? This is difficult to calculate, because there are too many hypothetical models, or sets of conditions, that we might postulate. All the models do suggest that copper, for example, is not heated to its melting point during polishing. We can also estimate confidently that Wood's metal does not melt when it is rubbed by a polishing wheel at low speed but will reach its melting point when rubbed at high speed. Looking into the situation experimentally by running the wheel at various speeds, we find that up to a certain critical speed the polisher removes material from the surface of Wood's metal at a rapid rate and produces a smooth finish; at speeds above that point the rate of material removal is less rapid and the surface is not polished smooth but becomes wavy [*see top illustration on opposite page*]. It seems reasonable to deduce that the critical speed transition represents the point at which the metal melts. Hence it follows that, at least in the case of Wood's metal, polishing is not promoted but is actually hindered by melting!

This brings us to a collapse of all the hypotheses and an apparent dead end. Polishing is not abrasion, it is not smearing and it is not based on melting. What, then, is it? Taking a different road to see if we can find useful clues, we have investigated the process known as burnishing, which is closely akin to polishing.

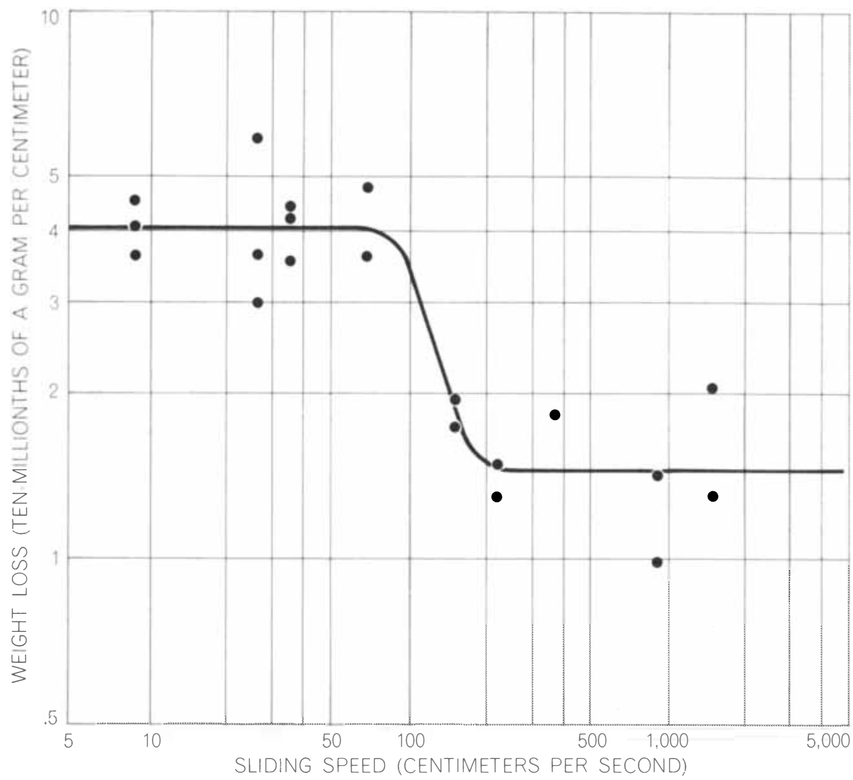
Burnishing is polishing without the use of abrasives; it is accomplished by rubbing the surface with another hard solid or with a cloth. Burnishing has been thought to involve melting of the surface. Both theoretically and experimentally, however, it can be shown that this is unlikely, because in many burnishing operations the temperature rise is very small. For example, an electric carving knife I use at home is developing burnished regions on the blades, yet it can be calculated that the temperature rise at the surface of the blade is no more than about 20 degrees C.

A characteristic feature of the burnishing operation is that it is carried out at low pressure, often against a resilient surface. To study the process in detail we set up a system that allows accurate measurement of the load, or pressure. The burnishing contrivance is a wire mesh of stainless steel placed on rubber sheeting for resilience. The metal specimen that is to be burnished is slid on this mesh. Since each knuckle of the mesh constitutes a contact point, we know the total number of points at which pressure is applied to the surface of the specimen.

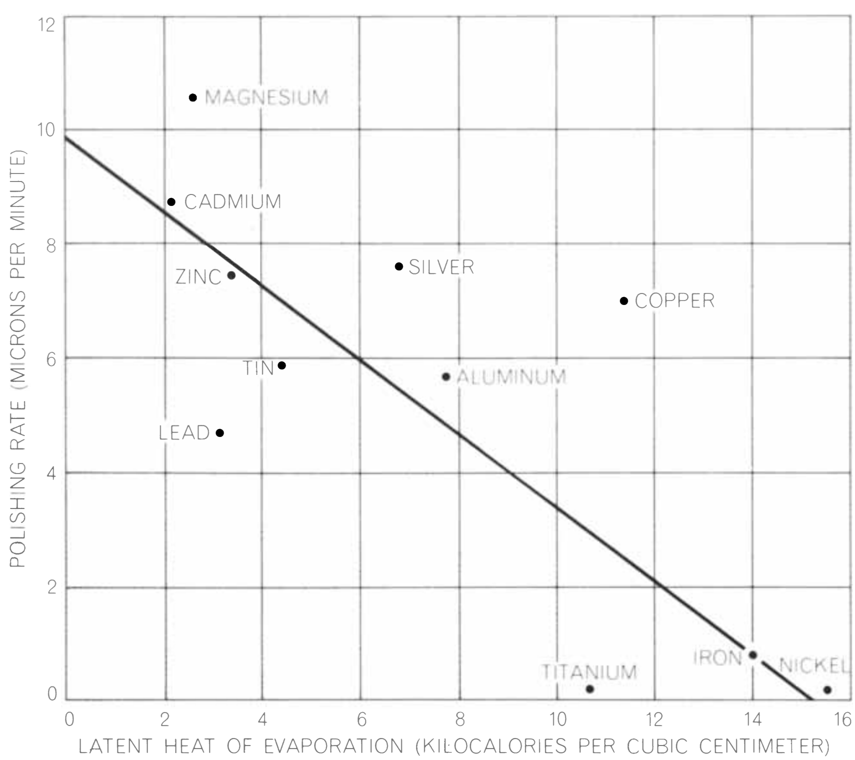
Testing a variety of metal specimens of different sizes on various meshes and at various loads, we found that a simple rule governed the burnishing effect. This rule applied to the size of the load. In all cases, if the load at each point of contact was less than about three hundredths of a gram, the surface of the specimen became well burnished, but when the pressure exceeded this value, the specimen surface was "galled," that is, made very rough.

What is the significance of the critical point (a load of around three hundredths of a gram) that divides burnishing from roughening? We have suggested an explanation that can be described in terms of a simplified analogy. Let us represent the contact points at the surface, where the mesh knuckles press on it, by elastic balls, and assume that the balls are embedded in a surface (such as hardened mud) from which they can be loosened. Suppose we press on the balls with a force that does not destroy their elasticity and then suddenly remove the force. The balls' elastic rebound to their original volume will tend to loosen them. We shall find, however, that the result depends on the size of the balls. At a given pressure all balls larger than a certain size will come loose but those smaller than that size will not. The reason the small balls are not loosened is that, because of their comparatively high ratio of surface area to volume, the energy of adhesion (which depends on surface area) in their case is greater than the elastic energy (which depends on volume).

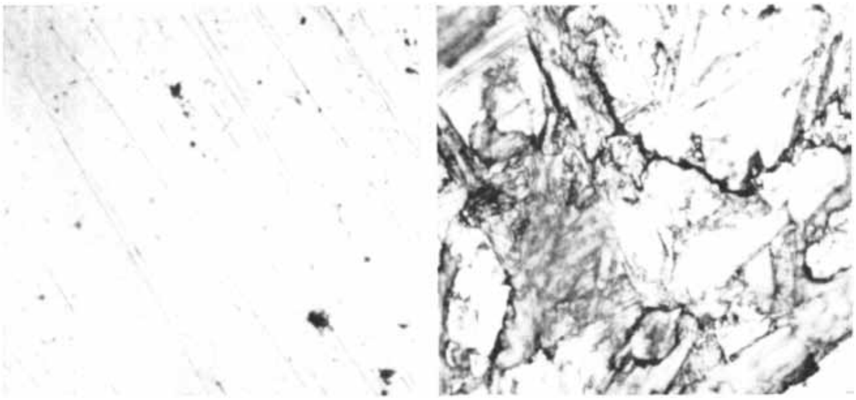
With reference to burnishing, the point of this analogy is that the lighter the load, the smaller the region of the surface that is elastically deformed. If a particle were formed at that spot, it too would have to be a small one. We have just seen, however, that small particles are stable against removal. It follows that an extremely light load will not remove substantial fragments of material. In all probability such a load will only strip off individual molecules (which ei-



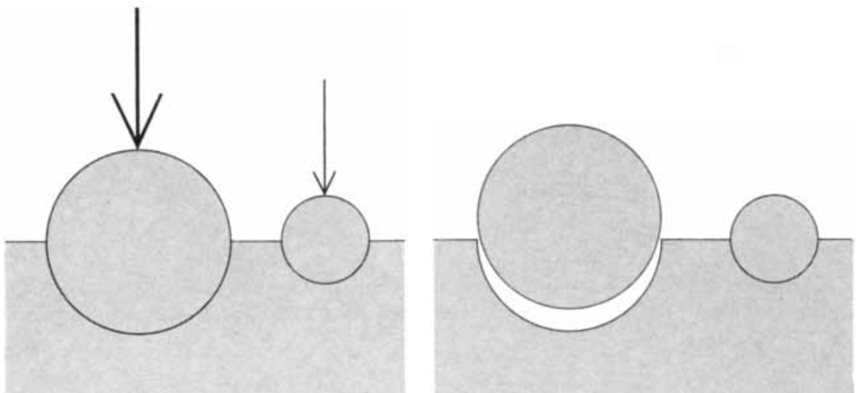
MELTING CAN HINDER POLISHING, as is indicated by this curve, which relates the rate at which material is removed from the surface of a sample of Wood's metal to the sliding speed of the polishing wheel. The critical speed transition presumably represents point at which the metal melts. Wood's metal is an alloy of bismuth, lead, tin and cadmium.



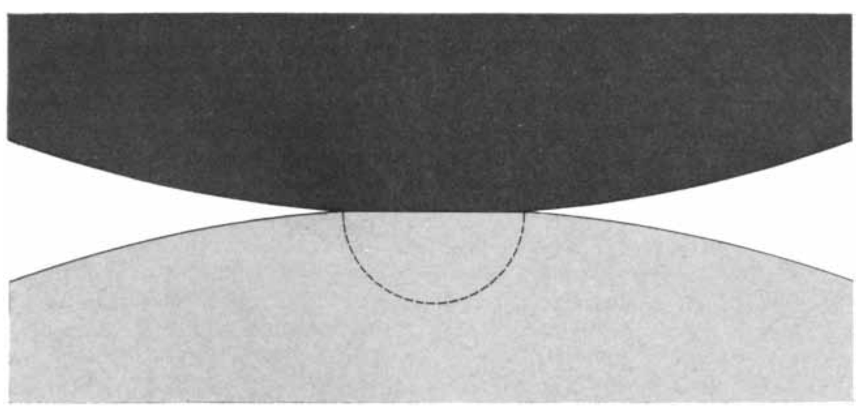
MOLECULE-BY-MOLECULE REMOVAL of material from a polished surface is strongly suggested by the good correlation that has been found between strong molecular bonding and a low polishing rate. In this chart the total strength of the molecular bonds is indicated for a variety of metals in terms of the latent heat of evaporation from their surfaces.



RESULTS OF BURNISHING EXPERIMENT show that when the load at each point of contact with a stainless-steel mesh was less than about three hundredths of a gram, the surface of a palladium specimen became well burnished (*left*), but when the pressure exceeded this value, the surface of the specimen was made very rough (*right*). In both cases the total load was 20 grams; the load-per-contact was changed by changing the mesh.



EXPLANATION OF BURNISHING EXPERIMENT relies on a simple analogy in which the contact points at the surface, where the mesh knuckles press on it, are represented by elastic balls embedded in a surface from which they can be loosened. First the balls are subjected to a force that does not destroy their elasticity (*left*) and then the force is suddenly removed (*right*). The balls' elastic rebound tends to loosen the large balls more readily than the small ones, because the small balls have a comparatively higher ratio of surface area to volume and hence an energy of adhesion greater than their elastic energy.



ELASTICALLY DEFORMED REGION below the point of contact of two sliding surfaces takes the form of a hemisphere that is analogous to the embedded balls in the analogy described above; the lighter the load, the smaller the hemisphere. It follows from the analogy that a very light load will not remove substantial fragments of material from the surface, whereas a heavy load will. Hence burnishing, using a subcritical load that rips molecules off the high spots, produces a surface that is smooth on a molecular scale.

ther stick to the burnishing tool or are discharged into the air). Consequently we can conclude that burnishing, using a subcritical load that rips molecules off the high spots, produces a surface that is smooth on the molecular scale.

Can we extrapolate now and suppose that the polishing process is essentially the same as that of burnishing? We have examined this hypothesis with polishing experiments designed to test the concept of a critical load. The standard surface in these experiments is the end face of a copper cylinder an inch in diameter. We polish this surface with a cloth that is wetted with mineral oil and contains very fine diamond grains as the abrasive. When we use a cloth of medium resilience and grains six microns in diameter, and rub the surface under a total load of two kilograms at a speed of 100 centimeters per second, we produce a surface that is on the borderline between abraded and polished, being rather shiny but showing many fine scratches under the microscope. If we change to a softer cloth or to finer diamond particles (say three microns in diameter) or to a lighter load (say half a kilogram), we get a much finer finish. Changing the sliding speed (up to a factor of two) does not affect the result.

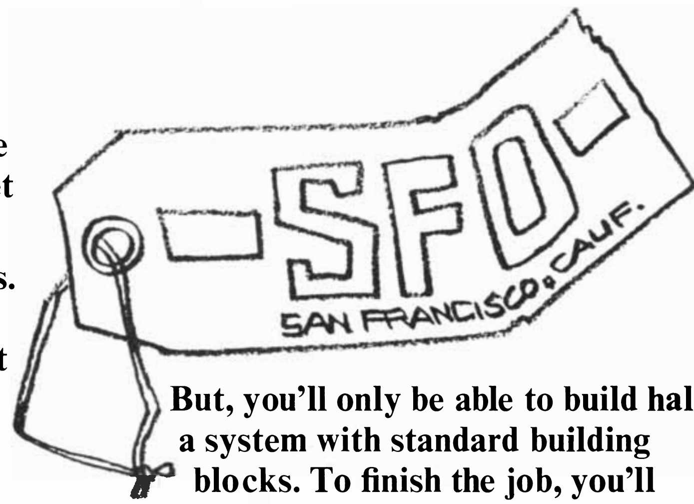
Our experiments show quite clearly why polishing is usually preferable to burnishing and is much more commonly used. Polishing permits the application of a considerably heavier load and hence is much faster. When we burnish our standard copper specimen, even with a very fine mesh, the maximum total load we can apply without galling the surface is 30 grams. On the other hand, our soft polishing cloth, when covered with diamond grains one micron in diameter, allows operation at a load of five kilograms without scratching. The number of grains (or contact points) in the cloth is so large that the load per contact point is considerably smaller than in the case of the burnishing mesh. We can polish the standard copper specimen within minutes, whereas burnishing it to an equivalent finish takes hours.

All our experimental results are consistent with the concept that polishing, like burnishing, is governed by a critical load and that below the critical load the process entails the removal of material molecule by molecule. The hypothesis is also strongly supported by basic physical evidence of a rather direct kind. If the hypothesis of molecule-by-molecule removal is correct, we should expect that the speed of polishing a metal will depend on the strength of the chemical bonds binding the molecules together: the weaker these bonds, the faster the metal can be polished. The total strength of the bonds between molecules can be measured in terms of the latent heat of evaporation from the surface. A plot of this measure against the polishing rate for various metals shows that there is indeed a good correlation between strong bonding and a low polishing rate [*see bottom illustration on page* 97]. Incidentally, there is an interesting parallel between the physical events in polishing and those in the evaporation of a liquid. When the evaporation rate is low, so that the vapor comes out molecule by molecule, the surface of the liquid remains smooth; on the other hand, the surface becomes very rough when a high input of heat (corresponding to the application of a supercritical load in polishing) causes the material to be removed in the large packages of vapor represented by bubbles.

Finally, the nonmechanical methods of polishing also tend to confirm the molecular concept of mechanical polishing. The best-known of these other methods is electrolytic polishing: the surface to be polished is immersed in an electrolytic solution, and protuberances on the surface are dissolved away as a current is passed through the solution. A surface polished in this way looks exactly like one polished mechanically (although it has no Beilby layer), and this is quite understandable if we accept the view that the mechanical operation, like the electrolytic one, is essentially molecular removal.

I should like to conclude by mentioning a particularly interesting new technique for polishing very hard materials. It entails a combination of chemical and mechanical action. For example, the extremely hard substance boron carbide can be polished rapidly with alumina as the abrasive on a wheel that is rotated at very high speed. The high temperature generated by the friction causes the boron carbide to be oxidized by the air so that its surface is converted to the softer compound boric oxide, and the alumina polishes this down to a smooth surface. (Diamond grains cannot be used as the abrasive in this case, because the diamond as well as the carbide would be oxidized.) It appears likely that the chemical-mechanical approach will be developed to solve many polishing problems that are now too difficult or that call for faster methods than have been available in the past.

Do you want to go LSI now?



If you really want LSI now, grab the next plane to Mountain View. (It lands in San Francisco.) It's the quickest, least expensive way to get LSI into your system.

Plan to bring along your blueprints. And be ready to answer a lot of questions. We'll need to know what you have in mind for sub-systems, functions and specs. And, don't be surprised when we ask "why" a couple of times. It's all part of Fairchild's systems approach to complex circuitry.

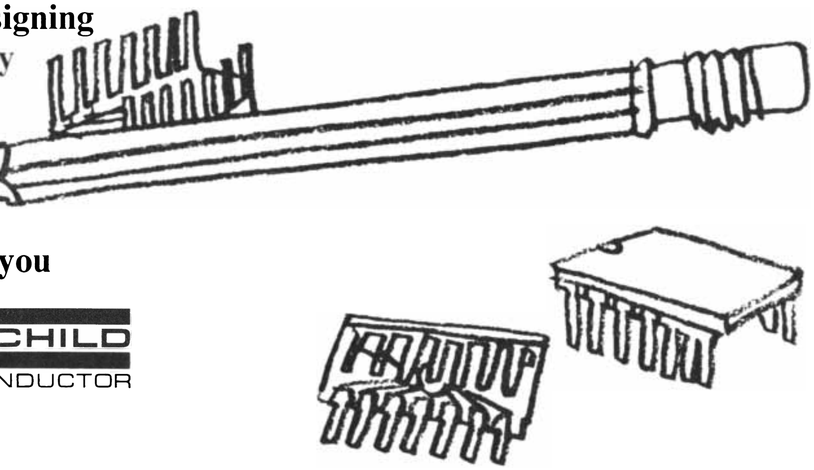
We'll take your requirements and match them against our family of fundamental building blocks. We've got LSIs (and MSIs) that work in any digital logic system. The most advanced circuitry on the market. Offspring of computer-aided design and double-layer metal technology. And, they're all so versatile, we can probably give you a counter that has a dozen other applications in your system.

But, you'll only be able to build half a system with standard building blocks. To finish the job, you'll need interface devices to tie the whole thing together. And, here's where Fairchild can really save you time and money. We don't have to custom design each LSI interface circuit. We use Micromatrix™–a unique cellular array that's completed when we add your specific interconnection pattern. Your specs customize the entire array for your system.

Of course, there's a lot more to the story. But, you ought to hear it in person. Just call your Fairchild salesman. He knows the flight schedule to San Francisco.

Or do you want to think about it?

We've got an LSI design kit. It's based on our new 4500 Bipolar Micromatrix Array—the first device in a highly versatile LSI family. The 4500 is an eight-cell array that can be customized for virtually any function. All it needs is your interconnection pattern. You can determine the pattern by designing your own Micromatrix array with our kit. You can buy a kit from your Fairchild distributor for about $100. And, in a couple of months, we'll see you in Mountain View.



FAIRCHILD
SEMICONDUCTOR

FAIRCHILD SEMICONDUCTOR A Division of Fairchild Camera and Instrument Corporation 313 Fairchild Drive, Mountain View, California 94040, (415) 962-5011 TWX: 910-379-6435

PLANTS WITHOUT CELLULOSE

It was once believed that cellulose was the structural material in the cell walls of all green plants. Now it appears that other substances are employed for this purpose in certain marine algae

by R. D. Preston

Until quite recently the statement that all green plants contain cellulose seemed about as correct as the statement that all vertebrates contain bone. Cellulose is the structural constituent of the walls of the cells of green plants; it is a basically fibrous substance that gives the cell walls form and rigidity. Wood is about 40 percent cellulose. Cotton, linen and the fibrous products made from wood pulp—paper, rayon and so on—consist of little else.

It has therefore been startling to discover that there are two groups of green plants in which the cell walls are based not on cellulose but on two quite different substances. In one of these substances the molecular subunits are linked together in a way that is different from the linkages in cellulose; hence the molecules pack together differently in the fibrils, the structural units of the cell wall. In the other substance the linkages are the same as those in cellulose but the substance seems to form fibrils only occasionally.

The first indication that green plants lacking cellulose might exist came some time ago, when it proved impossible to demonstrate the presence of cellulose in certain plants. These demonstrations relied, however, on staining methods, which are notoriously unreliable. Consequently the cell walls of the anomalous plants did not attract much attention. Then about five years ago, by one of those coincidences that come about in science presumably because the atmosphere is right, several laboratories in different parts of the world independently began to study these odd plants. One of the laboratories was our own at the University of Leeds. Using approaches that were not available to the earlier workers, we have shown that such plants do indeed lack cellulose, and we have gone on to explore their molecular architecture.

The problem of how the cell wall of plants is built is an important one even apart from the fact that such essential materials as wood, cotton and paper are virtually cell walls in their natural state. The problem is important because the cell wall forms a rigid or semirigid envelope around each living unit in all plants. A plant can grow only at such a rate and in such a way as its constituent cells will allow; their growth is in turn restricted by the physical properties of their walls, and these properties of course depend on the walls' detailed molecular structure. Accordingly the shape of a plant and the rate at which it reaches its final form can in principle be traced back to the structure of the cell wall.

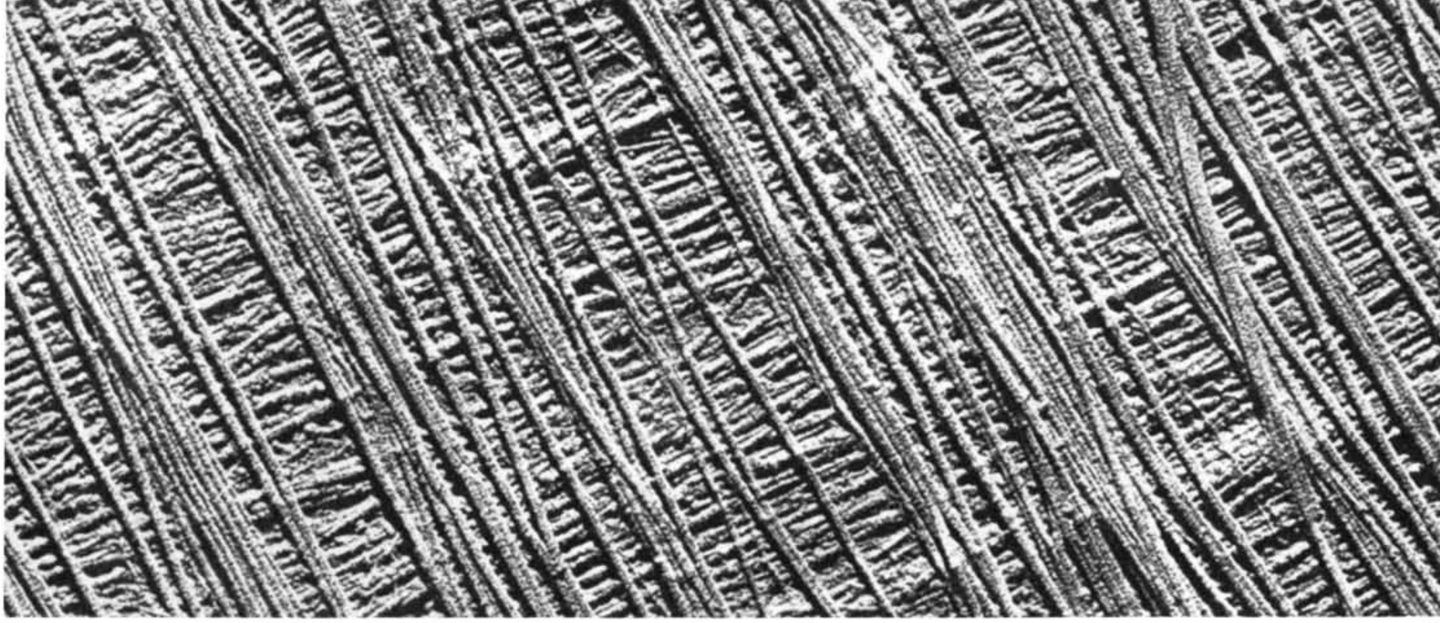
All the plants that lack cellulose are algae, and most of them are inhabitants of the warmer seas. They are interesting in their own right. Some of them, in spite of the fact that their cellular construction is comparatively simple, have achieved spectacular forms not surpassed by higher plants [*see illustration on page 104*]. One of them, *Acetabularia,* is widely used as a model cell in studies of the relation between the nucleus and the surrounding cytoplasm.

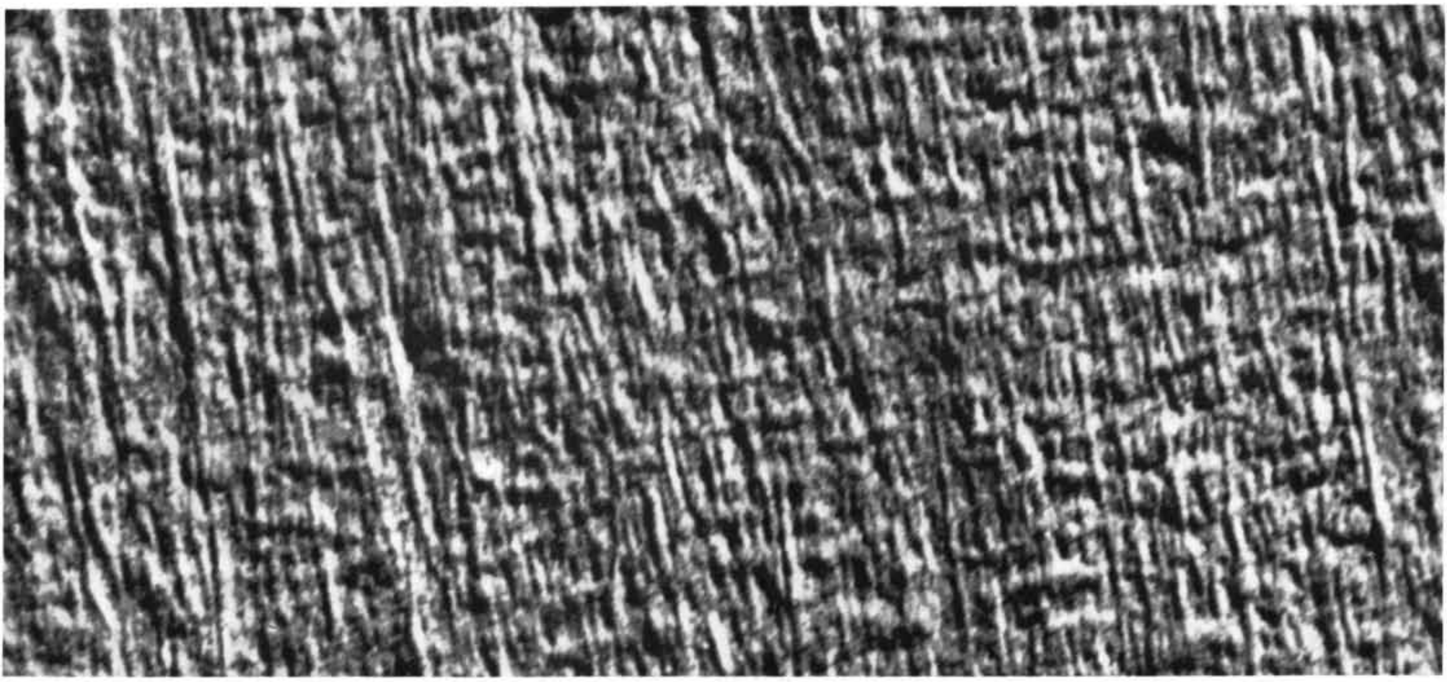
As a group these seaweeds have considerably broadened our understanding of the structure of plant cell walls. Since their cell walls are different from those of all other green plants, they broaden the range of possible structures affecting plant growth, offering a basis against which we can assess knowledge obtained from cellulosic plants and thus define the factors involved in plant growth more sharply.

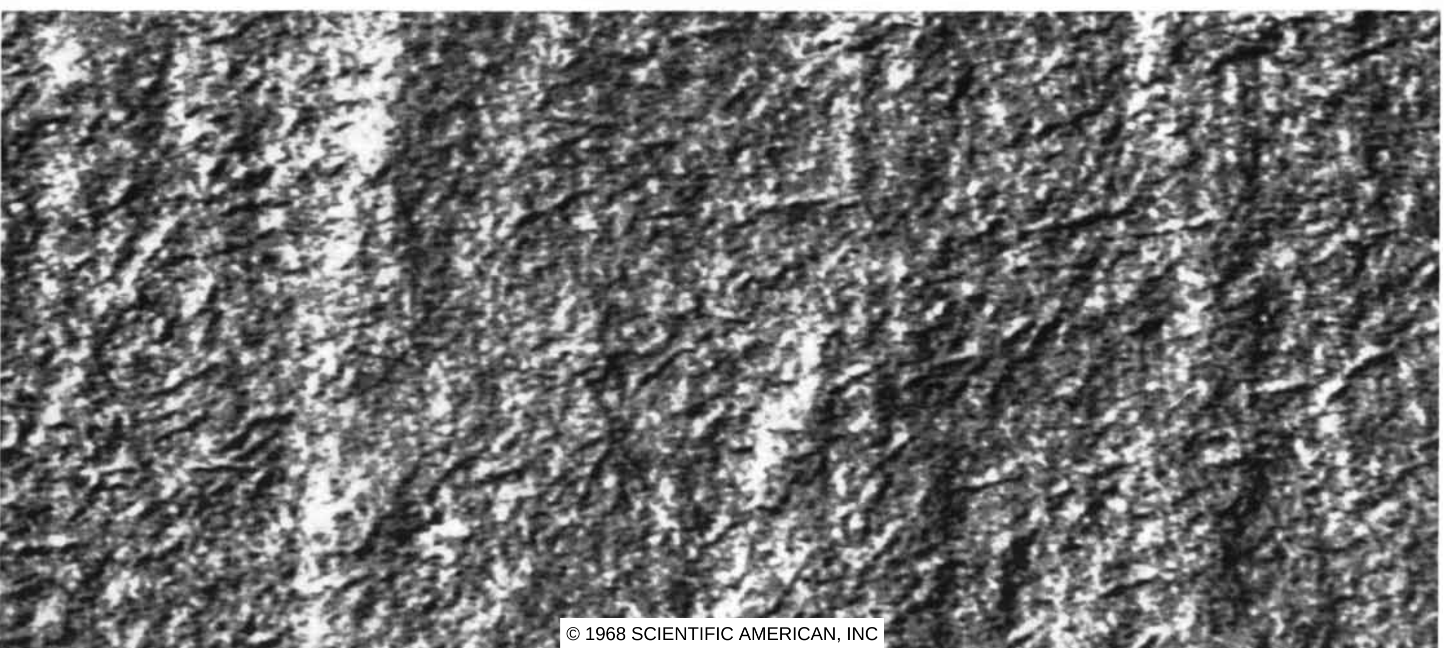
To understand how differently the walls of the noncellulosic plants are constructed, let us first consider the cell walls that contain cellulose. It is convenient, if somewhat oversimplified, to regard the cell wall as having two components. One of these components consists of partially crystalline microfibrils, that is, thin threads partly made up of long-chain molecules packed together in a regular parallel array. The microfibrils are between 100 and 200 angstrom units wide, about half as thick and so long as to be virtually endless. They are embedded in the second component of the cell wall, a less crystalline cementing matrix. The regular parallel arrays within the microfibrils are cellulose; the cementing matrix consists of substances that, like cellulose, are polysaccharides but are made up of different subunits.

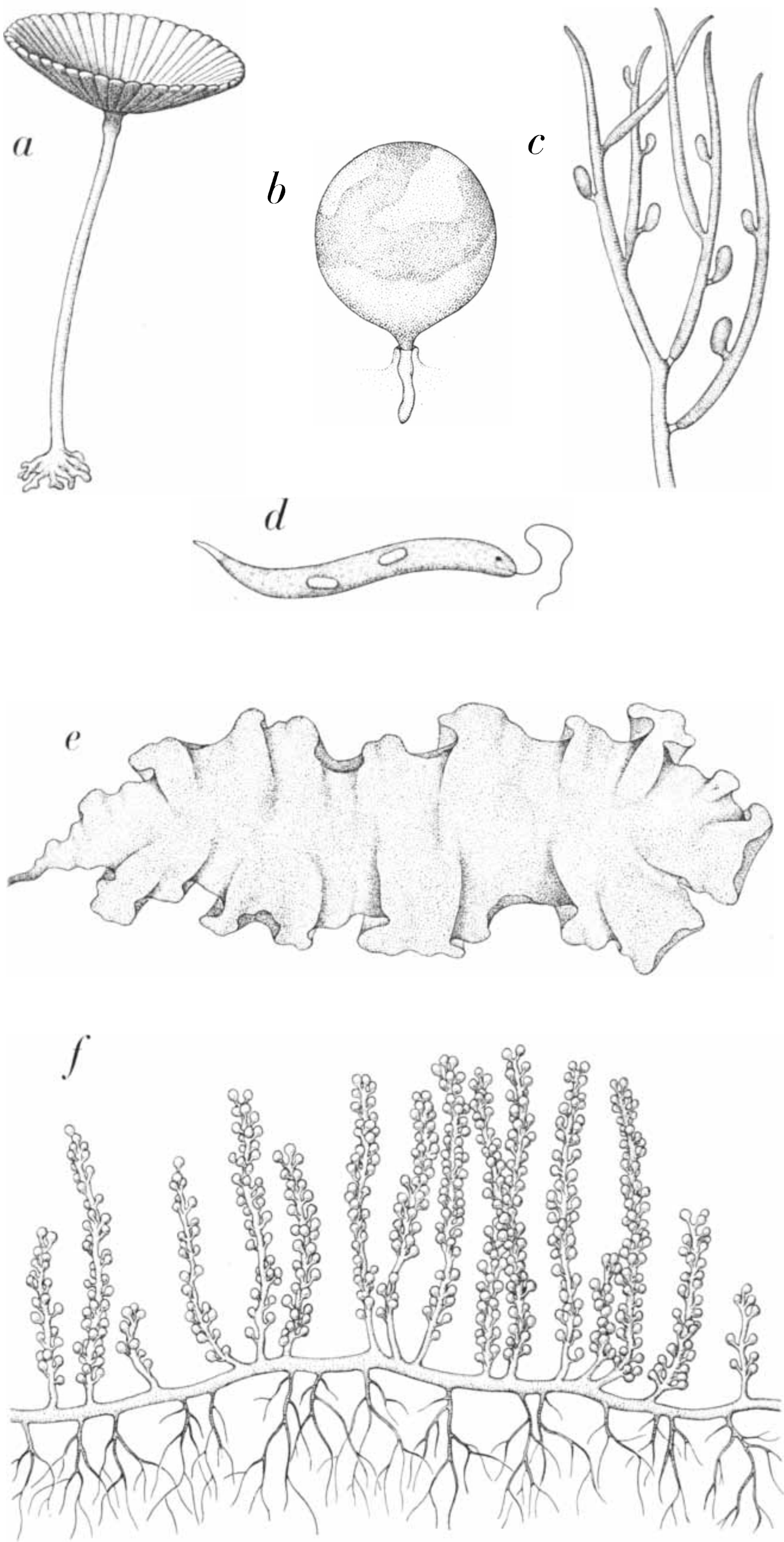
The subunits of cellulose are the simple ring-shaped structures of the sugar glucose. The ring includes five carbon atoms, each of which is identified by number [*see illustration on page 105*]. When one glucose molecule is linked to another, the carbon atom designated 1 is joined through an oxygen atom to carbon atom 4 of the other molecule. At either end of the dimer thus formed another glucose molecule can be attached in the

DIVERGENT STRUCTURE of the cell wall of plants is revealed in electron micrographs on opposite page. At top the tiny threads, or microfibrils, of the marine alga *Chaetomorpha melagonium* show distinctly. The microfibrils are composed of cellulose, as are those of all known higher plants. In the middle is a comparably magnified sample of the green alga *Penicillus dumetosus.* Short crossbars appear to connect the vertically running microfibrils. Although in other respects the fibrils resemble those in the micrograph at top, they are not made of cellulose. At bottom is the cell wall of the alga *Batophora,* which also lacks cellulose. No microfibrils are visible; instead the wall appears to consist mainly of granules. Magnification of the micrographs (from top to bottom) is 65,000, 75,000 and 100,000 diameters.









EXCEPTIONAL MARINE PLANTS differ from other green plants in cell structure. The single-celled *Acetabularia* (*a*) has its nucleus in the "stem," making it a useful model in cell studies. *Halicystis* (*b*) and *Derbesia* (*c*) are two generations of the same plant. The divergent feature in the structure of *Euglena* (*d*) is the paramylum, or food reserve, forming two lozenge-shaped bodies. *Porphyra* (*e*) is a papery red seaweed. *Caulerpa* (*f*) has structures like roots and branches but is a single cell. The plants shown here are not drawn to scale.

same way. If the process is continued, it ultimately gives rise to cellulose: a chain of perhaps 10,000 or 15,000 glucose units. The chain appears to be straight rather than coiled or folded (folded structures have been suggested but the evidence is not convincing), probably because of certain hydrogen bonds between its subunits. These straight chains, lying parallel to one another for at least part of their length, form a crystalline core in the microfibril.

The cementing matrix consists of such polysaccharides as xylan, mannan, araban, galactan, glucomannan and polygalacturonic acid. The subunits of these polysaccharides are sugars other than glucose. The molecular chains of matrix polysaccharides lie parallel to the microfibrils but are irregularly arranged and therefore only slightly crystalline. The cell wall owes its coherence to bonding between these amorphous substances and the microfibrils: hydrogen bonds, bridges through calcium and magnesium ions and, it is now believed, linkages to a specific protein found in cell walls.

This, then, is the general structure of the cell wall of the plants that contain cellulose. Let us now examine our anomalous algae. They are divided into two groups. Both were at one time classified in a single order, the Siphonales (a term that has since been dropped because it was not based on a legitimate family name). In one group cellulose is replaced by xylan, a polymer, or repeating chain, of the pentose sugar xylose; in the other group it is replaced by mannan, a polymer of the hexose sugar mannose. It will be convenient to examine the xylan seaweeds first.

All these plants are of filamentous construction. They range from a single-branched filament in *Bryopsis,* through an intricately formed filament simulating the habit of higher plants in *Caulerpa,* to a compact body of associated filaments in *Halimeda* or *Penicillus.* When subjected to X-ray analysis, the xylan plants all display the same diffraction pattern; it is markedly unlike the pattern obtained from cellulose. When the crystalline wall material of such plants is decomposed, it yields only xylose, indicating that the material is certainly a xylan.

The structure of the xylose molecule is much like that of the glucose molecule except that the sixth carbon atom, with its associated groups, is replaced by hydrogen. In the xylans found in the wall matrix of the cellulose-containing higher plants the xyloses are joined carbon 1 to 4, like the glucoses in cellulose. On the other hand, the X-ray pattern of the seaweed xylans is different from the pattern of higher-plant xylans; hence the seaweed xylan must be built up some other way. The only link possible is between carbon atoms 1 and 3.

This was the conclusion to which our studies led. It would perhaps have been the first demonstration of a link between the sugars of a polysaccharide by X-ray analysis alone. Before Eva Frei and I published our findings, however, 1,3-linked xylan had been detected in some of the seaweeds by chemical methods, first by I. M. Mackie and Elizabeth Percival of the University of Edinburgh and then by Y. Iriki and T. Miwa in Japan.

When the subunits of xylan are linked carbon 1 to carbon 4, they form a straight chain (although, as has been shown by Robert H. Marchessault of the State University of New York College of Forestry at Syracuse University, the chain is probably twisted around its long axis). With a 1,3 linkage the chain can only be curved. Nevertheless, in the electron microscope the fibrils of seaweed xylan are reasonably straight. In what way can curved chains pack together to form straight fibrils? One possibility is that the chains are coiled into straight helices. The helices would need to be fairly flat, because observations with the polarizing microscope show that the individual chains lie more nearly at right angles to the microfibrils than parallel to them. Evidence provided by X-ray analysis led us to conclude in 1964 that within a crystalline xylan fibril the chains are coiled in double helices. On the basis of these and other findings we worked out at that time a model of the xylan fibril.

Recently two of my colleagues, K. D. Parker and E. D. T. Atkins, have refined this model by applying helical diffraction theory to the X-ray diagram and by the use of polarized infrared spectrophotometry. They have demonstrated that three chains, not two, are coiled together, stabilized by interchain hydrogen bonding [*see bottom illustration on next page*]. At the moment it seems likely that the chains are coiled in a right-handed sense. We believe this represents an exceptionally precise determination of structure for a polysaccharide.

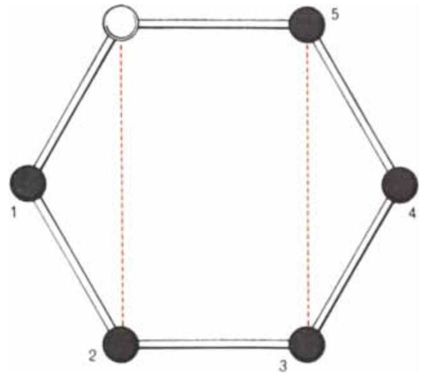
It is interesting that a specimen of xylan is more crystalline when it is wet than when it is dry; water is required (to the extent of 30 percent of the weight) if the chains are to lie in perfect order. This is quite different from the behavior of cellulose, which is equally crystalline dry or wet, water being unable to penetrate the crystal structure. It appears that insofar as crystallinity is indispensable to a structural polysaccharide, 1,3-linked xylan is better suited to water plants than to plants on dry land. This may be why land plants have not, as far as we know, used the substance as a supporting framework for their cells.

Although the xylan seaweeds use xylose in preference to glucose as a structural subunit, glucose does appear among the polysaccharides that form the matrix substance of their walls. Thus the roles of the two sugars in the xylan seaweeds and higher plants are reversed. It has been reported that the glucose units in the walls of the seaweeds are 1,3-linked. It is not clear to what extent the reversed roles of glucose and xylose are related to the 1,3 linkage as against the 1,4 one.

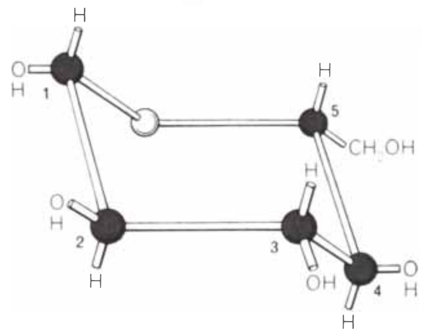
A number of other polysaccharides spread through the plant kingdom are known to be 1,3-linked. We and others have examined some of them and we have found that their X-ray patterns are much alike and similar to that of the xylan. We are now looking into the possibility that most polysaccharides so linked—for example the laminarin of brown seaweeds, the paramylum of *Euglena* and the callose of higher plants—also form helices. It is quite likely that the most abundant polysaccharides on the earth are not, as we once thought, the straight-chain 1,4-linked polysaccharides cellulose and starch but rather the polysaccharides that are 1,3-linked and helical. These substances can be expected to have mechanical properties quite different from those of the straight-chain ones.

The second group of plants I wish to examine here is unusual in quite a different way. These plants, which include *Acetabularia*, are again basically filamentous. The only crystalline polysaccharide present in their walls is mannan. It is identical with the mannan found in higher plants. Mannose, the sugar of which mannan is composed, closely resembles glucose; the molecular structure of the two sugars differs only in the reversed positions of a hydroxyl group (OH) and a hydrogen on one of the carbons in the ring. Like cellulose, the units of mannan are linked through carbon 1 to carbon 4.

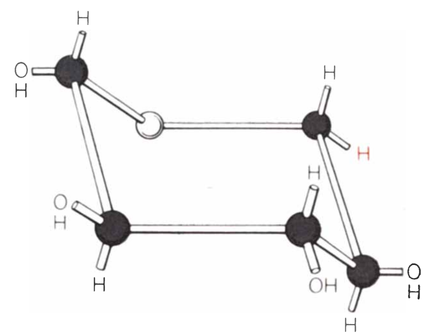
Although mannan is common among higher plants, it is detectable as a crystalline polysaccharide only in the seeds of one group of them. Even there it is not the only structural polysaccharide, the cell walls of the plants being basically cellulosic. This group is the palms, among them the date and the ivory-nut palm (the toughness of mannan is indicated by the name and the fact that laboratory-coat buttons are sometimes still



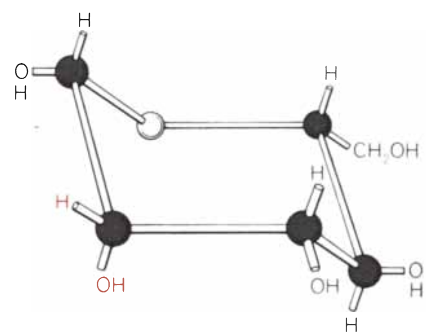
GLUCOSE



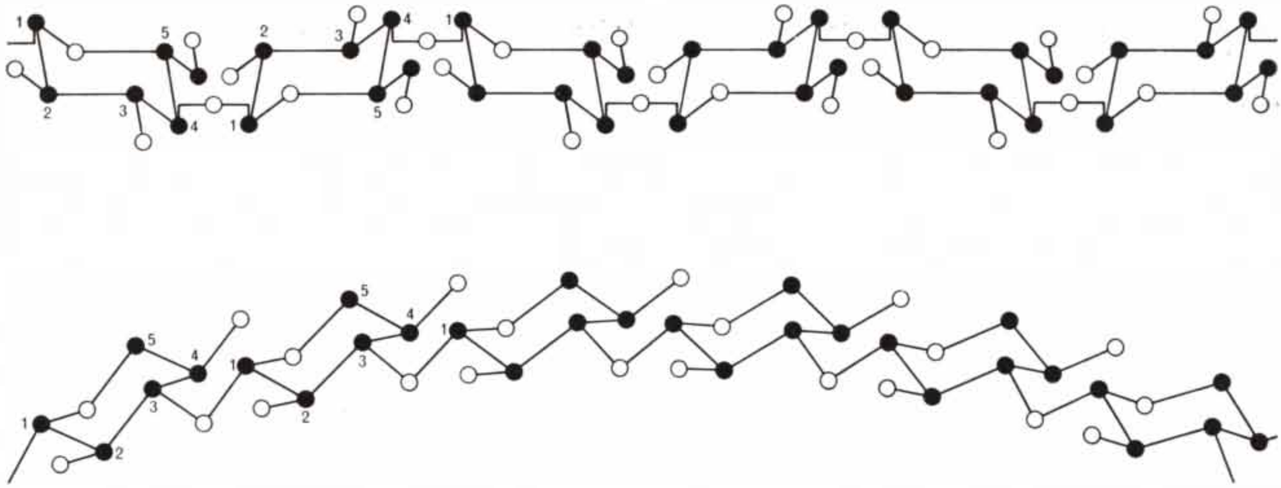
XYLOSE



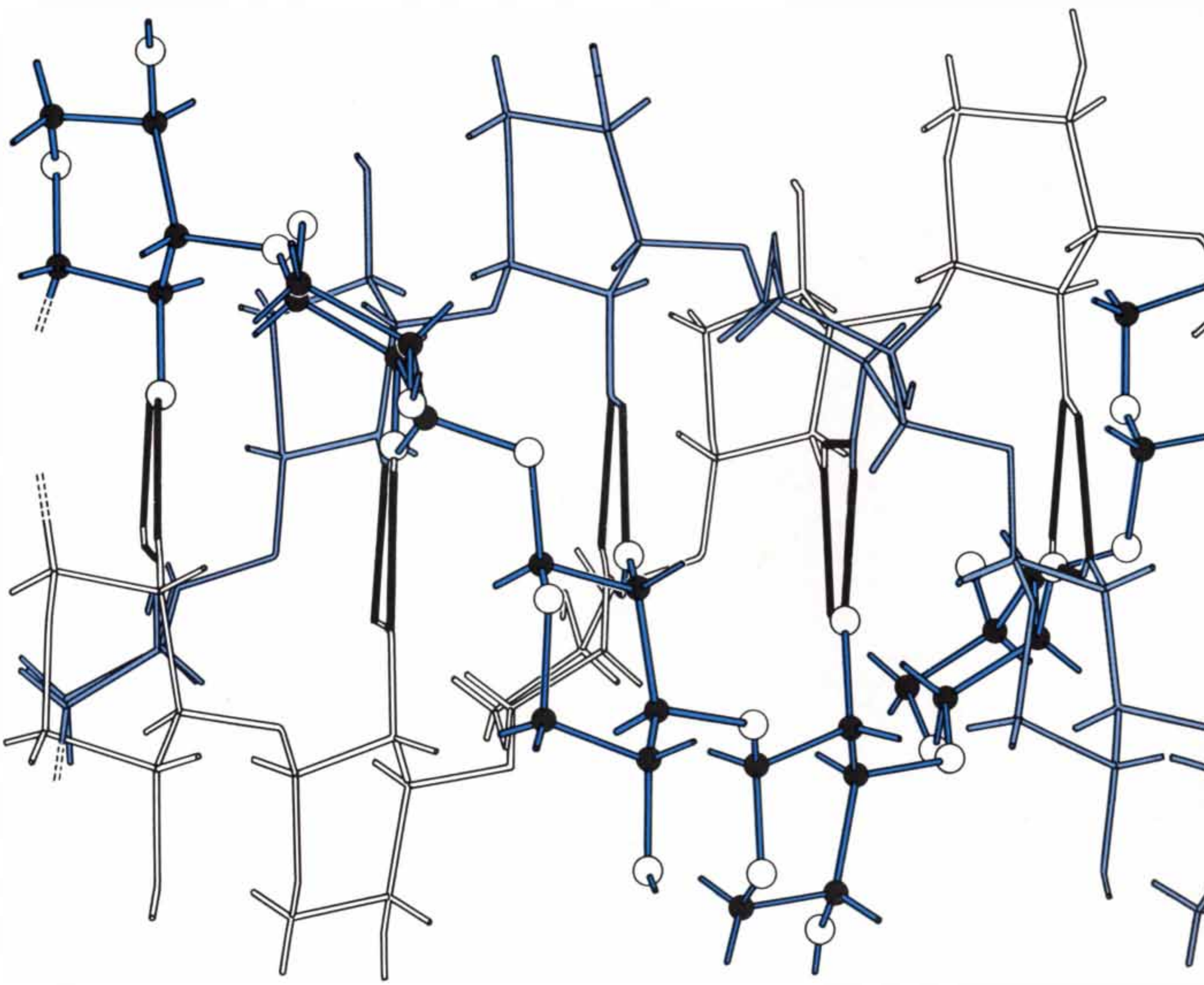
MANNOSE



MOLECULAR DIAGRAMS indicate (*color*) where xylose and mannose differ from glucose. All these sugars have a hexagonal ring (*top*) composed of carbon atoms (*black balls*) and an oxygen atom (*white ball*). In the diagrams this hexagon is seen from the edge with two corners bent. Cellulose is formed from glucose; xylose and mannose form the substances that replace cellulose.

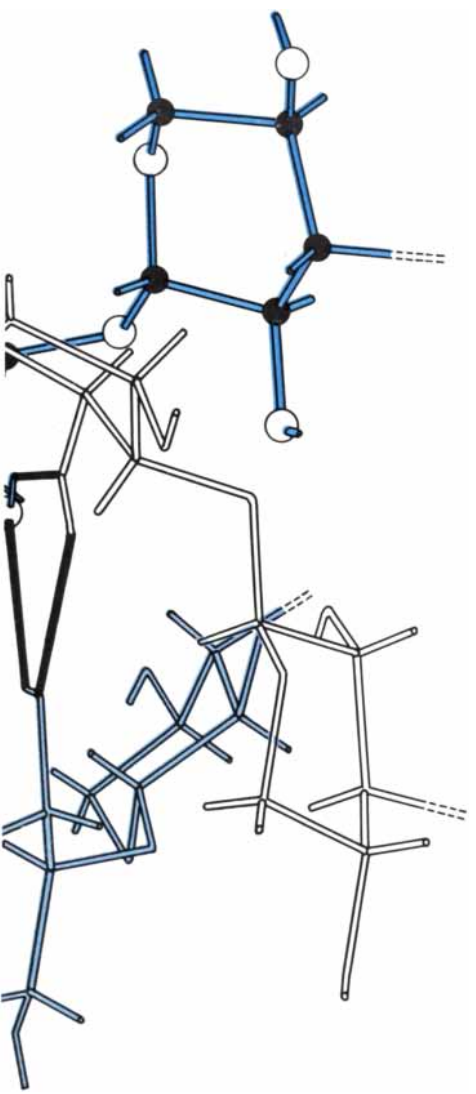


MOLECULAR CHAINS are linked through oxygen atoms. A short segment of the cellulose chain is shown at top with carbon atoms in the hexagonal ring of some of the units numbered. The linking in the chain of carbon atom 1 and carbon atom 4 gives rise to a regular alternation in the orientation of the glucose units and a straight chain. Below the cellulose chain appears the segment of a xylan chain that is composed of xylose units. The units are joined at carbon atoms 1 and 3, and this linkage produces a curved chain.



TWISTING OF XYLAN CHAINS gives rise to a straight microfibril. Each straight section of the three chains forming the helix represents a bond between atoms; the black linkages are hydrogen bonds that stabilize the chains. The chains are shown as being coiled in a right-handed sense; in one chain oxygen and carbon atoms are depicted. The drawing is based on a model worked out made of "vegetable ivory" in spite of the availability of plastics).

Through X-ray analysis of the cell walls of mannan seaweeds it has been possible for the first time to provisionally elucidate the crystal structure of mannan. It appears to resemble the crystal structure of cellulose in that the chains of mannose units lie parallel to one another; it is dissimilar in that the chains pack together somewhat differently. Neither fact is surprising in view of the specific difference between the molecules of mannose and glucose. The molecular chains of mannan are commonly reported to be much shorter than those of cellulose, ranging up to 80 mannose units. My colleagues W. Mackie and D. B. Sellen have given reason to believe, however, that the chains of seaweed mannan approach the length of cellulose chains.



by the author and his colleagues at the University of Leeds. Hydrogen atoms are omitted from this illustration and the one at top.

The surprise comes when one examines under the electron microscope a sample of the cell-wall material that attests (on the basis of X-ray analysis) to mannan's crystal structure. One would expect to find much the same kind of well-oriented fibril that one sees in a comparable micrograph of cellulose or xylan. In spite of the most determined efforts such fibrils have not been detected by the methods that succeed with cellulose and xylan seaweeds. These methods involve the removal of the noncellulosic polysaccharides by chemical means. The polysaccharides that surround the crystalline regions of mannan, however, are themselves mostly mannan; they cannot be removed to reveal a possible underlying fibril structure without the risk of destroying the structure. Although the microfibrils of cellulose and xylan are often visible without the removal of the surrounding matrix, it is still not safe to conclude that in mannan walls microfibrils are completely absent. In fact, Mackie has shown recently that exceptionally mild treatment of mannan walls reveals occasional microfibrils. Nevertheless, in electron micrographs seaweed mannan appears most often to take the form of granules or at most very short rods (no longer than 2,000 angstroms). The granules must be mutually oriented in an orderly fashion to provide the observed X-ray pattern.

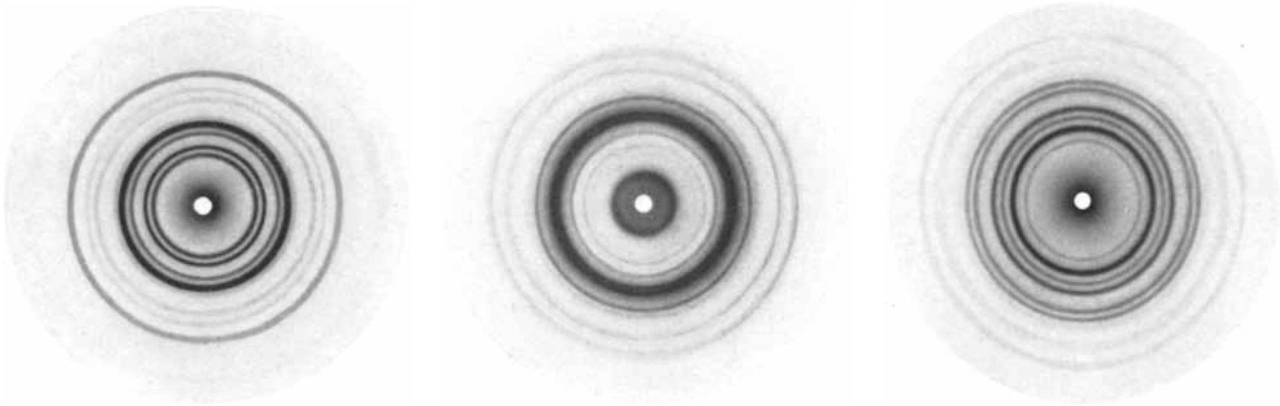
This presents problems even though microfibrils are occasionally present. If one assumes that the mechanical properties of the mannan walls are not much different from those of cellulose walls (this assumption is supported by manipulations of the walls), how does it come about that an array of granules behaves like an array of parallel threads? What mechanism specifies the particular order the granules display? It is possible to conceive of a mechanism by which threads can be arranged parallel to one another, and I have already proposed such a mechanism in general terms. It is much more difficult to imagine a mutual orientation of granules under the conditions that are known to exist at the cell surface.

In searching for an explanation we must bear in mind that the cell-wall layers examined in the electron microscope have been subjected to drastic drying in the process. Furthermore, under these conditions a structural element with one dimension of less than eight angstroms is not visible at all in the kind of material involved. One could therefore imagine the wall to be a parallel array of short molecular chains that overlap one another and that in small granule-shaped regions, and in these regions only, are regularly spaced and therefore crystalline. Such a structure could give rise to both our X-ray patterns and our electron micrographs, and would be in agreement with the chain lengths found by Mackie and Sellen.

The mannan cell walls appear to have significance for certain theories of plant growth. The growth rate of plant cells is known to be under the control of auxins, or plant hormones. The view most widely held today is that the auxins achieve their effect by changing the coherence of the cell wall. The cell-wall components believed until recently to be the most intimately involved are the pectic compounds, derivatives of polygalacturonic acid that are found in the matrix substances of all higher plants.

Now, the auxins are also said to affect the development of the seaweed *Acetabularia*. The wall of this plant is lacking not only in cellulose but also—according to our analyses and those of other laboratories—in pectic compounds. We must therefore assume either that this plant is peculiar in still another way or that the wall substance affected by the auxins is not polygalacturonic acid. The latter seems to me the more likely, particularly in view of work that points in quite another direction. One of my students, E. W. Thompson, has detected in the walls of a noncellulosic plant (*Codium tomentosum*, which contains mannan) an abundance of a specific protein that D. A. Lamport of Michigan State University has shown to be present in the walls of higher plants. Lamport gives reason to believe the protein is a wall component closely associated with cell-wall extensibility, and we have reached the same conclusion both for mannan-containing and cellulose-containing seaweeds. This may prove not to be the whole story, but our work implies that it is at least an important part of it.

When we first began our study of these odd plants, we suspected that (to argue teleologically) plants in the sea might have experimented with a variety of polysaccharides as cell-wall skeletal materials. As it has turned out this suspicion was justified. It remains to be seen what other surprises may await us among the lower plants. We know already of two other groups of plants, also seaweeds, that combine in themselves the structures found separately in the mannan and xylan algae. In one of these groups the prominent member is *Porphyra*, familiar as the papery red seaweed that in season clothes many of the rocks along coasts in the Northern Hemi-

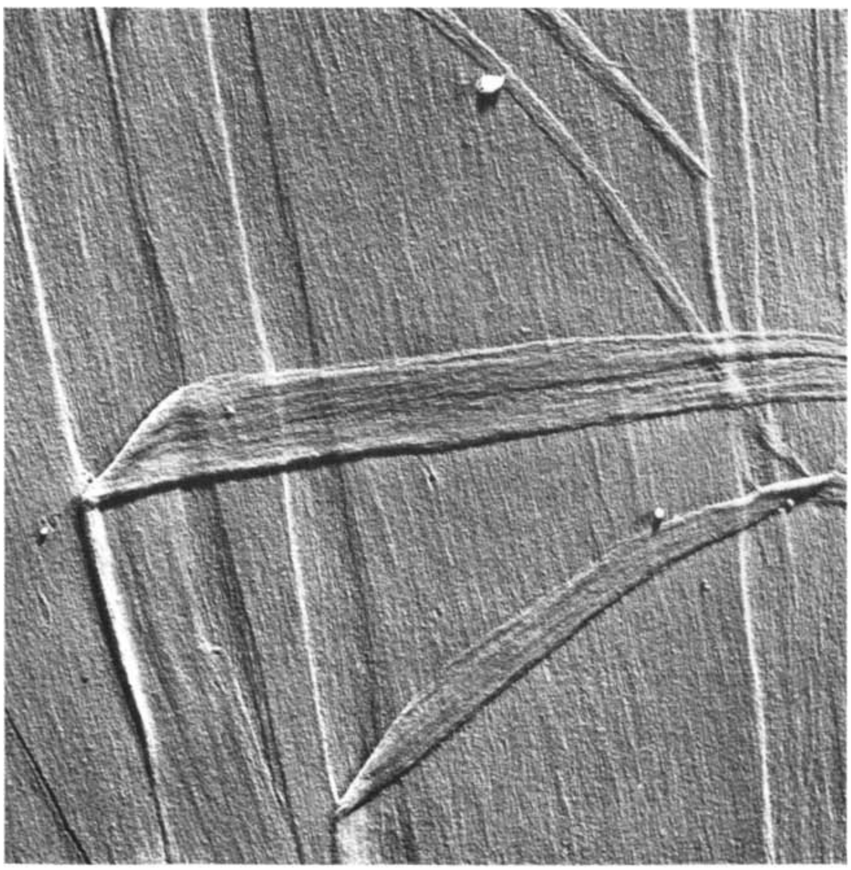


X-RAY DIFFRACTION PATTERNS indicate differences in the cell structure of seaweeds. At left is the pattern made by *Chaetomorpha*, whose cell walls contain cellulose. The middle pattern is of *Penicillus*, in which xylan replaces cellulose. At right is the pattern of *Batophora*, whose cell walls contain mannan, which is composed of mannose units and also substitutes for cellulose.

sphere. In this plant the cell walls contain crystalline 1,3-linked xylan, and the cuticle covering the walls contains crystalline 1,4-linked mannan.

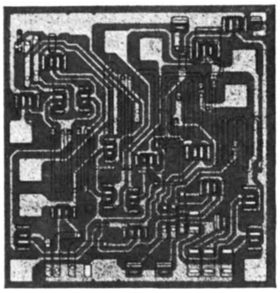
The other example of combined structure, involving the plant *Halicystis* (commonly known as sea bottle and consisting of single "cells" or vesicles as large as a pea), is somewhat more complicated. *Halicystis* is a haplont, which is to say that each of its nuclei has only a single set of chromosomes. During reproduction the nuclei fuse in pairs, and the resulting cell ultimately develops to form a plant body called the diplont generation. Eventually some or all of the nuclei of the diplont plant undergo the division known as meiosis, by which the chromosome number in each daughter nucleus is halved. The cells then divide by normal mitosis to reproduce the haplont plant body, and the cycle is repeated.

Now, although *Halicystis* is composed of roughly globular large cells, its diplont phase is finely filamentous; the diplont is known by the name *Derbesia. Halicystis* and *Derbesia* are two generations of one and the same plant. Nevertheless, the walls of *Halicystis* contain crystalline 1,3-linked xylan together with some cellulose but no mannan, and the walls of *Derbesia* contain crystalline mannan but neither cellulose nor 1,3-linked xylan. This is a clear case of a correlation between the chromosome complement of a cell and the constitution of its wall.



TEARING OF THE CELL WALL provides evidence of its underlying structure in the mannan seaweed *Dasycladus*. Like the cell wall of other mannan seaweeds, the wall of *Dasycladus* appears to be predominantly composed of granules. The fact that the specimen tears cleanly in a direction parallel to the grain of the wall indicates that the granules are in an ordered array. In this electron micrograph the specimen is enlarged about 6,500 diameters.

It is a rather odd circumstance that although water plants such as those discussed here must have lived for many millions of years with their peculiar walls, as far as we know none of these walls is represented among land plants. It would be too much to say that the structure of all land plants is known—there may be some surprises waiting in this realm as well. Nonetheless, the consensus is that all green land plants will prove to have cellulose walls. It appears that several polysaccharides and polysaccharide combinations can make a serviceable cell wall for water plants but only one kind of wall serves those plants that have managed to colonize dry land. All we can conclude is that plants on dry land need in their cell walls a balance between the rigidity necessary to hold the plant upright and an extensibility—perhaps even a controlled breakdown—that will allow the plant to grow. Perhaps this balance can be achieved only in a wall based on cellulose.



One company is developing the top reputation for integrated circuit reliability in the huge military aerospace projects.

MATHEMATICAL GAMES

Combinatorial possibilities in a pack of shuffled cards

by Martin Gardner

Playing cards, with their numerical values, four suits, two colors, backs and fronts and easy randomizing, have long provided recreational mathematicians with a paradise of possibilities. This month we consider a few remarkable new combinatorial problems and paradoxes for which playing cards are ideal working models.

In August, 1960, I mentioned briefly a curious principle discovered by a young amateur magician, Norman Gilbreath, who is now with the Rand Corporation in Santa Monica, Calif. Arrange a deck of cards so that its red and black cards alternate. Cut the deck to form two piles, breaking the deck so that the top cards of each pile are of different colors. If the two piles are now riffle-shuffled into each other, every pair of cards, from the top down, will consist of one red and one black card. (You can let someone else do the single shuffle and then play him 26 rounds of matching colors. You each take a card from the top of the deck; your opponent wins if the cards match. Of course you win every time.) Gilbreath later discovered that his principle is only a special case of what magicians now call the Gilbreath general principle. It applies to any repeating series of symbols and can best be explained by a few examples.

Arrange a deck so that the suits repeat throughout in the same order, say spades, hearts, clubs and diamonds. From the top of this deck deal the cards one at a time to the table to form a pile of 20 to 30 cards. (Actually it does not matter in the least how many cards are in this pile.) Riffle-shuffle the two parts of the deck together. Believe it or not, every quartet of cards, from the top down, will now contain a card of each suit. Dozens of subtle card tricks exploiting Gilbreath's general principle have been published in magic periodicals during the past few years. The simplest trick is to let someone deal and shuffle, take the deck behind your back (or under a table), then pretend to feel the suits with your fingers and bring out the cards in groups of four, each containing all four suits. It is necessary that one packet be reversed before the shuffle. Dealing cards to the table does this automatically. Another method is to cut off a portion of the deck, turn it over and shuffle this face-up packet into the rest of the deck, which remains face down. A third method is to take cards singly from the top of the deck and push them into the pack, inserting the first card near the bottom, the next anywhere above the previously inserted card (directly above it if you wish), the third above that and so on until you have gone as high as you can. This is equivalent to cutting off a packet, reversing its order and riffle-shuffling. The deck's original order is destroyed, of course, but the cards remain strongly ordered in the sense that each group of four cards contains all four suits.

A trick applying the Gilbreath principle to a repeating series of length 52 is to arrange one full deck so that its cards are in the same order from top to bottom as the cards in a second deck are from bottom to top. If the two decks are riffle-shuffled into each other and then cut exactly at midpoint, each half will be a complete deck of 52 different cards!

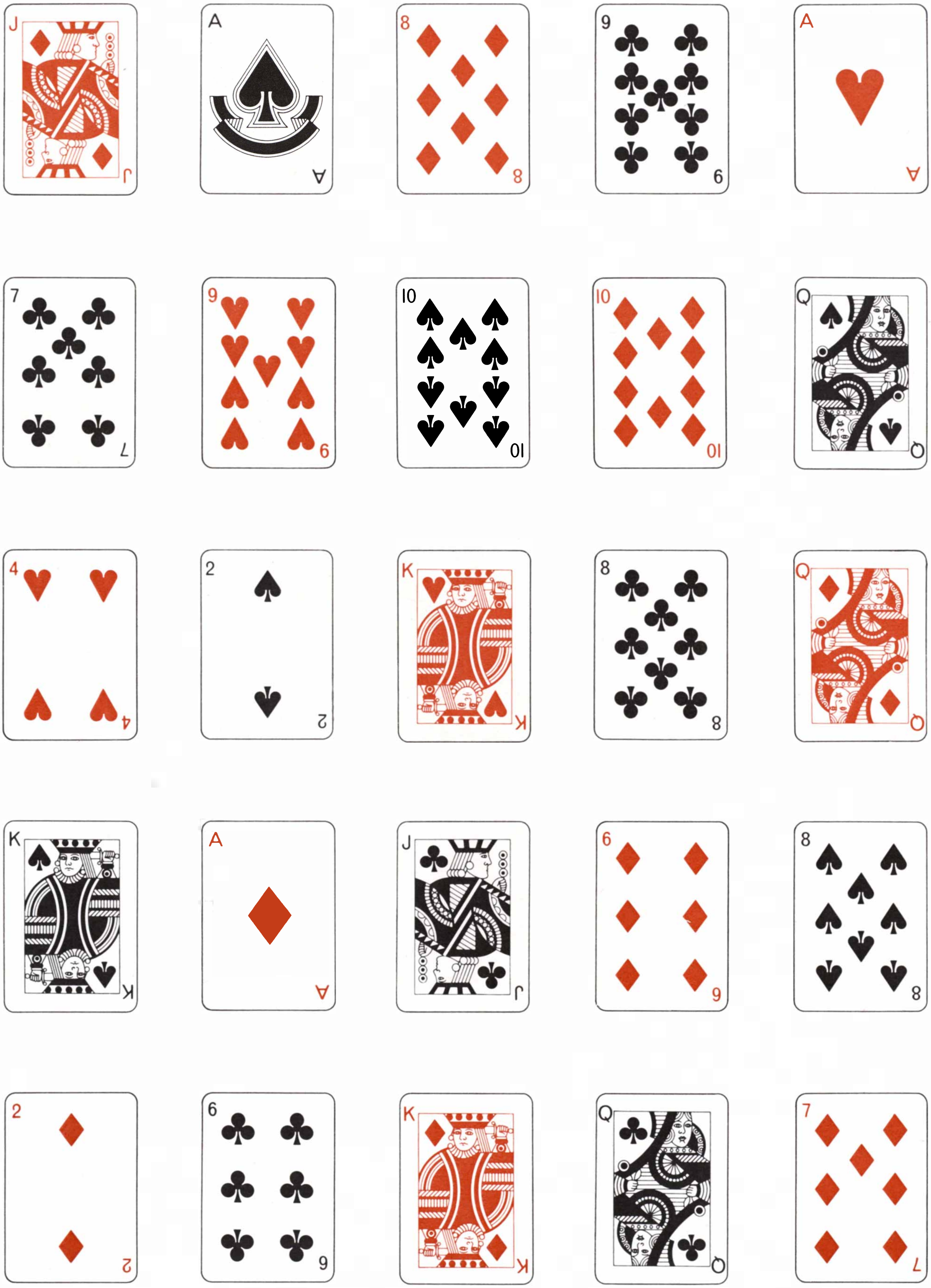
Gilbreath's general principle points up how poorly a riffle-shuffle randomizes. This inefficiency of the riffle-shuffle provided another mathemagician, Rev. Joseph K. Siberz of Boston College, with what may well be the first computer program that teaches a computer how to do a mystifying card trick. The trick uses 52 IBM punched cards, each bearing the name of a different playing card. Both program and "deck" are entered in the computer, which then prints the following instructions:

1. Give the deck several single cuts and a riffle-shuffle.
2. Cut the deck into two piles.
3. Look at the top card of one pile and remember it.
4. Bury this card in one of the two piles and riffle-shuffle them together.
5. Cut the deck, complete the cut and repeat several times if you wish.
6. Now give the deck back to me and I shall find your card.

If the card was, say, the five of hearts, the computer quickly prints out: "Your card was the five of hearts. Don't ask me how I do it. Magicians never reveal their secrets. Take another card and I shall do it again." If the person has failed to follow instructions exactly, the computer sometimes finds the card anyway, perhaps after asking the spectator for additional information: "I am having trouble determining the color of your card. Please help me by turning on switch *B* if it is black or switch *C* if it is red." This is followed by, "Thank you. Your card is...." If the instructions were not followed and the computer cannot find the card, it prints, "You did not follow my directions. Please take another card and try again." If this happens again, the computer politely asks for still another try, but after a third goof it says, "I won't find your $$=)$** card if you refuse to do it my way. Please try again."

It is not hard to see how the program finds the card. The two riffle-shuffles merely break the deck's original cyclic order into four interlocking sequences. If the instructions are followed correctly, a single card will be missing from where it should be in one of those sequences. While it is identifying the card, the computer memorizes the deck's new order and therefore is all set for an immediate repetition of the trick. The reader can easily perform the trick himself by recording the order of a deck or using an unopened pack, which comes from the manufacturer in a simply ordered sequence that can be memorized while you remove the joker and the extra cards. After a spectator has followed the instructions given above you can take the twice-shuffled deck to another room; by checking the cards off on your list it is easy to determine the single card that is out of place.

Several years ago on the television show *Maverick* the gambler Bart Maverick bet someone he could take 25 cards, selected at random, and arrange them into five poker hands each of which would be a straight or better. (The hands higher than a straight are flush, full house, four of a kind, straight flush and royal flush.) The same bet was made on television in 1967 by Paul Bryan in an episode of *Run for Your Life*. It is what gamblers call a "proposition"—a bet for which the odds seem against the person



Can these cards be arranged to form five poker hands, all straight or better?

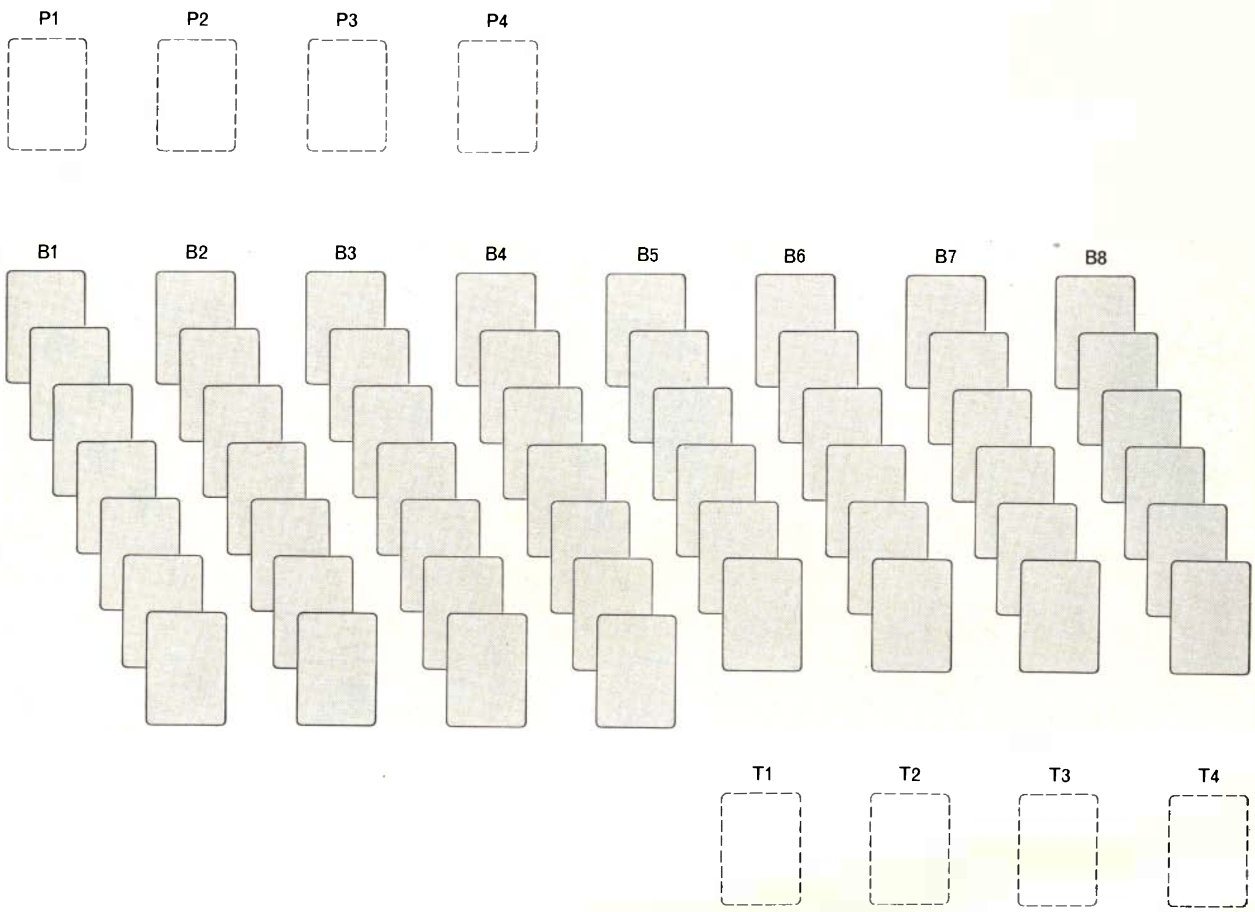
making it when actually they are strongly in his favor. If the reader will experiment with 25 randomly chosen cards, he will be surprised at the ease with which five hands can be arranged. Try the flushes first (there will be at least two), then look for straights and full houses. I have no idea of the actual probability of success, but it is extremely high. Indeed, the question arises: Is success always possible? The answer is no. There are sets of 25 cards that cannot be partitioned into five poker hands of straight or better.

With this introduction the reader is invited to consider the 25 cards shown in the illustration on the preceding page. Can the bet be won with this set? If so, find five hands. If not, prove that it is impossible. This ingenious puzzle is quickly solved if you go about it correctly; a single card is the key. The puzzle was sent to me by Hamp Stevens—a reader who did not give his address and whom I therefore take this opportunity to thank.

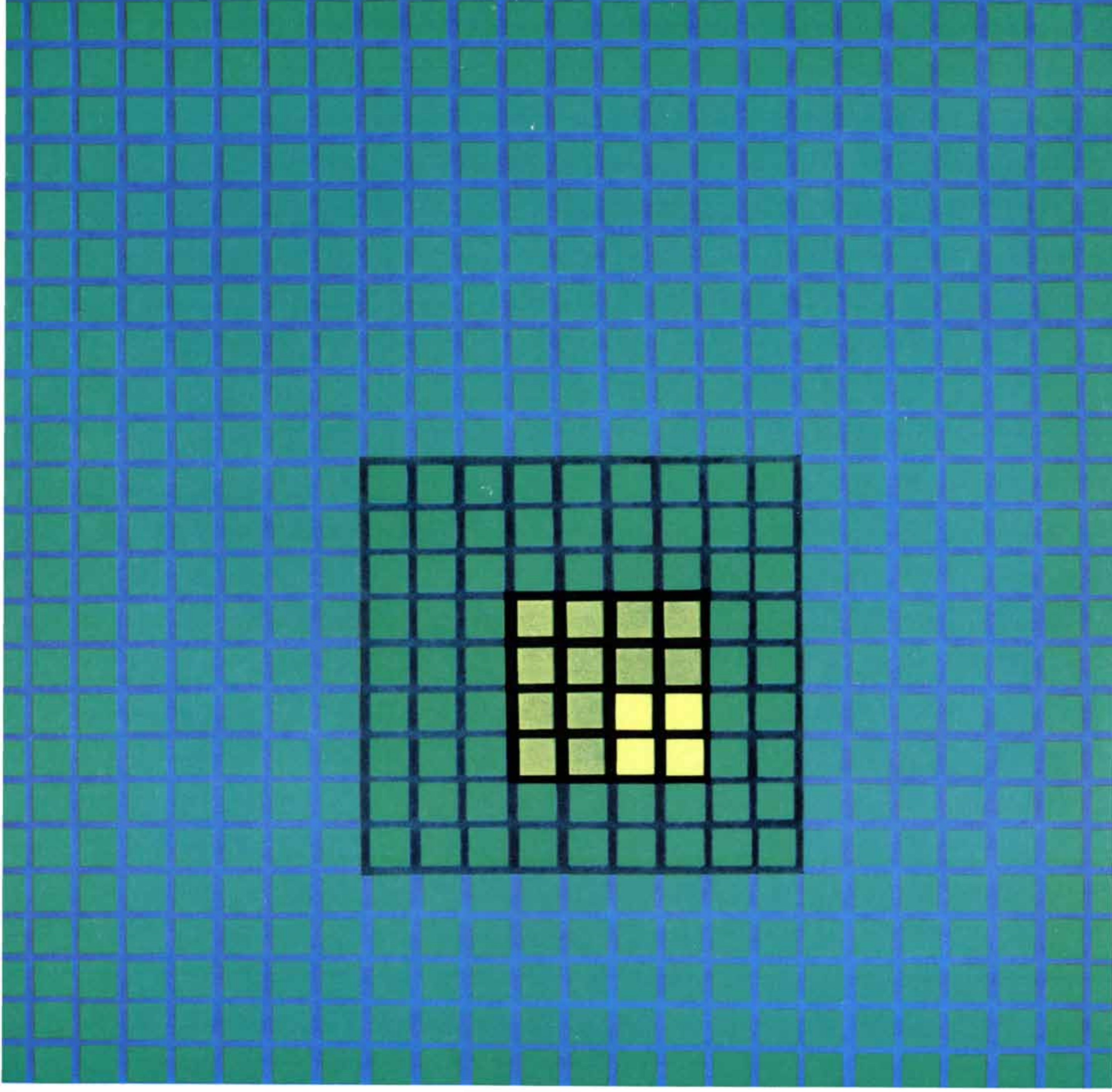
For a second combinatorial problem the reader is asked to place any three playing cards face down in a row. The task is to turn one card at a time and in seven moves produce all the $2^3 = 8$ different permutations of face-up and face-down cards, ending with the three cards face up. There are six ways to do it. Letting F stand for the face, B for the back, one solution is *BBB, BBF, BFF, BFB, FFB, FBB, FBF* and *FFF*. (These eight permutations, by the way, correspond to the eight rows of a "truth table" giving the eight possible combinations of true and false for three statements in the propositional calculus of symbolic logic.) Is there a solution with four cards? There are now $2^4 = 16$ different permutations, so that the problem is to start with four face-down cards, turn one at a time and in 15 moves run through all 16 permutations, the last one being the four cards face up. It turns out that this is not possible. The problem, which appeared recently in Mannis Charosh's column in *The Mathematics Student Journal,* is to find a simple way of proving impossibility. The proof leads quickly to a generalization for rows of n cards, as will be explained next month.

C. L. Baker, until recently a senior staff member of the computer sciences department of the Rand Corporation, has called my attention to a little-known solitaire game he found could be simplified to provide an endless series of intriguing combinatorial puzzles. The game was taught Baker by his father, who in turn learned it from an Englishman during the 1920's. It differs from most solitaire games in that, although the initial pattern is determined by chance, once the cards have been placed the player has complete information. Each initial layout is therefore either solvable or unsolvable, and finding a solution becomes a stimulating challenge. As in chess, one must think ahead many moves because any mistake in play is irreversible. The game has a peculiar flavor of its own, somewhat akin to sliding-block puzzles. The probability of winning is high if one is skillful, and the more one plays the more skillful one becomes.

To play the game with a full deck shuffle the 52 cards and then deal them face up into the eight-column array

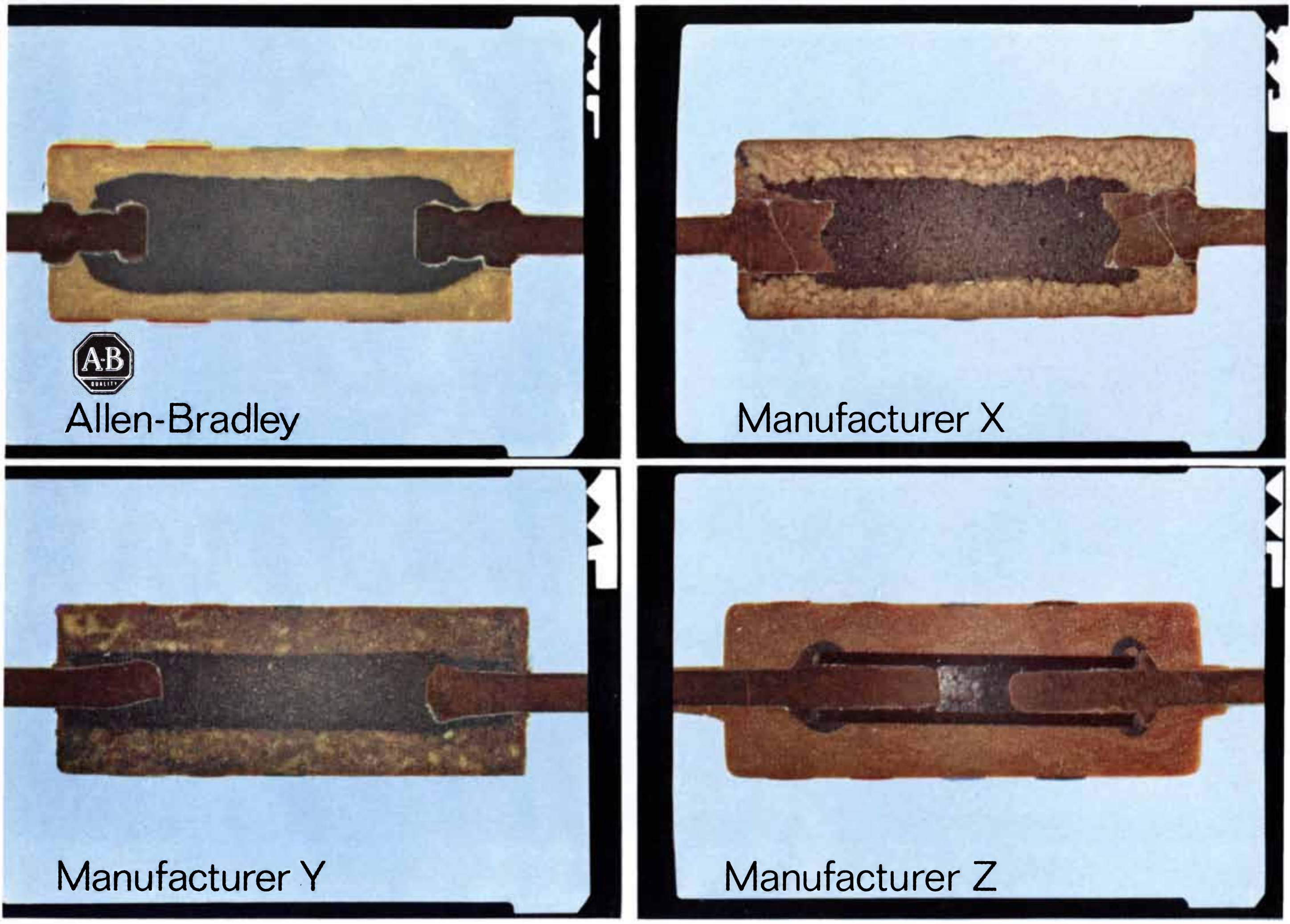


Schematic layout for C. L. Baker's solitaire game, order-4 version



with your reputation at stake, which resistor line would you specify?

take a close look—there'll be no question

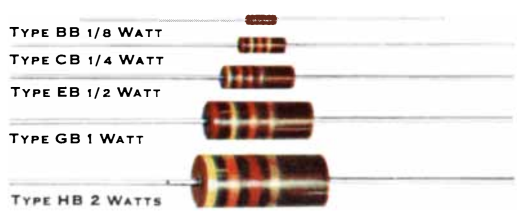


The above illustrations are from unretouched photomicrographs taken of four ½-watt fixed resistors. Compare the anchoring of the leads, the seal provided by the insulating jacket at the ends, the homogeneity of the resistance material, the sharp color code bands—and decide for yourself.

For more details on Allen-Bradley hot-molded resistors, please write for Technical Bulletin 5000: Allen-Bradley Co., 1204 South Third Street, Milwaukee, Wis. 53204. In Canada: Allen-Bradley Canada Ltd. Export Office: 630 Third Avenue, New York, N. Y., U.S.A. 10017.

1067E-4

A-B hot-molded fixed resistors are available in all standard resistance values and tolerances, plus values above and below standard limits. **A-B hot-molded resistors meet or exceed all applicable military specifications including the new Established Reliability Specification.** Shown actual size.



QUALITY ELECTRONIC COMPONENTS A-B QUALITY **ALLEN-BRADLEY** shown in the illustration on page 114. The dealing is left to right, with the cards overlapping as pictured. (This places seven cards in the first four columns and six in the last four.) Baker calls the columns "board columns" and labels them *B1* to *B8*. The four dotted cells above the layout are called "play-off cells," *P1, P2, P3, P4*. They are empty at the start. The object of the game is to place on each of those cells, in consecutive order starting with the ace, all 13 cards of the same suit. The game is won if, and only if, all four play-off cells are completely filled.

The four dotted cells below the layout, *T1, T2, T3, T4*, are called "temporary cells." In the course of play a single card (no more) can be placed on any one of those cells. They can, therefore, hold a maximum of four cards.

The rules are as follows:

1. Only one card may be moved at a time.

2. Only the top (uncovered) card may be moved from any *B* column.

3. An ace may be played on any empty *P* cell. On top of it may be played the deuce of the same suit, then the three, and so on through the king. These cards may come from the exposed ends of columns or from the *T* cells.

4. An uncovered card in a *B* column may be shifted to become the uncovered card of another *B* column only if it goes on a next-higher card of the *same suit*.

5. Any card may be played on an empty *T* cell and remain there until you wish to move it somewhere else.

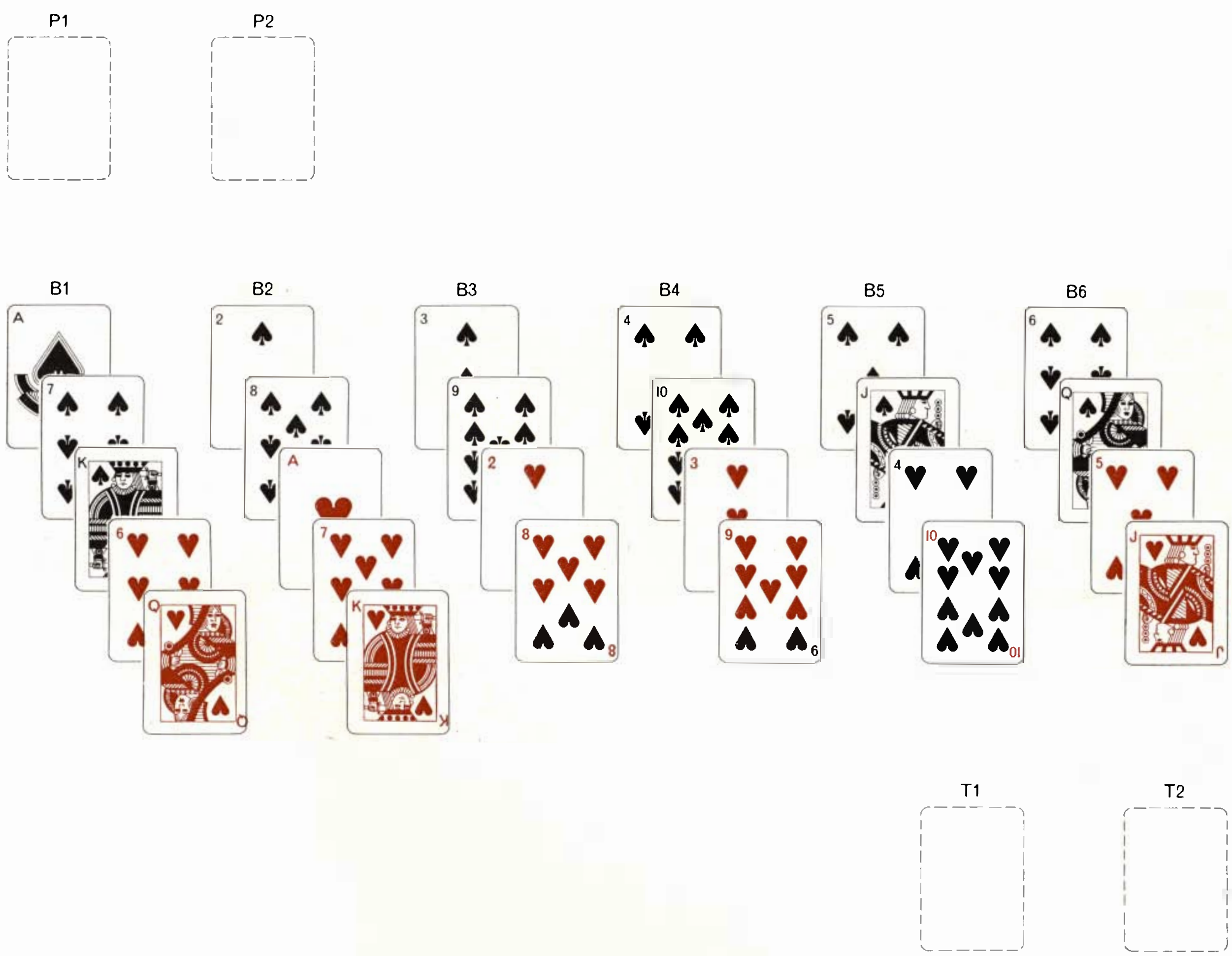
6. If a *B* column becomes empty, any movable card may be placed as a new starting card for that column.

It was Baker's happy discovery that removing one, two or three suits from the full deck creates games of "lower order." For the three-suit, or order-3 game, the cards are dealt into seven columns, and there are three *P* cells and three *T* cells. The order-2 game (two suits) has six columns, two *P* cells and two *T* cells. (The order-1 game, with five columns, one *P* cell and one *T* cell, is trivial because every possible layout has a solution that is easily found.)

The order-2 is an ideal introduction to the game. The reader is urged at this point to obtain a deck, remove two of the suits, shuffle the remaining 26 cards and deal a random layout. Only actual play will convey the game's fascination. It is a good plan to keep a record of each starting pattern because if you fail to win, you may want to restore the original layout and try a different strategy. Perhaps a friend or a member of the family will take a crack at the same pattern. Not all starting layouts are solvable, but often a seemingly hopeless pattern can finally be broken by devious lines of play.

For our final problem the reader is asked to try his skill at the order-2 game shown below, in which the spades and hearts are arranged consecutively. Next month I shall give the shortest solution I have found (54 moves) and report in a later column if any reader has solved it in fewer moves.

All kinds of difficult combinatorial questions are posed by Baker's game (I call it that because I have not so far dis-



Can

covered if the game has a name). Among many questions raised by Baker, and for which he has no answers, are the following: Does the probability of winning decrease as order-n increases? If so, does it decrease to zero for some finite n or merely to some nonzero limit? For a given order what is the maximum number of moves that may be required for a minimum-move solution? Can a computer program be written for finding minimum-move solutions to low-order games, or even for testing whether or not a solution exists?

The first of last month's problems was to determine the sizes of two circles, each of which touches three mutually tangent circles with radii of one, two and three units. Using the formula given last month,

$$2\left(1+\frac{1}{4}+\frac{1}{9}+x^2\right)=\left(1+\frac{1}{2}+\frac{1}{3}+x\right)^2,$$

where x is the radius of the fourth circle, one obtains a value of 6/23 for the radius of the smaller circle, 6 for the larger one.

The second problem concerned three grapefruits with three-inch radii and an orange, all resting on a counter and mutually touching. What size is the orange? The plane on which they rest is considered a fifth sphere of infinite radius that touches the other four. Since it has zero curvature it drops out of the formula relating the reciprocals of the radii of five mutually touching spheres. Letting x be the radius of the orange, we write the equation,

$$3\left(\frac{1}{3^2}+\frac{1}{3^2}+\frac{1}{3^2}+\frac{1}{x^2}\right)=\left(\frac{1}{3}+\frac{1}{3}+\frac{1}{3}+\frac{1}{x}\right)^2,$$

which gives x a value of one inch.

The answer to Leo Moser's paradox of the hypercubic chessboard in four-dimensional space is that *no* portion of a white cell remains unenclosed by the hyperspheres surrounding each black cell. The radius of each hypersphere is $\sqrt{4}$, or 2. Since the hypercubic cells have edges of length 2, we see at once that each of the eight hyperspheres around a white cell will extend all the way to the center of that cell. The eight hyperspheres intersect one another, leaving no portion of the white cell unenclosed.

Correction: In last month's answers to the short questions about dollar bills the answer to question No. 2 was incorrect. The word "ten" appears 13 times on a \$10 bill, including *ten* in "*ten*der" and "sep*ten*t."

See the other side of the coin

There's more to Europe than history-steeped castles, picturesque scenery, windmills, traditional costumes and centuries of culture. In the research laboratories of the Philips group of companies, scientists are cooperating in many fields of fundamental and applied science. Every member has creative freedom, in small teams with excellent facilities, plus the responsibility of seeing a project through to its logical conclusion. The European-based scientist scores because of better career prospects, free exchange of ideas with his colleagues in other fields - and the unparalleled opportunity to recharge his mental batteries on the other side of the coin. If you are under 35, have a Ph. D or equivalent, are attracted by a career in Europe and feel that intellectual curiosity is your strong point, we would like to hear from you. Tell us about your career and where you would like to live and work, (our laboratories are located throughout Western Europe). Whilst we are digesting this, we will send you a brochure highlighting some activities of Philips research laboratories in Solid State Physics and Chemistry, Information Processing, Telecommunications, Television and Mechanics. Send your curriculum vitae (including list of published papers) to:
The Office of the Director for Research Dr. H. B. G. Casimir,
Philips Research Laboratories Eindhoven, The Netherlands.

PHILIPS


Where do we go from here?
Snarled freeways. Foul air. Polluted water. Crime in the streets. Soaring medical costs. Overcrowded, understaffed hospitals.
Solving top priority national problems is a TRW specialty.
For over a decade, our balanced blend of systems engineering services and technological skills have been used on America's major space and defense programs. Now we are successfully applying this experience to a variety of Civil Systems problems.
Before a shovel was turned, we saved the Province of Alberta more than $6 million in planning its new $100 million Edmonton Health Sciences Centre. We are working with the Department of Transportation on high speed ground transportation systems for use between Boston and Washington. For California we have developed a statewide land use information system. Our seasoned systems engineers are also working on automobile inspection, public safety, urban re-development, banking, water resources planning and flood plain management programs.
For more information about TRW Civil Systems capabilities, contact Marketing Services, TRW Systems Group, One Space Park, Redondo Beach, California 90278.
TRW®
TRW Systems Group is a major operating unit of TRW INC. (Formerly Thompson Ramo Wooldridge Inc.), where 75,000 people at over 200 locations around the world are applying advanced technology to electronics, space, defense, automotive, aircraft, and selected commercial and industrial markets.

THE AMATEUR SCIENTIST

A plan for an analogue computer that can be built for about $50

Conducted by C. L. Stong

Many an amateur experimenter would be delighted to have a computer of his own to predict the outcome of experiments or to analyze experimental data. An electronic digital computer is likely to be out of the question; commercial models are obviously expensive, and I have not heard of any amateur building one of any size. An analogue computer is another matter. Instead of using digits, such a machine represents quantities by dimensions: the size of an electric charge, the displacement of a lever or the rotation of a shaft. The machine also generates the solutions of problems in the form of analogues—usually as graphs drawn automatically on a sheet of paper.

The substitution of analogues for digits makes it considerably easier for the amateur to build a computer of his own. An analogue computer capable of solving most of the problems that are likely to interest amateurs need occupy no more than two cubic feet of space and can cost less than $50. Such a computer, specially designed for amateur construction, has been developed by Gordon F. Pearce, professor of mechanical engineering at the University of Waterloo in Canada, who writes:

"My computer is entirely mechanical, consisting of screws, shafts, disks, wheels, sprockets and chains. All parts except the disks, shafts and fittings come ready-made. The machine can be assembled with hand tools, although a lathe is useful for making the disks and reducing the diameter of shafts. Various combinations of these parts perform by their motions the equivalent of addition, subtraction and multiplication. Two of the subassemblies also compute the growth of variable quantities—the operation known as integration.

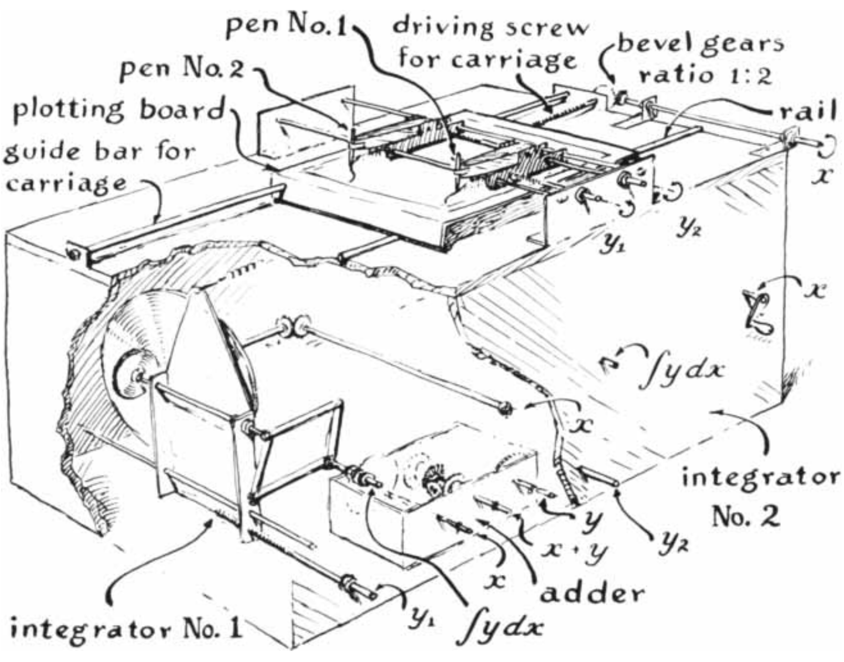
"Addition and subtraction are done by a set of gears similar to those in the differential of an automobile. In the computer a bevel gear is fixed to the inner end of a pair of shafts that are equivalent to the rear axles of an automobile. The bevel gears mesh with a differential gear that is free to turn on a short shaft fixed at right angles to its supporting shaft [*see top illustration on opposite page*]. Power is applied to the shafts that carry the bevel gears, which drive the shaft attached to the differential gear.

"The rotation of either bevel gear turns the differential shaft a proportional amount. When both bevel gears turn in the same direction, the rotation of the differential shaft is equal to the sum of their rotations. When the bevel gears rotate in opposite directions, the rotation of the differential shaft is equal to the difference of their rotations.

"Mathematically the action can be expressed as $W = c(x + y)$, in which W is equal to the sum or the difference of x and y multiplied by a constant c, which is determined by the ratio of external gears that drive the unit. Either x or y can be considered a negative quantity depending on the direction in which its shaft rotates. By convention, clockwise rotation symbolizes a positive quantity, counterclockwise rotation a negative quantity.

"The machine is designed so that all input and output shafts are parallel and extend from the front panel, where they can be fitted with sprockets for interconnecting the several mechanisms. The sprockets, which are coupled as needed by chains of the ladder type, serve not only to drive the mechanism but also to multiply one quantity by another. For example, an input shaft equipped with a sprocket of 12 teeth that makes one revolution will impart a three-quarter turn to an output shaft equipped with a sprocket of 16 teeth. The action is equivalent to multiplying a quantity x by .75. The input quantity x can have any value.

"Multiplication by a negative number is accomplished by crossing the chain so that the sprockets rotate in opposite directions. A pair of meshed gears would work, but gears cannot be interchanged as handily as sprockets in a machine equipped with shafts in fixed positions.



Overall view of Gordon F. Pearce's computer

"The mechanism that performs the mechanical equivalent of integration consists of a wheel that rolls on the face of a smooth disk and a carriage that can shift the path of the wheel between the center and the edge of the disk [*see bottom illustration on this page*]. Mechanisms of this type find occasional use as speed changers. The disk is driven by a hand-operated crank that represents the variable input x. The carriage that transports the wheel is moved by a sprocket-driven screw, whose rotation represents the second variable quantity, y.

"The rate at which the wheel turns with respect to the rotation of the disk depends on the point at which the wheel makes contact with the disk. The wheel stands still when it is at the center of the disk but rotates at an increasing rate as it is shifted toward the edge. In a sense the device totals the product of two quantities that can vary in size continuously while they are being multiplied. The rotation of the shaft that carries the wheel represents the output of the integrator.

"In the symbolism of the calculus the output W is written $\int y dx$, the long s meaning 'the sum of.' The product of any two quantities, including that of the variables y and dx, can be depicted as an area. For example, the product of 3 times 4 can be represented by a rectangle that contains four rows of three squares. Similarly, the integration of a variable quantity with respect to a constant can be represented by an area bounded on one side by a curve. In this regard the integrating mechanism of the computer resembles a simple planimeter, the instrument used for measuring areas enclosed by a curving line [see 'The Amateur Scientist'; SCIENTIFIC AMERICAN, August, 1958].

"All the mechanisms except the sprockets and chains are enclosed in a box of sheet metal. The top of the box serves as the base of an automatic recorder fitted with two movable pens that write on a rectangular sheet of graph paper [*see illustration on opposite page*]. The paper rests on a flat table that is moved sideways along the x coordinate of the graph by means of a screw. The screw is driven by a pair of bevel gears equipped with a sprocket that is accessible on the front of the machine. Similarly equipped screws drive two pen carriages at right angles to the movement of the paper, along the y coordinate of the graph. Hence two output quantities, y_1 and y_2, can be recorded simultaneously. The machine includes two integrators and one unit for adding and subtracting.

"The fabrication and assembly of the machine can be performed easily by anyone with the basic shop experience acquired in high school. The necessary gears, sprockets and chain are all standard items and can be bought locally from dealers in mill supplies. The accuracy of the computer will depend in part on the workmanship and the care used in assembly.

"The housing of the addition-subtraction unit can consist of a channel section formed by screwing sheet-metal sides to a block of wood. Holes through the sheet metal serve as bearings for three shafts. The shafts of my computer are 4½-inch lengths of drill rod 3/16 inch in diameter. The x and y shafts each carry a spur gear (Boston Y4884) locked in place by setscrews. The $x + y$ shaft carries four loosely fitting gears, consisting of two bevel gears (Boston G463Y) each of which is soldered to a companion spur gear (Boston Y4842).

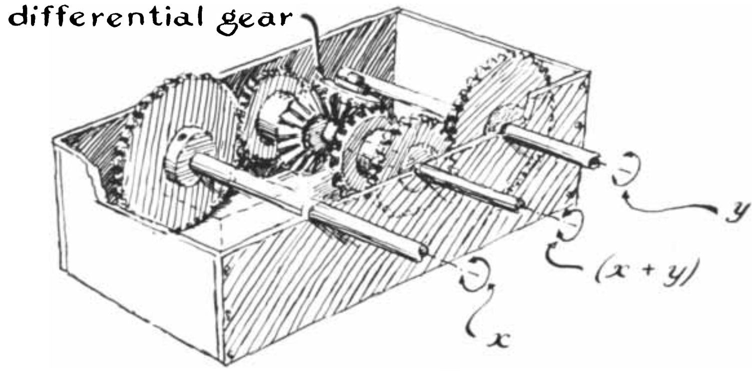
"To solder the gears, I tinned the mating faces of a spur gear and a bevel gear, slipped the gears onto a scrap of rod to align the holes and heated them until the solder melted. When the gears cooled, I reamed the hole so that the assembly ran smoothly on the $x + y$ shaft. Incidentally, all gears may as bought have slightly undersized holes. If so, ream them to fit their shafts.

"The differential gear (Boston G463Y) turns on a shaft that extends from a carrier block locked to the $x + y$ shaft by a setscrew. I made the block of 1/2-inch hexagon bar stock 3/4 inch long, but square stock would do. A shallow hole is drilled in the center of one end. Into the hole is soldered a length of drill rod 3/16 inch in diameter. The rod is then cut off at a point 5/8 inch from the end of the block. This stub shaft supports the differential gear.

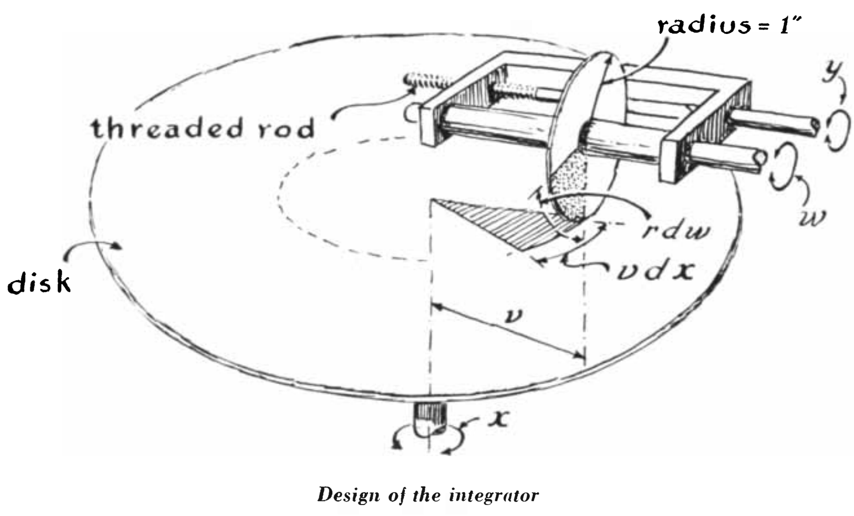
"At right angles to the stub shaft drill a hole 3/16 inch in diameter through the block. Space the center of this hole exactly 1/4 inch from the end of the block to which the stub shaft is attached. This transverse hole should make a snug but sliding fit with the $x + y$ shaft.

"In the end of the block opposite the stub shaft drill a hole that penetrates the transverse hole and thread it for a setscrew. Finally, near the outer end of the stub shaft drill a transverse hole 1/16 inch in diameter through the stub shaft. After the differential gear has been assembled on the stub shaft slip a cotter pin through the 1/16-inch hole.

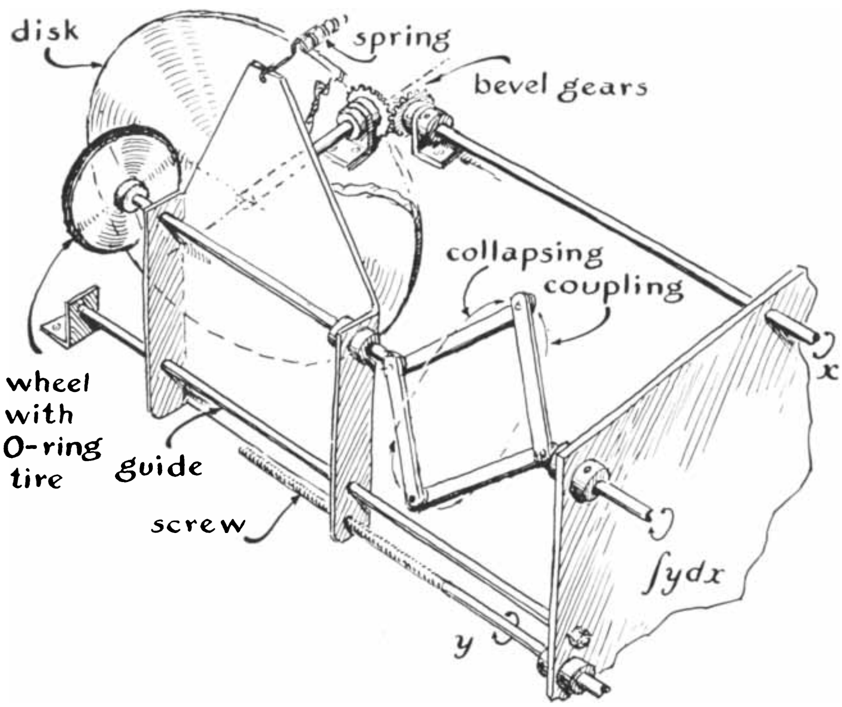
"When assembling the unit in the



Addition-subtraction mechanism of the computer



Design of the integrator

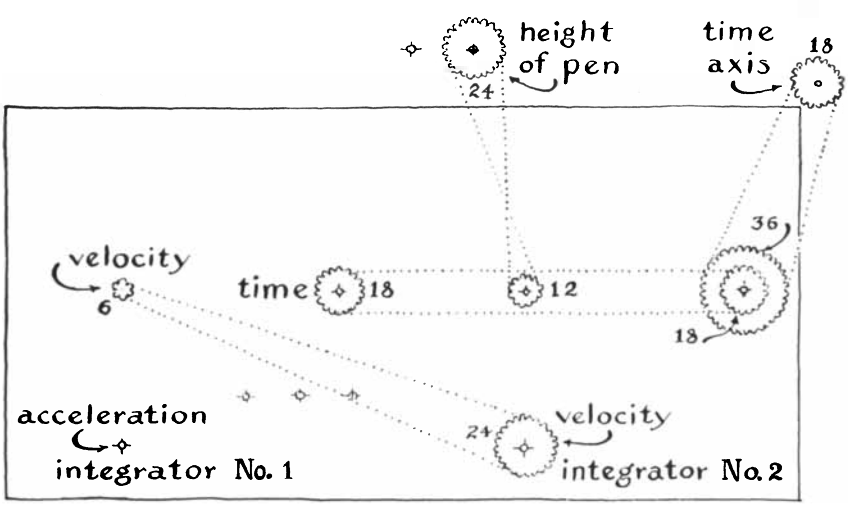


Details of construction of the integrator

housing, pass the $x + y$ shaft through the outer bearing and into one of the spur-bevel gear subassemblies. Slip the assembled carrier block and differential gear on the $x + y$ shaft. Pass the shaft through the remaining spur-bevel gear and the rear bearing. Lock the carrier block to the shaft by its setscrew. The $x + y$ shaft should turn freely, even when either of the spur-bevel gears is held stationary.

"The two integrators are made exactly alike. The rotating disk consists of two parts, a base of 1/4-inch plywood and a disk of 18-gauge sheet metal. The metal is facing for the plywood. The two parts are fastened together at the edge by four countersunk machine screws with flat heads and attached at the center to a flange that fits a shaft 1/4 inch in diameter. I made the flange with a lathe, but a spur gear about two inches in diameter could be substituted.

"The wheel that rolls on the disk consists of a steel pulley fitted with an O ring of rubber slightly more than two inches in diameter. The effective radius of the wheel becomes one inch when the O ring is pressed against the disk by a helical spring that exerts a force of eight ounces. A collapsing coupling links the shaft of the wheel to a second shaft that extends through the front panel of the machine [*see illustration above*].



Sprocket program for solving the falling-stone problem

"The screw that drives the carriage of the wheel is 1/4 inch in diameter and has 20 threads per inch. All threaded shafts of the computer are made from the same stock. Bevel gears (Boston G464Y) couple the input shaft x of the integrator to the drive shaft of the disk. Similarly, a Boston G481-Y-P bevel gear, which is locked to input shaft x of the recorder, meshes with a Boston G481-Y-G bevel gear to drive the table sideways. The movement represents the x coordinate of the graph. I find that pens equipped with plastic nibs are more reliable than ball-point pens, although they draw wider lines.

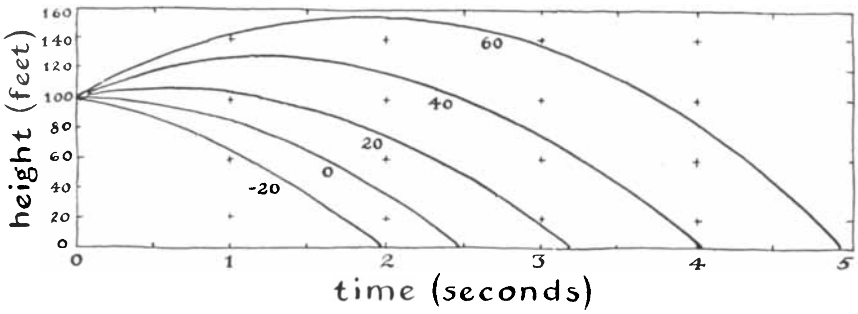
"A set of 15 sprockets in various sizes enables the user to program the machine for solving problems that are of most interest to amateurs. All the sprockets in my machine, as well as the gears, were made by the Boston Gear Company. My set consists of two CBA6 sprockets, two CA9, one CA10, two CBA12, four CBA18B, two CBA24B and two CBA36 sprockets. (The numeral in these code numbers indicates the number of teeth on the sprocket.) About six feet of ladder chain that matches the sprockets is required.

"After assembly all traces of grease must be removed from the rubber O ring of the integrator wheels and the faces of the disks, preferably by a degreasing agent such as Varsol. The wheels must not slip on the disks. All shafts must turn easily in their bearings. A lubricant such as Molyslip is useful during the initial running period.

"The operation of the computer is perhaps best explained by an example. Consider the physical problem of determining how the position of a stone, dropped from a building 100 feet high, will vary with time. In elementary physics the equation that describes the motion of a stone in free fall states that the acceleration a is equal to the acceleration of gravity $-g$. In this example upward acceleration is assumed to be positive. Downward acceleration is indicated by the negative sign.

"In this computer quantities are represented by the rotation of shafts. To feed a problem into the machine, the programmer begins by specifying the number of revolutions a shaft must make to represent one unit of the quantity under consideration. This ratio is known as the scale factor.

"In the case of the falling stone the y shaft of the first integrator is selected to represent acceleration. It can be arbitrarily assumed that one revolution of the y shaft should equal an acceleration of one foot per second per second. Some



Curves representing falls of a stone

other scale factor could have been selected. It could have been assumed, for example, that 10 revolutions were to equal one unit of acceleration, but a scale factor of one is practical.

"Having made this decision, the programmer can feed into the y shaft the acceleration of gravity: -32.2 feet per second per second. (Gravity acts in the downward direction, so that the quantity is negative.) This quantity is entered by rotating the y shaft 32.2 turns in the counterclockwise or negative direction, which moves the wheel away from the center of the disk, its zero position.

"The time during which the stone falls will be fed into the x shaft of the first integrator. A scale factor must also be selected for this shaft. In making the selection account is taken of the fact that the scale factor of the output shaft of the integrator is determined by the scale factors of the x and y shafts. The integrators of the machine are designed so that the output shaft's scale factor (S_3) is equal to the product of the scale factors of the x shaft (S_1) and the y shaft (S_2) divided by 20. ($S_3 = S_1S_2 \div 20$).

"A scale factor of 40 can be assigned to the x shaft, that is, 40 revolutions of the x shaft will represent one second of time. The integrator combines time in seconds with acceleration in feet per second per second to determine velocity in feet per second, which is represented by the rotation of the output shaft. As explained, the scale factor of the output shaft is determined by multiplying the scale factors of the inputs and dividing by 20: $40 \times 1 \div 20 = 2$. Therefore two turns of the output shaft will represent a velocity of one foot per second.

"The position of the stone at any instant after it has been dropped depends on how long it has been falling. To find any position the velocity of the stone's fall must be combined with the interval of time through which it has been falling. The calculation can be made by feeding the output of the first integrator into the y shaft of the second integrator, and time into the x shaft of the second integrator. The x shafts of the two integrators, which represent time, are therefore coupled by a ladder chain, which links sprockets of equal size.

"However, sprockets chosen for a speed reduction of 1 : 4 are used between the output of the first integrator and the y shaft of the second integrator. This arbitrary reduction in speed lowers the torque imposed by the load on the output shaft of the first integrator and decreases the tendency of the wheel to slip on its driving disk. The arbitrary reduction is taken into account when computing the scale factor of the output shaft of the second integrator: $40 \times 40 \times 1 \div 20 \times 20 \times 4 = 1$, indicating that one revolution of the output shaft is equivalent to a displacement of one foot in the position of the falling stone. The initial velocity of the stone is zero. This information is fed into the machine by rotating the y shaft of the second integrator by hand until the wheel stands at its zero position in the center of the disk.

"The scale of the graph that will be drawn by the movement of the pens and the table must also be determined. The screws that drive the pens and the table have 20 threads per inch. Assume that the horizontal or x coordinate of the graph will display time—the quantity represented by the rotation of the x shafts of the integrators. The scale factor of these shafts is 40. By coupling either x shaft to the screw of the table by sprockets of equal size the graph can be moved two inches to represent one second.

"The vertical scale of the graph is similarly determined. A displacement of one foot in the position of the stone is represented by one revolution of the output shaft of the second integrator. By falling through 100 feet the stone causes the output shaft to make 100 revolutions. Coupling the output shaft directly to the shaft of the pen would cause the pen to move five inches along the y coordinate of the graph during 100 revolutions. The movement is equal to a displacement of 20 feet per inch. It is desirable, however, to minimize the torque imposed on the output shaft of the integrator. A combination of sprockets that reduces the speed by a ratio of 1 : 2 results in a scale of one inch per 40 feet of displacement and a graph of reasonable size. The chain that couples the output of the second integrator to the pen must be crossed to indicate a negative quantity, because the stone falls downward.

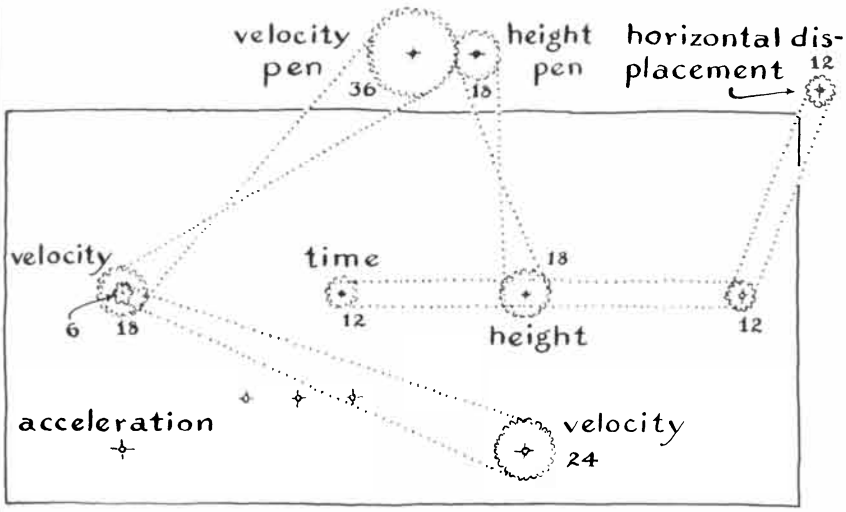
"A sheet of graph paper ruled with rectangular coordinates is placed on the table and attached at the corners by adhesive tape. The shafts of the pen and the table are turned by hand until the nib of the pen rests on the y coordinate at a point 2½ inches from the x coordinate. If desired, the x and y coordinates can be lettered to indicate seconds and feet respectively.

"The recorder is then coupled by chains to the driving sprockets. All chains should fit snugly, being neither so tight as to cause excessive wear or friction nor so loose that backlash results. The links of the chain can be opened and closed easily with a pair of long-nosed pliers. A hand crank bent from drill rod is attached to any x shaft by means of a coupling equipped with setscrews. The accompanying diagram [*bottom of opposite page*] shows the pattern of chains and sprockets used for programming the problem of the falling stone. The numerals in the diagram indicate the number of teeth on the sprockets.

"To solve the problem turn the crank counterclockwise. The resulting graph will take the form of a smooth, downward-sloping curve that begins at the 100-foot point on the y coordinate and ends just short of the 2.5-second point on the x coordinate. The graph is identified by a zero in the accompanying illustration [*above*] to indicate that the velocity of the stone was zero at the moment it was released.

"The computer can be programmed to display the behavior of the stone thrown upward or downward with various velocities. For example, to solve the problem for an assumed upward velocity of 60 feet per second insert 60 into the velocity shaft (y) of the second integrator. The scale factor of this shaft is $V/2$. The initial setting of the shaft is therefore 60/2, or 30 turns in the clockwise direction. Turning the handle of the computer now generates the new solution. The consequences of assuming other initial velocities, such as -20, 20 and 40 feet per second, were similarly computed and resulted in graphs as shown.

"The behavior of a bouncing ball can also be computed. Assume that the ball is projected horizontally at known ve-



Sprocket program for the bouncing-ball problem

locity from a predetermined height, that friction between the ball and the air is negligible and that the ball loses 40 percent of its kinetic energy at each impact with the ground. The problem is to determine the path of the ball. Two pens can be used, one to display the velocity of the ball and the other the height. The pattern of interconnected sprockets that solves this problem appears in the accompanying illustration [*above*].

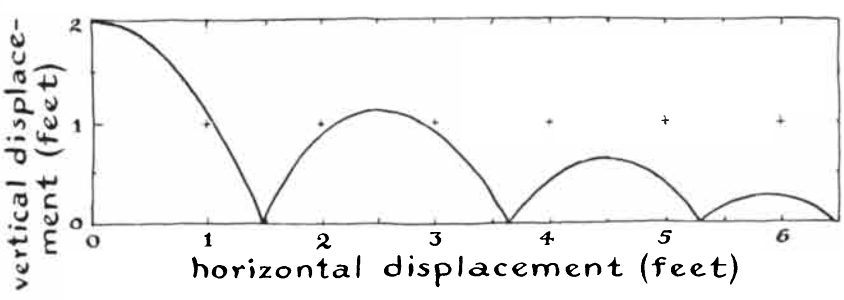
"An interesting procedure is to solve the problem and plot both the vertical displacement and the vertical velocity simultaneously against the horizontal displacement. When the ball strikes the ground, stop the computer and read the velocity as recorded by the pen connected to the output of the first integrator. Multiply it by −.774 to find the lowered velocity caused by the impact and set the new velocity as the revised initial condition in the second integrator. Restart the computer by turning the handle counterclockwise and repeat the procedure each time the ball strikes the ground. The accompanying illustration [*below*] shows how the ball bounces.

"To reset an integrator without disturbing the chains lift the wheel from contact with its disk by pulling the carriage against the force of the spring. While holding the wheel away from its disk, rotate the sprocket that drives the velocity pen to the point at which the pen indicates the revised velocity. This operation simultaneously shifts the carriage of the second integrator to its proper revised position.

"Other interesting problems that can be programmed include the trajectories of projectiles; the decomposition of chemicals such as dinitrogen pentoxide; the steady-state conduction of heat; damped vibration; the response of instruments such as thermometers and thermocouples to abrupt changes in temperature, and the paths of rockets.

"The amateur who undertakes the construction of this computer will find many uses for it. Probably he will discover that it can become an interesting experimental project in its own right."

Programs for using the computer to investigate problems in mechanics, chemistry, thermodynamics and mathematics will be included in a manual to be published in the near future. The manual will include detailed working drawings of all the parts. For details concerning the availability of the manual write to Gordon F. Pearce, 43 George Street, Waterloo, Ontario, Canada.

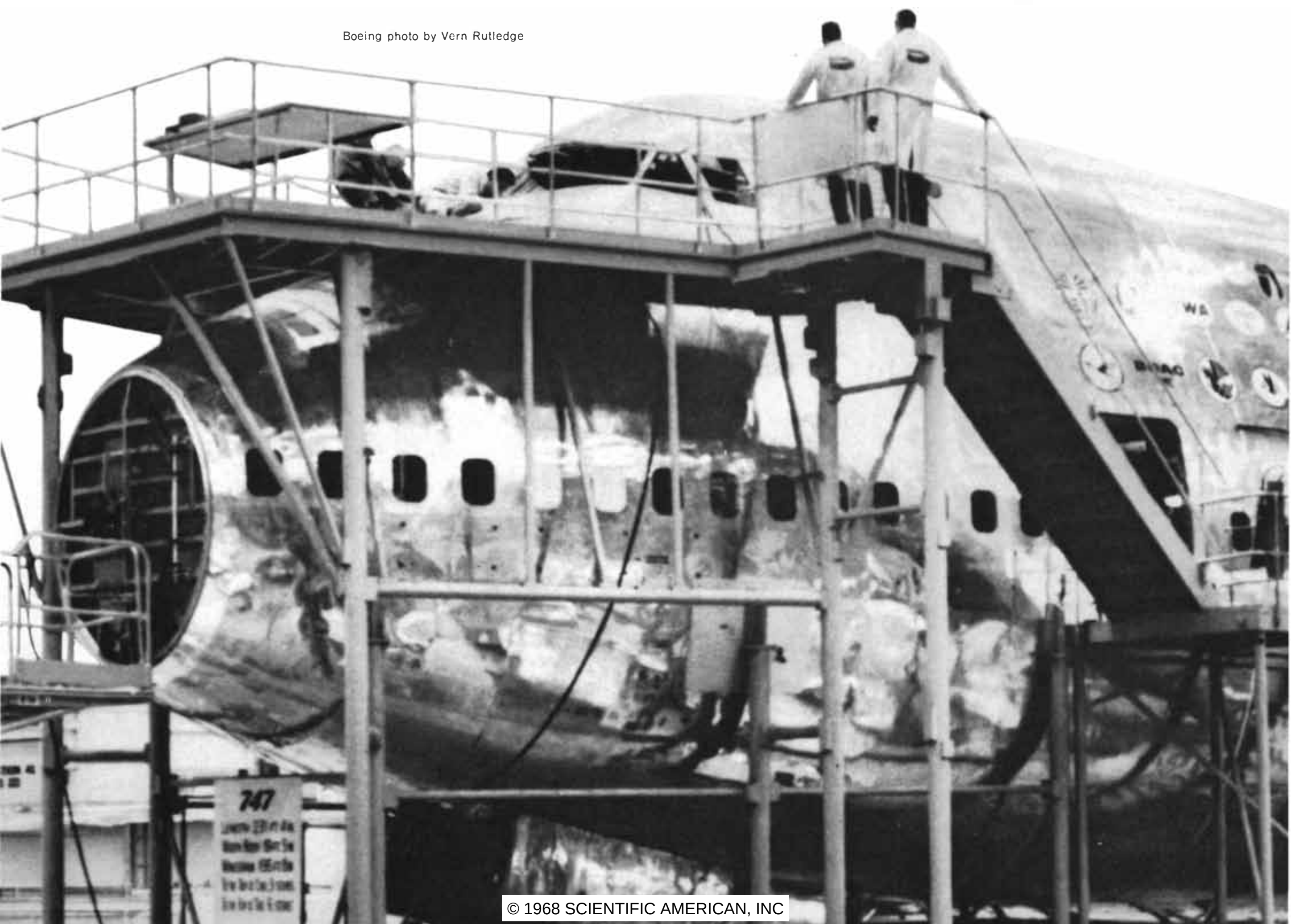


Curves representing the bounces of a ball

Bendix is the kind of company that people you depend on depend on.

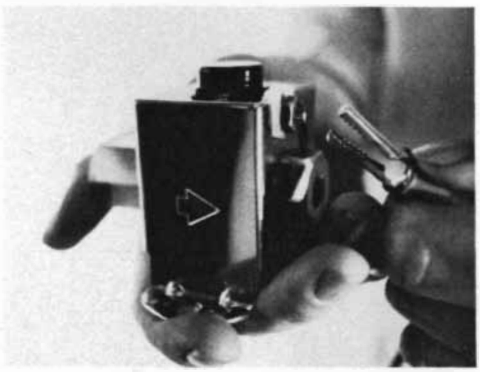
Aboard the new superjets, for instance. Taking shape here is the largest aircraft ever designed for commercial use—the Boeing 747. Starting in 1969, it will carry more than 350 passengers at cruising speeds up to 625 miles an hour. It's a lot of airplane. And a lot of Bendix is going into it. The first production 747 will use equipment from 11 Bendix divisions—including weather radar, a power system with 360,000-watt capacity, five communication/navigation systems, flight control computers, landing gear and aileron servo actuators, wheel and brake assemblies and other systems, subsystems and components. In aviation—as well as in automotive, oceanics, aerospace, automation and electronics—the heart of our business at Bendix is creating new ideas and developing them to maximum usefulness. The Bendix Corporation/Fisher Building/Detroit, Michigan 48202.

Boeing photo by Vern Rutledge



Out where the oil is. Bendix is getting more involved in exploration for offshore drilling—from making environmental studies for platform construction and pipeline placement to surveying areas for petroleum deposits in the first place.

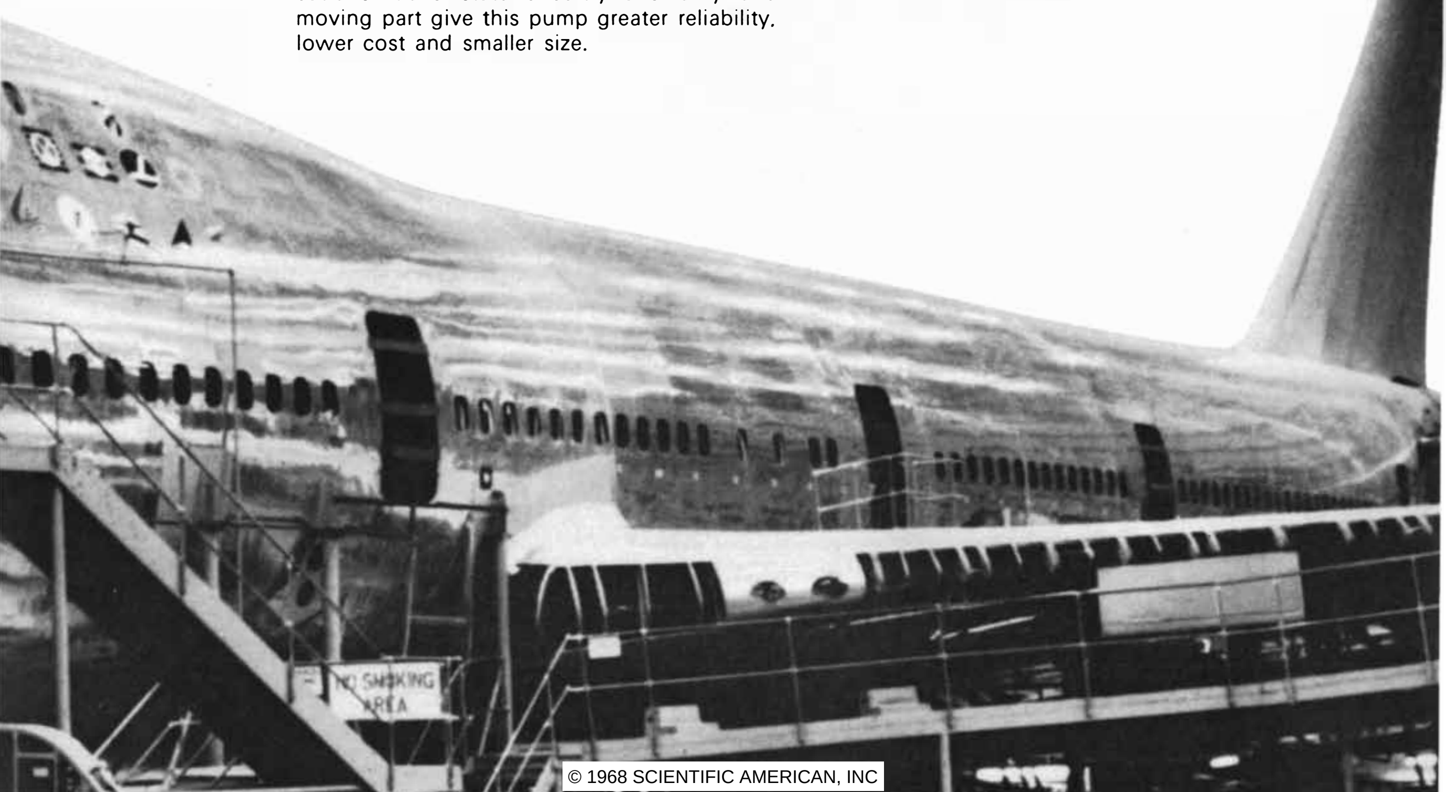
At the finish line. This room-size automatic grinder made by our subsidiary, Besly-Welles Corporation, finish grinds the sides of large automotive transmission gears at a rate of 1,200 an hour. All its operations are automated—including loading and unloading.



In the solid state. A Bendix technician tests our new solid state fuel pump for farm tractors, marine engines and industrial applications. Solid state circuitry and only one moving part give this pump greater reliability, lower cost and smaller size.

Bendix

Where ideas unlock the future



BOOKS

The psychological wreckage of Hiroshima and Nagasaki

by J. Bronowski

DEATH IN LIFE: SURVIVORS OF HIROSHIMA, by Robert Jay Lifton. Random House ($10).

The second world war began in the summer of 1939 with a pact between Hitler and Stalin and ended six years later with the dropping of two atomic bombs on Japan. To almost everyone at the time the second of these events was as unexpected and shocking as the first had been. Evidently the huge enterprise of inventing, building and mounting the atomic bomb had been the best-kept secret of the war. And for most people, scientists and nonscientists alike, it also turned out to be the most grisly secret. After the first days of triumphant wonder a kind of shudder went through the world, a swell of fear and revulsion together, which 20-odd years have now smoothed out of our memories. Everyone at the time had a sense of guilt about the atomic bomb, and although most people naturally shifted the blame to science, that desperate disclaimer was also a sign of penitence.

Twenty years is too long for sorrow, which time does not so much heal as blunt. The bombs that wiped out Hiroshima and Nagasaki have been allowed to become modest weapons in the tactical armory, and people read with resigned indifference that hydrogen bombs more than a hundred times as powerful are carried overhead in clusters 24 hours of the day. In that ebb tide of conscience, in which we let governments argue *about* disarming, the moral impulse of 1945 has been eroded. We might have supposed that the sense of guilt had been washed away without a trace, had not Professor Lifton discovered it still haunting (of all people) the survivors of Hiroshima. The discovery gives his quiet and penetrating book a kind of cosmic irony that, more than any burst of righteousness, ought to shake us all out of our somnambulism.

Professor Lifton had spent four years in Japan, off and on since the war, before he paid a visit to Hiroshima. For the last two of those years he had worked on a psychological and historical study of Japanese youth. There he found (among other things) what we all know and resolutely forget:

"The great majority had either no memory of the war at all or only the most meager recollections of it. But what became clear when I explored with them their sense of themselves and their world was the enormous significance for them, however indirectly expressed, of the fact that Japan alone had been exposed to atomic bombs."

So he decided early in 1962 to stay on for another six months and to spend them in Hiroshima, with a few days in Nagasaki added.

His method of study was to interview 75 people, usually for two periods of two hours each. The interviews were carried out in Japanese through a research assistant, although Professor Lifton does speak some Japanese. Forty-two of those interviewed were chosen for their known and articulate prominence in atomic bomb matters, and the other 33 were taken at random from the official list. All were *hibakusha,* which means that either they were within the city limits when the bomb fell, or entered the inner city in the next 14 days, or came into close contact with bomb victims, or that their mother was in one of these groups and was pregnant with them at the time.

Several different estimates have been made of the number of people killed by the bombs in Hiroshima and Nagasaki. I shall stick to the figures that my colleagues and I in the British Mission to Japan worked out in November, 1945, there. We computed that in Hiroshima when the bomb fell on August 6 there were 320,000 people, of whom 80,000 were killed, and that in Nagasaki on August 9 there were 260,000 people, of whom 40,000 were killed. Large numbers of people have died since then from the aftereffects of radiation from the atomic bombs. Allowing for these and for normal deaths over 20 years, the figures are in fair agreement with the official number of *hibakusha* now, namely 160,000 from Hiroshima and 130,000 from Nagasaki.

The scenes after the bombs fell have been described in eerie detail by John Hersey from the testimony of survivors in Hiroshima and by Dr. Takashi Nagai at first hand in Nagasaki. Every victim believed the bomb had exploded directly above him. Those in the open were badly burned by the flash, so that often their own families could not recognize them. (This happened to two of Professor Lifton's survivors.) Those indoors were buried and when they struggled out, almost naked, they found themselves surrounded by fires. Everyone who could move filed in numb silence to the rivers; the injured were abandoned and could be heard in the still heat crying for water. Professor Lifton quotes one of his survivors who was a schoolgirl at the time:

"I felt my body to be so hot that I thought I would jump into the river.... The teacher from another class, a man whose shirt was burning, jumped in. And when I was about to jump, our own class teacher came down and she suddenly jumped into the river.... Since we had always looked up to our teachers, we wanted to ask them for help. But the teachers themselves had been wounded and were suffering the same pain we were."

Another of Professor Lifton's survivors, a professor of history, saw the destruction from a hill overlooking the city:

"That experience, looking down and finding nothing left of Hiroshima—was so shocking that I simply can't express what I felt.... Hiroshima didn't exist—that was mainly what I saw—Hiroshima just didn't exist."

But those inside the city saw a greater destruction in the breakdown of human consciousness, so that the refugees seemed to them to be "a people who walked in the realm of dreams":

"Those who were able walked silently toward the suburbs in the distant hills, their spirits broken, their initiative gone. When asked whence they had come, they pointed to the city and said, 'That way,' and when asked where they were going, pointed away from the city and said, 'This way.' They were so broken and confused that they moved and behaved like automatons."

So much for what we knew and have been diligently burying in the backs of our minds. What have 20 years done to those 290,000 people who were there and who cannot so easily tidy away the memory of what they saw and how they behaved? Is there indeed a single theme in their lives? Are they still dominated by the atomic bombs?

Certainly Hiroshima has become the atomic bomb city. It has a Peace Park, of course, a memorial hall, a children's monument and a Peace Museum. There is a cenotaph with the inscription: "Rest in peace. The mistake shall not be repeated." The word "mistake" is ambiguous enough to make many citizens feel that they are being blamed for the bomb. (This is a common complaint among *hibakusha*, which they express in the ironic sentence "I apologize for having been exposed to the atomic bomb.") A reinforced concrete building almost under the bomb that stood up to the blast pretty well has been preserved as a permanent Dome of Peace, even though some survivors are still distressed by the sight of it.

But these sober *memento mori* are put in the shade by the other showplace of the peace industry, which is the Hiroshima entertainment district. Nowhere else in Japan is there such a splendor of bars, cafés, restaurants, geisha houses, dance halls and what Professor Lifton politely calls "transient quarters for various kinds of illicit sex." Those who saw the film *Hiroshima, Mon Amour* will remember the contrast between the two aspects of the new Hiroshima, and the strange implication that nevertheless ran behind it that they are inseparable. And so they are: the bomb is entwined in the lives of those who survived it, whether they lead a children's march or show their keloid scars in a Hiroshima brothel. The *hibakusha* leaders may rage at those who "sell the bomb," but their anger is also a form of self-accusation; they cannot help themselves, they must exploit the bomb like any crippled postcard-seller.

The *hibakusha* have not been able to escape the ambivalence that always dogs the victim of misfortune. They would like other people to treat them as though they were normal, and at the same time they are hurt if they are not given special sympathy. The effect of these contradictory demands is to frighten those who were not exposed to the bomb, so that survivors find it hard to get jobs, to marry and even to mix with others. Twenty years ago their neighbors were afraid because the *hibakusha* were still psychologically numb, were often ill and (who knows?) might beget monsters. But now the alienation is different in temper, and simply puts the *hibakusha* aside as people who *have something else on their minds.*

The clear August day in 1945 possesses the mind of the survivor as an experience unlike any other, which totally overthrew his inner ordering of the world. He had woken that morning with the confidence, built so carefully through the years of growing up, that things go like this and not otherwise—that teachers help you, that the city is a solid home and that people act together by choice. By nightfall that framework of unwritten laws that had seemed to be laws of nature had fallen apart into meaningless pieces—the teacher had jumped into the river, Hiroshima didn't exist and its people behaved like automatons. Just as sometimes a great man has the order in the world revealed to him in a vision (René Descartes on November 10, 1619, for example, and Blaise Pascal on November 23, 1654), so ordinary men and women in Hiroshima that day had a direct vision of a counterrevelation: the failure of the human order in the world. Professor Lifton calls this "the replacement of the natural order of living and dying with an unnatural order of death-dominated life." Thus his stress is on "the indelible imprint of death immersion," when I would stress the fatal immersion in the collapse of human values. But in principle Professor Lifton and I are at one, and what he finds is the same withdrawal of confidence, a cutting of the roots of conduct, that I felt there three months after the bomb was dropped.

Somehow the roots have to heal, of course; the delinquents disappear from Hiroshima's station, the widows move into the entertainment district and the men whose assurance has been sapped ask their firms without fuss to let them work at lesser jobs. But a psychological wound that is healed is still a wound, a kind of bomb scar or keloid of the personality, which expresses in another form the ambiguity of the *hibakusha*. They have been the victims of a disaster that was manufactured by others, yet their sense of failure is more anguished than we expect, and we see that there is another wound under the scar. The victim has not only been a victim; he has also witnessed and (by his inaction) has condoned the action of turning one's back on other victims. Every survivor has memories of those he did not help:

"I heard many voices calling for help, voices calling their fathers, voices of women and children.... I felt it was a wrong thing not to help them, but we were so much occupied by running away ourselves that we left them."

"His head was covered with blood, and when he saw us he called to us.... 'Yano [he said to my daughter], please take my child with you. Please take him to the hospital over there.'... I heard later that he survived...but that the child died.... And when I think of not helping him despite his begging me to help, I can only say that it is a very pitiful thing."

Because family ties are strong in Japan the memories are particularly painful in those who feel they neglected their parents. For example, a girl who was 14 at the time is full of remorse for her father's death, although she only complained that his wounds smelled.

The keloid on the personality of the survivor at Hiroshima and Nagasaki is the sense of guilt. "I apologize for having been exposed to the atomic bomb" is not altogether a joke after all, if we read it to mean "I apologize for having *survived* the atomic bomb." Even when the victim was helpless at the time and could have done nothing to help, he is disrupted by doubt and a feeling of inadequacy. All around him people died; why did he deserve to live? Will that act of *hubris* be visited on his children? "Those who died are dead," a survivor from Nagasaki said to Professor Lifton, "but the living must live with this dark feeling." There is no shaking off the divided feeling between one's own fate and the fate of others, between suffering and fear, between pity and revulsion. It is symbolized by the memory that comes to one *hibakusha* at a Japanese feast:

"The color of my brother's keloid—the color of his burns—mixes together with my feeling...what I saw directly—that is, the manner in which he died—that's what I remember.... The color was similar to that of a dried squid when broiled—so that I think of it whenever I see dried squid.... I have...a very lonely feeling."

Professor Lifton is masterly in his analysis of the ambiguities that make the *hibakusha* so disturbed in himself and disturbing to us. He writes without jargon and without hectoring, with a personal air of courtesy that invites the reader's assent but does not presume on it. It is notoriously hard to persuade scientists that there is any point in psychological analyses that do not give unique

answers. (It is Karl Popper's complaint about Freud and Adler.) Yet I think Professor Lifton will persuade even a skeptical scientist that it is the nature of tragedy to divide the human personality against itself, and that the survivors of Hiroshima act out this division symbolically in their sense of guilt.

The *hibakusha* resents his own feeling of guilt, yet he cannot resolve it; he is equally unhappy as victim and as survivor. The inner struggle between the roles of victim and survivor is displayed particularly plainly by the Japanese, for two reasons. First, they are brought up in a rigid code of family and social propriety, so that the breakdown of conduct at Hiroshima and Nagasaki was very stark for them. And second, the Japanese pay much attention to symbolic meanings, so that the division in the *hibakusha*'s feelings is constantly reinforced by the ambivalence in the symbols that express them. (For example, the citizens of Hiroshima are wild supporters of their baseball team, but it usually comes in last.)

It was therefore natural for Professor Lifton to think of applying his theme also to some other body of survivors who are not Japanese. In his last chapter, "The Survivor," he makes some comparisons with the men who went through the Nazi concentration camps and lived. What he says here is worth reading, and is evidently consistent with his findings in Japan. But since he has had to take his evidence at second hand from other people's writings we now miss the force of direct speech that makes the rest of the book so convincing. We can see that those who survived the camps are troubled by guilty memories as the *hibakusha* are, but the analysis has become more formal, and there is just a hint of a classroom thesis in the argument.

For the rest, I am convinced by Professor Lifton's powerful book, and I am at variance with his analysis at only one point. As his choice of title shows, he is preoccupied with death as the visible cause and symbol of the survivor's guilt, and in fact he commonly uses the single phrase "death guilt" for it. He says early on, "I shall use the term 'death guilt' throughout the book to encompass all forms of self-condemnation associated with literal or symbolic exposure to death and dying."

Now, it is true that the victims of the man-made disasters at which we have stood by were much exposed to death and dying. I have quoted the casualty figures at Hiroshima and Nagasaki—and as for the concentration camps, "a person who fully adhered to all the ethical and moral standards of conduct of civilian life on entering the camp in the morning would have been dead by nightfall." Nevertheless, I think that the distress of the survivors was caused, more profoundly than by the encounter with death, by the dissolution of "the ethical and moral standards of conduct of civilian life" that robbed them of their bearings.

Certainly the fear of death (and of the unpredictable way death would strike in Hiroshima and Auschwitz) is the infecting virus that begins the social dissolution. Yet the girl in Hiroshima filled with remorse for her father's death had not killed him; what she blamed herself for was disrespect. Or think of one of the men I wrote about in *The Face of Violence*, say Joseph Wiener, once professor of international law at the University of Vienna, whom the Nazis drove mad and put in charge of the camp pigs. He informed against prisoners who stole food from the pig swill; yet it was not the presence of death that deranged him but (as he knew in his sane moments) the debasement in his person of human dignity. Such examples seem to me to make plain that what unhinges the victim's self and leaves it rudderless is not an inner split between life and death but a split between himself and the social order. From childhood he has been taught to submit his own demands to those of society (this is my theme in *The Face of Violence*) and suddenly not life but society dies; he sees walk into the open the anarchy he once dreamed of in secret.

I have left to last the question that must be uppermost for many readers: What did the Japanese think of the Americans, who, after all, had dropped the atomic bombs? I found this the most puzzling issue to get to grips with 20-odd years ago, and it seems to be so still. The Japanese seldom spoke out in plain resentment; perhaps they were either too stunned or too polite. They seemed mostly to be aware that we knew as little about the effects of the bomb in advance as they did; one or two professors spoke to me ironically about the "experiment," and the deepest anger Professor Lifton finds is at having been treated like guinea pigs.

Many Japanese feel they were singled out as no white enemy would have been, as something less than human; some of them may have seen the pictures of Japanese looking like vermin (like the Nazi pictures of the Jews) that were current in America during the war. There was a rumor in Nagasaki when I was there that the atomic bomb burned only dark-skinned people; it was not true, but it put the right pinch of scientific fact in the racial stew.

But the dominant feeling was and is that Americans are simply insensitive. Professor Lifton gives many examples to justify that: the early censorship, the display of power and wealth, the clinical examinations and the policy of studying the victims without treating them. One wonders what the Japanese would now think if the first bomb had in fact been dropped on Kyoto, as General Groves's target group had proposed. I invented my own rumor at the time, which is not true but which I am glad to spread in *Scientific American,* that a member of the target group was told this would be like bombing Florence and that he asked "Florence who?"

There is nothing to say about the prospect that has not been said already. As Professor Lifton's book demonstrates, we have to get it into our heads that the atomic weapons do not create casualties but chaos—a lasting chaos of the human values. The *hibakusha* are haunted and lamed by a shame that is not their own, and that is 20 years old—and so are we. Like them we have an ambivalence between self and society, nation and humanity, that prevents us from forming any policy of right conduct. And the guilt that comes from facing two ways bites deeper, because it prevents us from crystallizing any *principle* of right conduct. Professor Lifton's last message is that we should learn what he calls survivor wisdom, and no one can now doubt that survivor wisdom says that only men of principle survive whole.

Short Reviews

GREAT WATERS, by Sir Alister Hardy. Harper & Row, Publishers ($10.95). In 1925 Captain Scott's wooden square-rigger, the Royal Research Ship *Discovery,* sailed out of the mouth of the River Dart again for the Southern Ocean. Refitted and crammed with scientists and their gear, she was bound not for the ice-locked continent but for the waters that wash the antarctic shores, the realm of the wandering albatross, the great blue whale and the green and red plankton pastures of the open sea that feed them all. The *Discovery's* chief zoologist, the author, is a lanky, inventive, humorous, sensitive and now distinguished scholar; his book is a journal of that voyage, a grand and winning mix of narrative, diary, maps, afterthoughts, photographs, watercolors, pen-and-ink drawings, anecdotes, doggerel and scientific analysis, completed 40 years after the sailing and nearly all produced by his own hand.

How the 40 years floated by is a story in itself. The first *Discovery* mainly studied the whaling grounds off the Falklands and South Georgia. She was relieved after five years by the steamer *Discovery II,* whose range allowed work on a more suitable scale than did the slow reaches of the wooden square-rigger. Then World War II came, and after the war Sir Alister, by then the senior surviving working scientist of his voyages, and a professor at the University of Oxford, began to see that any personal account of the *Discovery* voyages was up to him. But he had somehow come to spend a dozen more years writing a two-volume natural history of the open sea around Britain, so that it was not until 1961 he could begin assembling his story. A wonderful story it is. He argues, and one gladly agrees with him, that it was not too late; now he could view his own years in the perspective of the work that followed, the 34 volumes of published reports, the tens of thousands of samples in jars.

Sir Alister is a student of plankton. He is also an instrument designer and something of an engineer in the high British tradition. On his first voyage to the wide antarctic waters he brought his continuous plankton recorder, a contraption that dragged a roll of gauze behind the ship to strain out the plankton, unreeling the gauze to expose fresh areas as the ship moved. The roll of gauze becomes a chart in space and time of the life of the depths. Preelectronic, the device is shown with its cheerful inventor: "Proud father and child."

Insight and meaning crowd the pages. Here is a sketch of the green flash at sea (from which we learn that Sir Alister reads *Scientific American*), there a delightful and casual explanation of the colors of pelagic life. The deep-sea beasts are jet black or scarlet; both hues are effectively black in the deep sea, where the light is all blue-green. The fish can make melanin more easily and are black; the crustaceans synthesize the carotenoids and are red. The predators of the top 100 meters have blue-green backs and silver sides ("doing it with mirrors"). The shallow-water plankton are mainly quite transparent. The many deep forms that carry downward-pointing luminous organs have adopted an active form of countershading to prevent their detection as dark shadows across the dim light seen looking up from below; at a distance their predators cannot easily resolve the glowing spots and see only a reduction of the shadow. The most important point made in this always enjoyable book is the role of the krill, the single shrimplike species that is the principal food of the whales. Writes Sir Alister: "This great Antarctic Zone, . . . so rich in life, is bound to play an increasing part in Man's affairs. . . . In time, I believe, great steam or diesel—nay perhaps atomic—artificial 'whales' will collect the krill . . . to feed man. . . . It must not be thought, because the Southern Ocean is so vast, . . . that it would not be necessary to exercise any control over such a fishery. . . . Without such guidance Man is most likely to blunder again."

This is a book less to read through than to dip into again and again, a book to start out from. We are fortunate to have got it at last and to find it still so young of heart.

THE BALKAN NEPHROPATHY, edited by G. E. W. Wolstenholme and Julie Knight. Little, Brown and Company ($3.50). A pocket-sized book with such a title will remind some readers of hours they spent long ago immersed in tales of intrigue set on the speeding trains and in the ancient towns of that polyglot and diverse heart of Europe. Here again is a mystery unfolding on the shores of the Danube, only now it is not fiction. It is the enigmatic, challenging and tragic account of a one-day international meeting of specialists, held last year by the Ciba Foundation in London to look into the cause of the deaths of thousands of men and women. They were all poor farm people, dwellers in the lowlands near the central reaches of the Danube, stretching 100 kilometers or so above and below the Iron Gate in Romania, Yugoslavia and Bulgaria. The disease is a chronic defect of kidney function, leading in some 10 years to almost certain death by the inability to remove protein breakdown products from the blood. Children do not die of the illness, although recent tests show that some even of them have signs of incipient failure.

The condition seems new. It has been recognized by physicians for a decade, although there are rumors that the few doctors among these hardworking peasants a generation ago also knew it. It might be very old and merely long unrecognized. Clinically the disease resembles lead poisoning (indeed, it is even more like cadmium poisoning, although it is more often fatal) and clearly the first task was to search for these metals in the region. The food—mainly the grain of local fields, with meat served only a couple of times a week—the air, the water, the fertilizer contained no dangerous amounts of these elements. One miller was found who had patched his millstones with solder; his village was being slowly dosed with lead, but he was a special case. Fifteen trace elements have been looked for, but none are found in more than the normal amounts, not even in the tissues of the dead.

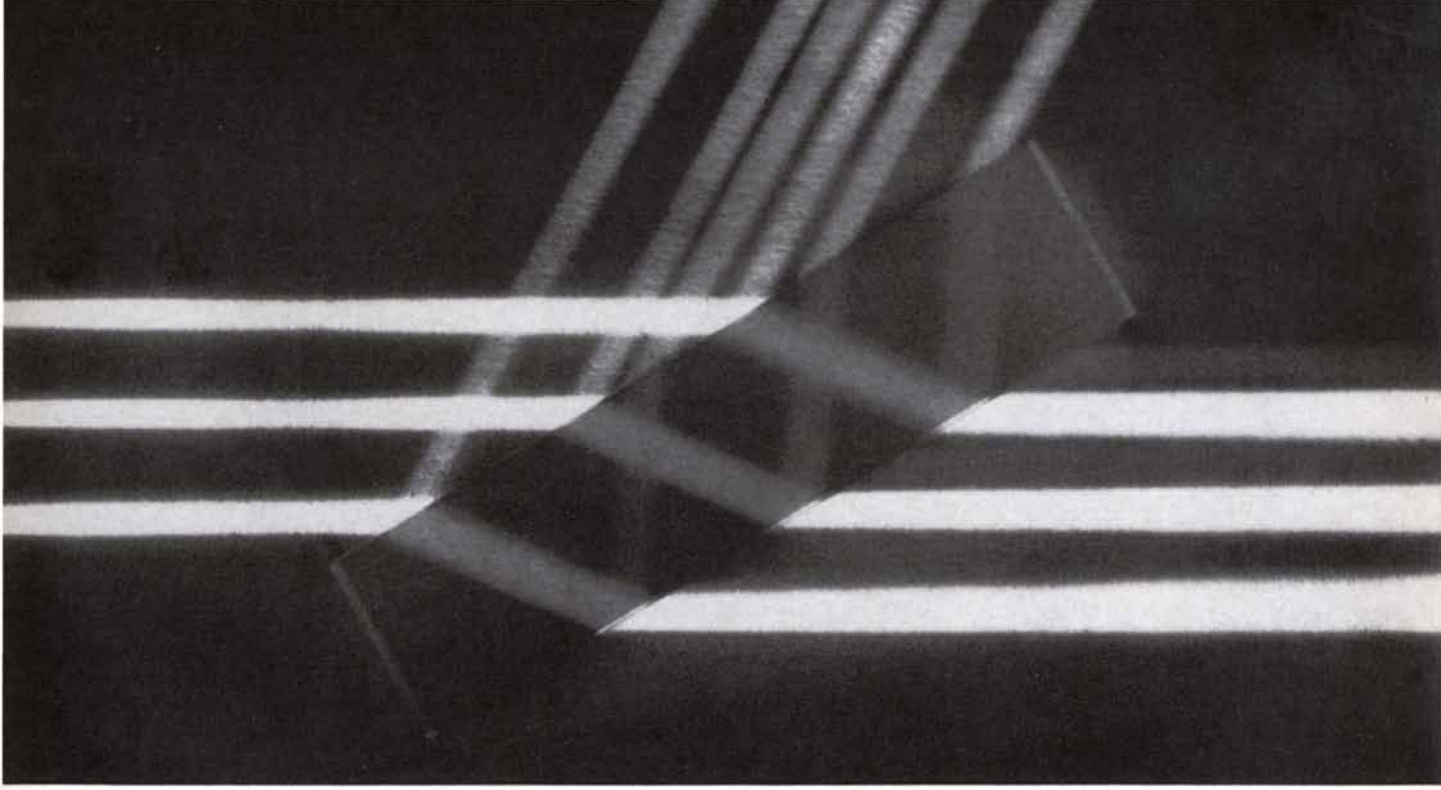
Is the disease hereditary? Certainly it afflicts families; whole families have been wiped out by it in the past decade. That is too complete for a dominant gene, and the children of susceptible families who are sent to live in towns, where the disease is not found, escape. One man lost two wives to the condition. He took a third from a far-off village where the disease was unknown. In a few years she too was dead. Lowland villages have the disease; upland ones do not. In one village on the boundary between the affected and the disease-free region 16 percent of those who lived in Lower Glogovac were affected; only 5 percent of those in Upper Glogovac, 50 feet higher, were threatened. "No differences were to be found between the two parts of the village in housing conditions, diet, disposal of waste, customs, occupations, diseases of men and domestic animals, the use of fertilizers, insecticides, pesticides and other chemicals, consumption of alcohol, or in the economic, social and other ecological conditions. The only difference [is] in the water supply and . . . altitude." So far no one has found anything out of the ordinary in the well water.

Is it strange herbs used in the "people's tea"? No; the village schoolteachers collected samples, and they were harmless. Households without this habit were not always safe. Is it a bacterial infection? No unusual antibodies are found. Is it some fungus in the grain or in the soil, perhaps brought in floodwaters? None has been found, although perhaps one will be. Is it the copper stills used to make slivovitz? No; exactly the same are used elsewhere.

The people themselves say particular houses bring the disease. Sometimes the maps bear them out. One entire village has been evacuated and resettled as an experiment; it is still too soon to perceive results.

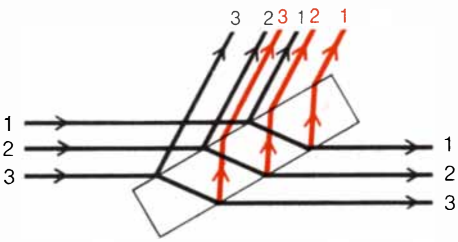
The World Health Organization and specialists from the U.S.S.R., Denmark, the U.S. and the Balkan countries are all in the field and hard at work. The mystery remains; the killer is at large.

AFRICAN MINIATURES: GOLDWEIGHTS OF THE ASHANTI, by Margaret Webster Plass. Frederick A. Praeger, Publishers ($10). The Ashanti nation was



PHOTOGRAPH BY BAUSCH & LOMB.

Three beams of light are reflected from the surface of a glass (at an angle equal to the angle of incidence) and refracted as they enter and issue from the glass (at an angle fixed by the ratio of the speed of light in air and in the glass). The beams are also reflected from the interior surface of the glass and refracted as they issue into air (colored lines in diagram at right).



SCIENTIFIC AMERICAN

Announces a single-topic issue devoted to

LIGHT

To be published in September, 1968

unified at the end of the 17th century, around the miracle of the arrival of the Golden Stool, repository of the souls of all the people. The wonderful stool itself became the recipient of blood sacrifice, held yearly before the Asantehene in his palace at Kumasi. The Ashanti were rich both by conquest and by husbandry, and it seems possible that they first campaigned toward the sea to possess the placer gold of the Gold Coast. It is certain that their court lived in golden splendor, and that the wealthy noblemen used no currency except gold nuggets and gold dust. A wealthy traveler always took along (by bearer) his delicate pan balance (called "balance of the wind" because it trembled in the lightest breeze) and his personal set of weights. Buyers and sellers alike had sets. The manufacturing goldsmiths, who formed a powerful guild, used a similar kit of tools. The weights were cast in brass, adjusted to a unit originally based on the weight of a small seed. Weighing anywhere from a tenth of a gram to a kilogram, never standardized in pattern, they were made after the fancy of the user and the foundryman. They form a corpus of miniature sculptural art (finely detailed because it was first modeled in wax) in every genre: abstract, droll, whimsical, grotesque, satirical or simply figurative. They remind one—not in detail but in concept and variety—of those ivory carvings used to fasten the Japanese gentleman's belt: the famous netsuke.

This book features clear photographs, reproduced two or three times life size, of more than 150 of the finest examples of this art. On one page is a group: a man and a woman pounding yams, with a small child seated at the mortar—a three-inch masterpiece. On another are a few cavalrymen riding lean horses (which in reality could hardly survive in the tsetse-infested bush and were rarely used in battle) carrying small brass cannon fore and aft. The modeling and the use of space, and of spare but telling decoration, are unfailingly attractive. There are even some weights that were cast not in the lost-wax technique but rather in the lost-peanut or lost-locust one; the actual organic form was used as the pattern for the clay mold and burned out, just as the beeswax normally used was melted and poured out of the mold. Ashanti life of a century or two ago is made to live in this intense and subtle art form.

Types are classified in a wearyingly long and logic-chopping appendix, which will be dear to collectors. There is no matching study of the weights as craftsman's tools. What size weights were used most? What system of multiples is found—binary, decimal? What precision of adjustment is implied? None of these matters seems to have gone beyond the beginning made in the classic book on the Ashanti culture written by R. S. Rattray a generation ago.

PALEOLITHIC CAVE ART, by Peter J. Ucko and Andrée Rosenfeld. McGraw-Hill Book Company ($4.95). The brilliant and original work of André Leroi-Gourhan has reopened the dark caverns of the cave paintings to scientific examination after half a century of domination by a single view and a single method. His statistical studies seem to make clear that there was in fact a profound order in the haphazard throng of images and symbols made by the Paleolithic artists. Here is the rejoinder. These writers, an anthropologist and a physicist, make a strong case against the idea that we know very much about the purposes of the art. The statistics seem fragile to them, on the bases of doubtful categorization of location and type, of nonrandom selection and of small samples. They cite some quite mysterious decorations: in the vast chamber of Bédeilhac the walls are bare except for two small bison on the ceiling and one engraved in the farthest corner "so that the artist must have placed himself in a most uncomfortable and cramped position [and] as if to test the credulity of their modern survivors... represented a bison upside down." Apparently damage and change cannot explain this away.

They do not offer a substitute thesis. They recognize that great art is likely to have had many purposes, many ends and many artists whose nature we shall find hard to penetrate. This pocket-sized book, adorned with many pointed maps and photographs, sets out the problem very clearly. The writers conclude: "Some and perhaps many Paleolithic expressions were made for reasons which still totally elude the modern observer."

NAVAJO WILDLANDS, photographs by Philip Hyde, text by Stephen C. Jett, edited by Kenneth Brower. Sierra Club ($25). "Elsewhere the sky is the roof of the world; but here the earth was the floor of the sky," wrote Willa Cather about New Mexico. That is why the large form and high gloss of this sensitively made volume are not pretentious. Centered near the Four Corners of Utah, Colorado, Arizona and New Mexico, the landscapes from Shiprock to Window Rock—Black Mesa, Monument Valley and the Canyon de Chelly—can support this showmanship, which might crush a less strong-boned countryside. Even the cliffsides shining purple and crimson in these photographs, given a low sun, are not false in tone, unreal though they seem. The wide blue sky, the snow-washed shadows of winter, the ancient pictographs are here. The photographer shows physiographic vista and single rock, hogan and trail, yet he never photographs a man's face. The Navaho who hold the land are too private a people to cheapen with candid shots, he explains with a modesty and a taste only the most serious photographers possess, and he had no time to spend the years living with them that he would need "to know how not to violate."

The text is mainly a set of lyrical and apt citations, from Willa Cather and Oliver La Farge and Navaho myth. The landscape holds a magical appeal to eye and mind that rises from these pages like smoke from piñon fire.

DISCOVERY OF THE ELEMENTS, by Mary Elvira Weeks, completely revised by Henry M. Leicester. Journal of Chemical Education ($12.50). This classic of the history of chemistry appears in a thoroughly rearranged seventh edition. Retaining its painstaking display of innumerable sturdy trees, the forest is now made visible by the grouping of the narrative according to various common themes: the three major gases, the periodic-table predictions, the results of X-ray analysis, and so on. Better than ever for reference and for casual delighted reading, the book lacks only a small chapter on the zeroth element, the neutron. One small plum: It was Mikhail Lomonosov and A. Braun who first found, one winter day in St. Petersburg in 1759, that mercury could be as solid as "a pure silver wire."

ATMOSPHERIC ELECTRICITY, by J. Alan Chalmers. Pergamon Press ($15). An up-to-date second edition of this comprehensive yet nearly nonmathematical account of all such phenomena. The work is not always as critical as it should be, but it is both complete and clear on instruments, theories and results. There are a few new points. Even some of the skeptics are now recanting; ball lightning *does* exist, although what it is, is not yet plain. The fundamental mechanism in charge separation within thunderstorms is still not certain; there are surely thunderstorms too warm to have any freezing within them, although the theorists agree that the main separation of charge seems to involve the formation of ice.

INDEX OF ADVERTISERS

JUNE 1968

BIBLIOGRAPHY

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

THE MODULATION OF LASER LIGHT

ELECTROOPTIC LIGHT MODULATORS. I. P. Kaminow and E. H. Turner in *Applied Optics,* Vol. 5, No. 10, pages 1612–1628; October, 1966.

LIGHT MODULATION BY THE ELECTROOPTIC EFFECT IN REVERSE-BIASED GaP *P-N* JUNCTIONS. D. F. Nelson and F. K. Reinhart in *Applied Physics Letters,* Vol. 5, No. 7, pages 148–150; October 1, 1964.

ORIGIN AND USES OF THE FARADAY ROTATION IN MAGNETIC CRYSTALS. J. F. Dillon, Jr., in *Journal of Applied Physics,* Vol. 39, No. 2, Part II, pages 922–929; February 1, 1968.

A REVIEW OF ACOUSTOOPTICAL DEFLECTION AND MODULATION DEVICES. E. I. Gordon in *Applied Optics,* Vol. 5, No. 10, pages 1629–1639; October, 1966.

STABILIZATION AND MODULATION OF LASER OSCILLATORS BY INTERNAL TIME-VARYING PERTURBATION. S. E. Harris in *Applied Optics,* Vol. 5, No. 10, pages 1639–1651; October, 1966.

WIDE-BAND INFRARED MAGNETO-OPTIC MODULATION. R. C. LeCraw in *IEEE Transactions on Magnetics,* Vol. Mag-2, No. 3, page 304; September, 1966.

A STONE AGE CAMPSITE AT THE GATEWAY TO AMERICA

THE ARCHEOLOGY OF CAPE DENBIGH. J. L. Giddings. Brown University Press, 1964.

THE BERING LAND BRIDGE. David Moody Hopkins. Stanford University Press, 1967.

STARS IN CONTACT

CLOSE BINARY SYSTEMS. Zdeněk Kopal. John Wiley & Sons, Inc., 1959.

CONTACT BINARIES. O. J. Eggen in *Memoirs of the Royal Astronomical Society,* Vol. 70, Part 4, pages 111–164; 1967.

MODES OF MASS EJECTION BY BINARY STARS AND THE EFFECT ON THEIR ORBITAL PERIODS. Su-Shu Huang in *The Astrophysical Journal,* Vol. 138, No. 2, pages 471–480; August 15, 1963.

ON THE STRUCTURE AND EVOLUTION OF W URSAE MAJORIS STARS. Robert P. Kraft in *Publications of the Astronomical Society of the Pacific,* Vol. 79, No. 470, pages 395–413; October, 1967.

STANDARDS OF MEASUREMENT

ATOMIC STANDARDS OF FREQUENCY AND TIME. John M. Richardson and James F. Brockman in *The Physics Teacher,* Vol. 4, No. 6, pages 247–256; September, 1966.

CONCEPT OF A NATIONAL MEASUREMENT SYSTEM. R. D. Huntoon in *Science,* Vol. 158, No. 3797, pages 67–71; October 6, 1967.

MEASURES FOR PROGRESS: A HISTORY OF THE NATIONAL BUREAU OF STANDARDS. Rexmond C. Cochrane. U.S. Department of Commerce, 1966.

THE BRAIN OF BIRDS

BRAIN LESIONS IN BIRDS: EFFECTS ON DISCRIMINATION ACQUISITION AND REVERSAL. Laurence J. Stettner and William J. Schultz in *Science,* Vol. 155, No. 3770, pages 1689–1692; March 31, 1967.

EFFECTS OF ENDBRAIN LESIONS UPON VISUAL DISCRIMINATION LEARNING IN PIGEONS. H. P. Zeigler in *The Journal of Comparative Neurology,* Vol. 120, No. 2, pages 161–194; April, 1963.

OBSERVATIONS ON THE COMPARATIVE ANATOMY OF THE AVIAN BRAIN. Stanley Cobb in *Perspectives in Biology and Medicine,* Vol. 3, No. 3; Spring, 1960.

THE DISCOVERY OF DNA

THE CELL IN DEVELOPMENT AND HEREDITY. Edmund B. Wilson. The Macmillan Company, 1928.

CELL, NUCLEUS, AND INHERITANCE: AN HISTORICAL STUDY. William Coleman in *Proceedings of the American Philosophical Society,* Vol. 109, No. 3, pages 124–158; June, 1965.

DIE HISTOCHEMISCHEN UND PHYSIOLOGISCHEN ARBEITEN. Friedrich Miescher. Verlag von F. C. W. Vogel, 1897.

ZELLSUBSTANZ, KERN UND ZELLTHEILUNG. Walther Flemming. Vogel Verlag Leipzig, 1882.

POLISHING

THE FRICTION AND LUBRICATION OF SOLIDS. F. P. Bowden and D. Tabor. Oxford at the Clarendon Press, 1950.

FRICTION AND WEAR OF MATERIALS. Ernest Rabinowicz. John Wiley & Sons, Inc., 1965.

METALLOGRAPHIC POLISHING BY MECHANICAL METHODS. L. E. Samuels. Sir Isaac Pitman & Sons Ltd., 1967.

THE PROPERTIES OF GLASS SURFACES. L. Holland. Chapman and Hall, 1964.

SURFACE FLOW IN CRYSTALLINE SOLIDS UNDER MECHANICAL DISTURBANCE. G. T. Beilby in *Proceedings of the Royal Society of London: Vol. LXXII.* Harrison and Sons, January, 1904.

PLANTS WITHOUT CELLULOSE

CELL WALLS. D. R. Kreger in *Physiology and Biochemistry of Algae,* edited by Ralph A. Lewin. Academic Press, 1962.

CELLULOSE. R. D. Preston in *Scientific American,* Vol. 197, No. 3, pages 157–168; September, 1957.

THE MOLECULAR ARCHITECTURE OF PLANT CELL WALLS. R. D. Preston. John Wiley & Sons, Inc., 1952.

NON-CELLULOSIC STRUCTURAL POLYSACCHARIDES IN ALGAL CELL WALLS, I: XYLAN IN SIPHONEOUS GREEN ALGAE. Eva Frei and R. D. Preston in *Proceedings of the Royal Society,* Vol. 160, Series B, No. 980, pages 293–313; September 29, 1964.

NON-CELLULOSIC STRUCTURAL POLYSACCHARIDES IN ALGAL CELL WALLS, II: ASSOCIATION OF XYLAN AND MANNAN IN PORPHYRA UMBILICALIS. Eva Frei and R. D. Preston in *Proceedings of the Royal Society,* Vol. 160, Series B, No. 980, pages 314–327; September 29, 1964.

NON-CELLULOSIC STRUCTURAL POLYSACCHARIDES IN ALGAL CELL WALLS, III: MANNAN IN SIPHONEOUS GREEN ALGAE. Eva Frei and R. D. Preston in *Proceedings of the Royal Society,* Vol. 169, Series B, No. 1015, pages 127–145; January 16, 1968.

MATHEMATICAL GAMES

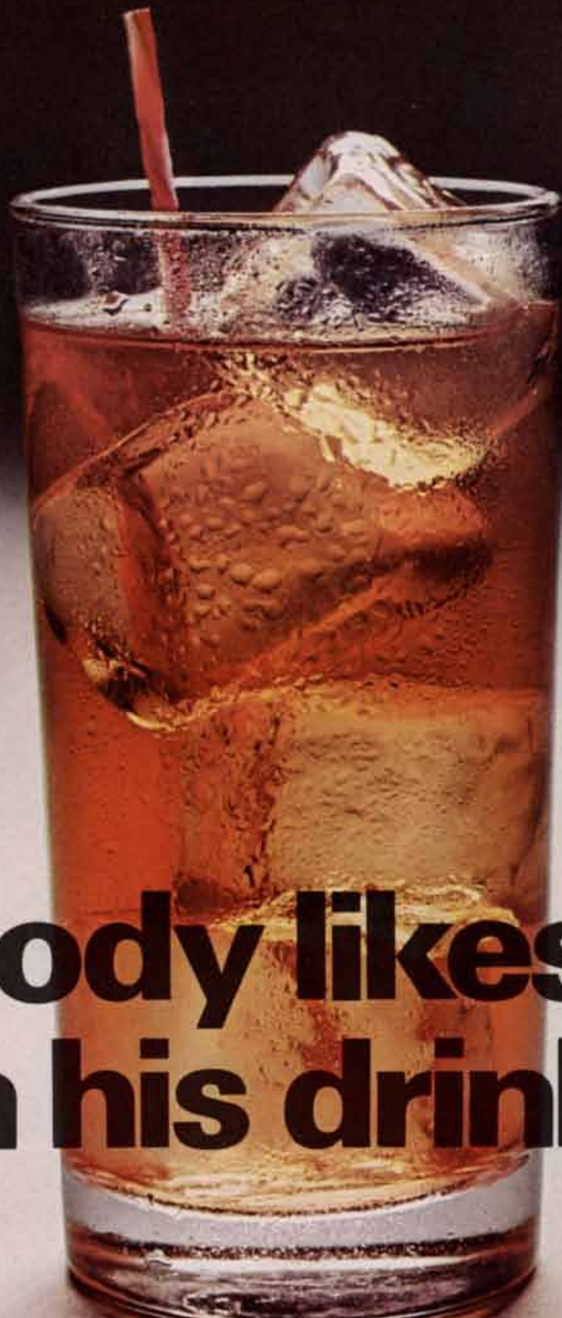
THE CARD CORNER. Charles Hudson in *The Linking Ring,* Vol. 46, No. 7, pages 63–69; July, 1966.

COMBINATORIAL MATHEMATICS. Herbert John Ryser. Carus Mathematical Monographs No. 14, The Mathematical Association of America, 1963.

HOCUS POCUS PARADE: NORMAN GILBREATH'S GENERAL PRINCIPLE. Edited by Eddie Clever in *The Linking Ring,* Vol. 46, No. 6, pages 69–88; June, 1966.

THE AMATEUR SCIENTIST

ANALOG METHODS: COMPUTATION AND SIMULATION. Walter J. Karplus and Walter W. Soroka. McGraw-Hill Book Company, Inc., 1959.



Nobody likes dirt in his drink.

You don't. Neither does any responsible distiller or bottler. They don't want anything to do with a product that isn't completely clean, pure and clear. (After all, every time they put their name on the bottle, they put their reputation on the line.)

They go through the most particular filtration you could imagine to see that nothing ends up in your glass that doesn't belong there.

And Avisco® rayon is usually part of that filtration. In fact, Avisco rayon is used in all kinds of filters for all kinds of liquids from whiskey to milk to shaving lotion to paint to lubricating oils.

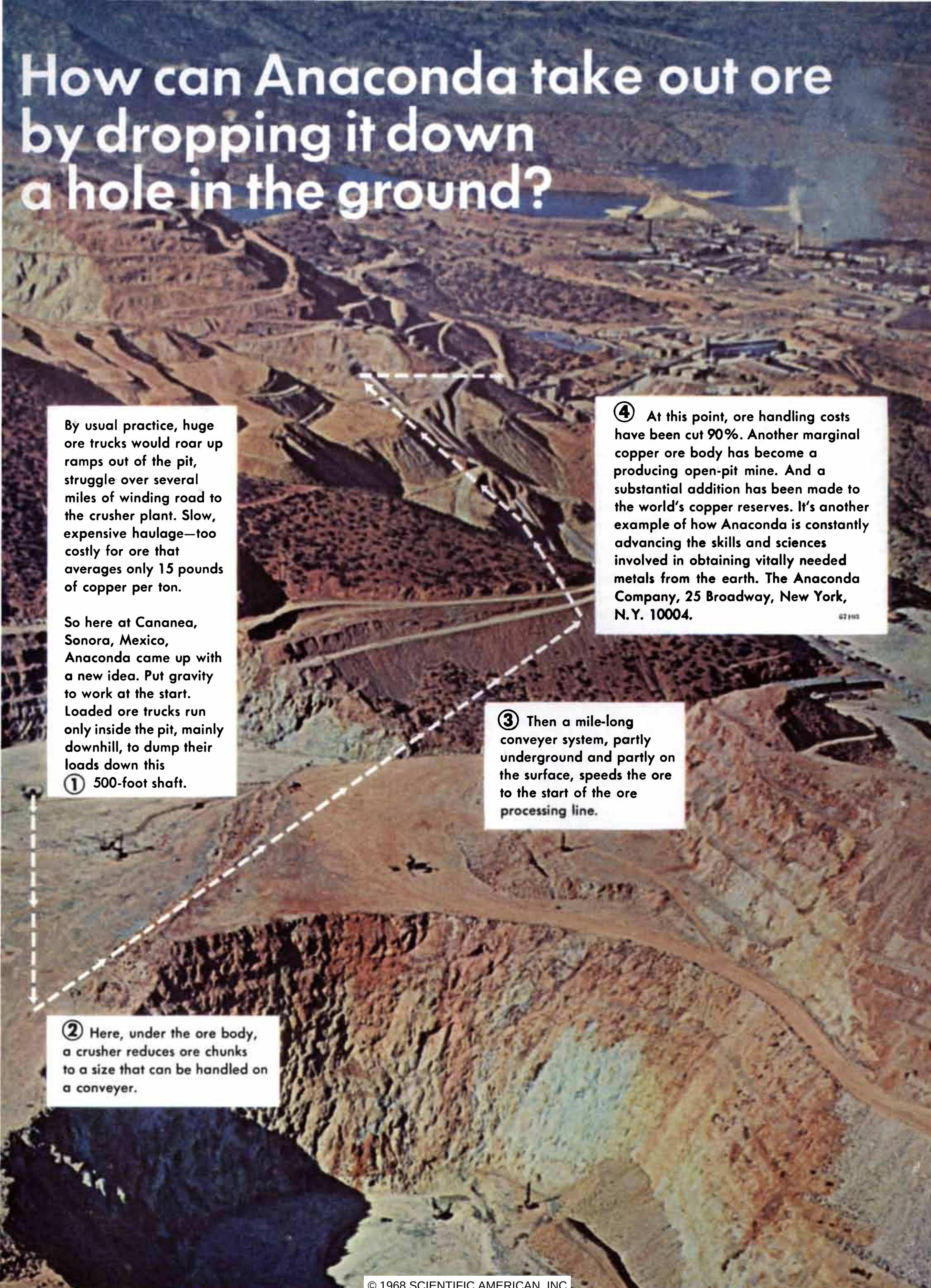
That's because rayon is man-made. It can be made very fine. Uniform in strength and size. Completely predictable. Completely clean. And very, very strong. To hold up under demanding filtration loads.

We can do all these things with Avisco rayon without putting a big price tag on it because it's inherently designable. Perhaps that's why so many companies are calling on rayon to do so many different jobs.

How about your company? Isn't there a problem we can help you clean up? Just ask us. Empire State Building, New York, N. Y. 10001.

AVISCO FIBERS
American Viscose Division
fmc CORPORATION ®

Is there anything we can't make them do?


How can Anaconda take out ore by dropping it down a hole in the ground?
By usual practice, huge ore trucks would roar up ramps out of the pit, struggle over several miles of winding road to the crusher plant. Slow, expensive haulage—too costly for ore that averages only 15 pounds of copper per ton.
So here at Cananea, Sonora, Mexico, Anaconda came up with a new idea. Put gravity to work at the start. Loaded ore trucks run only inside the pit, mainly downhill, to dump their loads down this ① 500-foot shaft.
② Here, under the ore body, a crusher reduces ore chunks to a size that can be handled on a conveyer.
③ Then a mile-long conveyer system, partly underground and partly on the surface, speeds the ore to the start of the ore processing line.
④ At this point, ore handling costs have been cut 90%. Another marginal copper ore body has become a producing open-pit mine. And a substantial addition has been made to the world's copper reserves. It's another example of how Anaconda is constantly advancing the skills and sciences involved in obtaining vitally needed metals from the earth. The Anaconda Company, 25 Broadway, New York, N.Y. 10004.