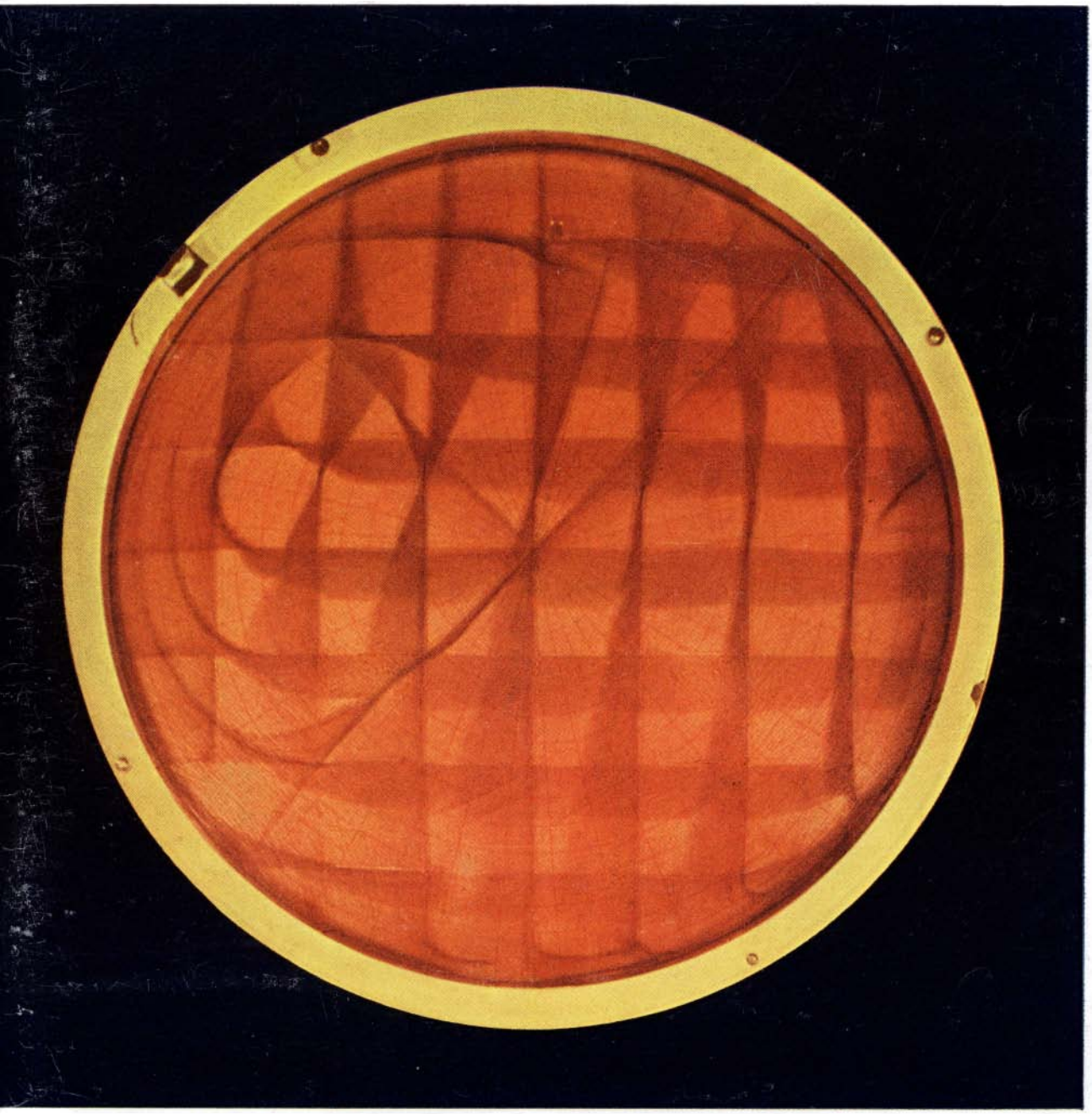
SCIENTIFIC AMERICAN

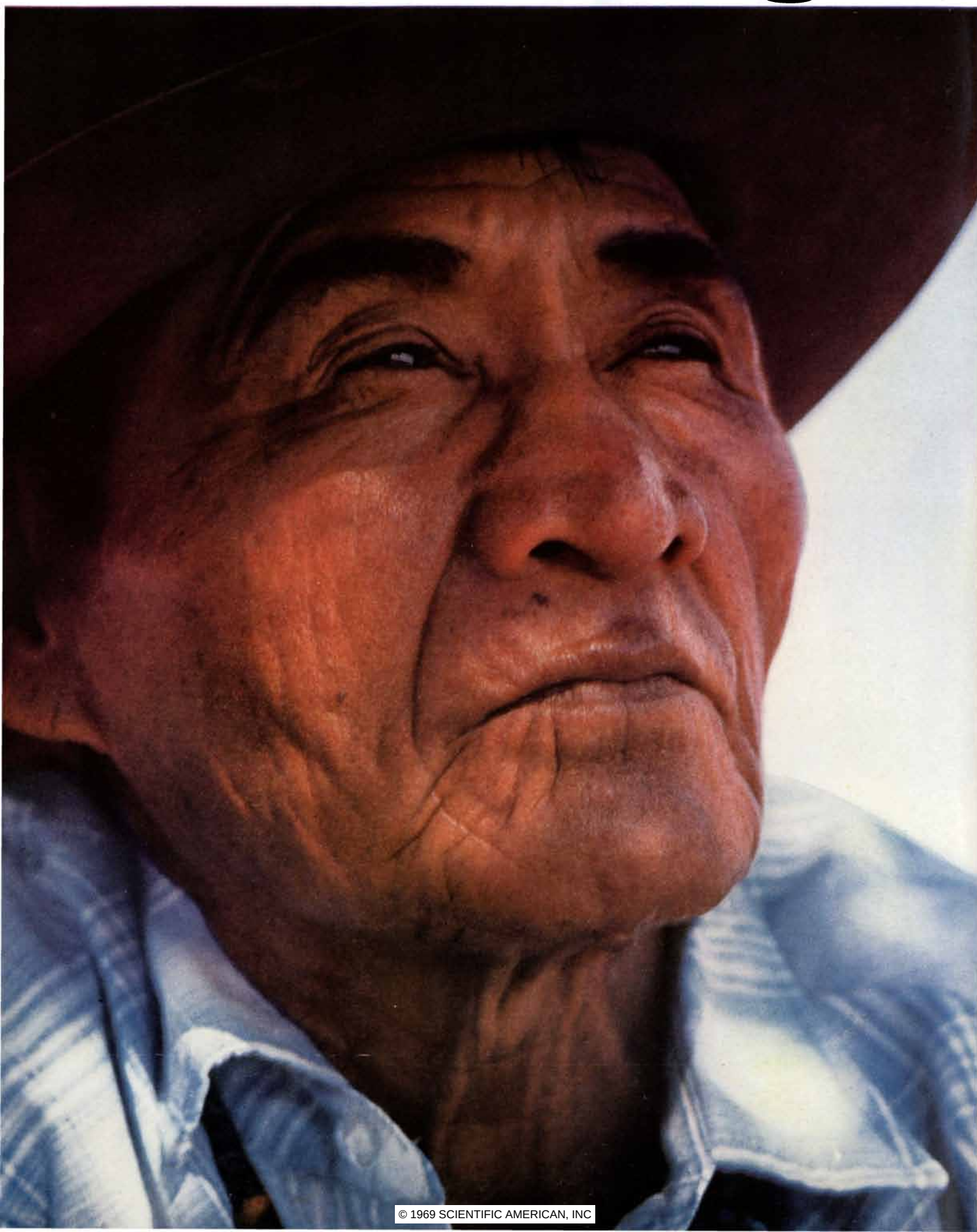


MODEL OF THE OCEAN

ONE DOLLAR

January 1970

The last thing he



wants is a handout.

He is the Navajo.

His roots are set deep in the land he fought for, lost and regained over 100 years ago. With his limited mineral revenues, he has set up his own government, established tribally owned industries and a 10-million-dollar college scholarship fund.

He knows the natural resources he has relied on will eventually run out. To avoid the economic disaster that would follow, the Navajo is drawing on his greatest resource: The Navajo.

He's bringing outside industry to his reservation by offering a pool of fast-learning people whose natural intelligence exceeds their formal education. He's combining that with favorable tax, leasing and construction advantages.

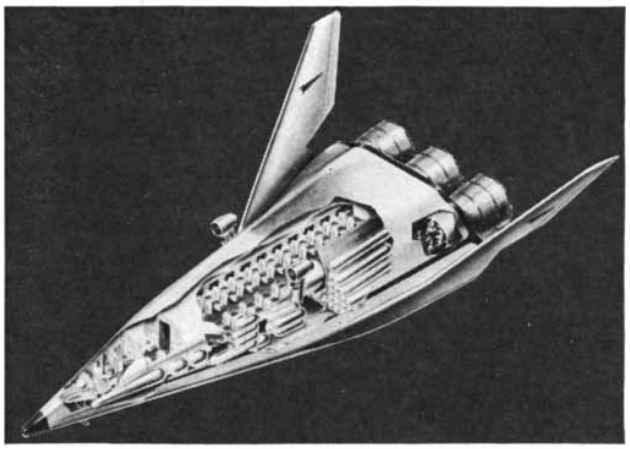
General Dynamics was among the first to discover that the Navajo's way works.

In our facility near the tribal capitol at Window Rock, Arizona, most production supervisors, all inspectors and assembly workers are Navajos. They're putting together highly complex electronic assemblies for aerospace systems and tearing apart a lot of popular misconceptions about Indians in general and Navajos in particular.

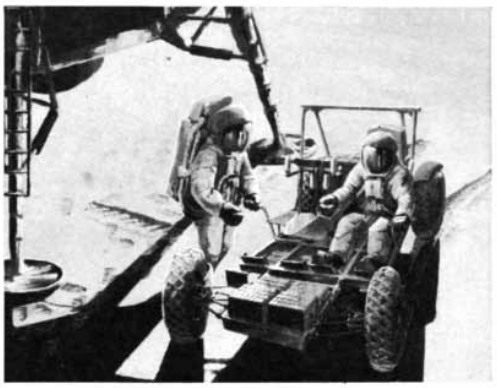
By building a new economy, the Navajo is making one thing clear...he's not about to be counted as a "vanishing American."

GENERAL DYNAMICS

Boeing at work: in space travel, national defense, lunar exploration.



1. *Space Shuttle Vehicle*

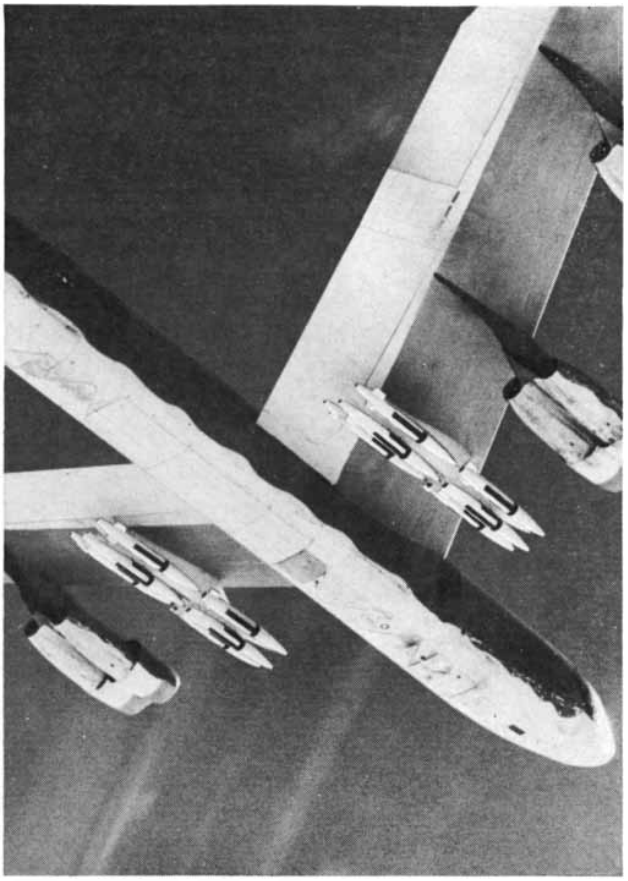


3. *Lunar Rover*

1. Space Shuttle. To cut the cost of taking payloads into space, Boeing and Lockheed are jointly studying a reusable, chemically fueled shuttle vehicle.

The craft would have two stages, a large booster stage and a smaller shuttle orbiter which would perform space missions. Both stages would return to earth for airplane-like landings. The cutaway view, at top left, shows how a 50-passenger shuttle orbiter stage of the future might look.

Boeing space and re-entry vehicle studies date from the 1958 Dyna-Soar space glider project. Boeing has invested some $24 million on research and development related to reusable boosters, and brings to the project intensive experience in airplanes, spacecraft and launch vehicles.



2. *SRAM*

2. SRAM. A Boeing B-52H is shown carrying U.S. Air Force short-range attack missiles. Now being flight tested, SRAM is a rocket-propelled air-to-surface bomber-launched missile. It is designed to provide stand-off capability to assist in penetration of sophisticated enemy defense systems. SRAM, under development by Boeing, is planned for use on the FB-111 and late model B-52 bombers.

3. Lunar Rover. Sometime in 1971, two astronauts will set off to explore the moon surface in a Boeing two-seater Lunar Rover. The vehicle, one of four now being designed and built by Boeing for NASA, will have woven wire wheels, each powered by an electric motor.

The 10-foot-long Rover, folded like a golf cart, will be carried to the moon in the storage bay of a manned lunar module. Boeing and General Motors (major subcontractor on the project) have studied lunar surface vehicles since the early '60s.

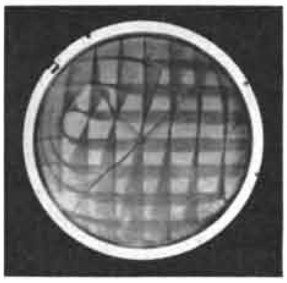
BOEING

Established 1845 **SCIENTIFIC AMERICAN** January 1970 Volume 222 Number 1

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. 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: $10 PER YEAR.



THE COVER

The photograph on the cover shows a laboratory model of an ocean basin (see "Models of Oceanic Circulation," page 114). The model, which here represents the North Atlantic Ocean, is 40 centimeters in diameter, and its "ocean" is one centimeter deep. The water is enclosed between blocks of plastic that are shaped in such a way that the water is held in the shape of a segment of the surface of a sphere, the configuration an ocean has on the surface of the earth. The position of the model is nearly vertical to correspond to the position of the North Atlantic as viewed from a point in space above the Equator. When the water is set in motion by rotation of the lower plastic block, the currents that result are made visible by a dark dye that is generated by a rectangular grid-electrode system. A prominent feature in the photograph is a western boundary current analogous to the Gulf Stream.

THE ILLUSTRATIONS

Cover photograph by D. James Baker, Jr., Harvard University

Page	Source
20–28	Jerome Kuhl
30	Leo V. DiCara, Rockefeller University
31–34	Bunji Tagawa
35	Leo V. DiCara, Rockefeller University
36	Bunji Tagawa
37	Leo V. DiCara, Rockefeller University
38–39	Bunji Tagawa
40–41	Gary Koopman, Catholic University
42–45	Jim Egleson
46	Jim Egleson (*top*); M. G. Davies, University of Liverpool (*bottom*)
59–70	Allen Beechel
76	Lee Boltin
78	R. F. Zallinger (*top*), Tom Prentiss (*bottom*)
79	Steven Boyer
80–82	Tom Prentiss
83	Lee Boltin
84	Tom Prentiss
89	Albrecht K. Kleinschmidt, New York University School of Medicine
90–102	Eric Mose
105	Stephen Manville, courtesy of American Geographical Society
106–112	Jerome Kuhl
114	Paul Weller
115	D. James Baker, Jr., Harvard University
116	Paul Weller
117–119	Dan Todd
120	Dan Todd (*top*); D. James Baker, Jr., Harvard University (*bottom*)
121	D. James Baker, Jr., Harvard University
124	New York Public Library
125–127	Alan D. Iselin
131–139	Roger Hayward

Srinivasa Ramanujan
(1887-1920)

Woodcarving by William Ransom
Photographed by Max Yavno

"...[Ramanujan] was not particularly interested in his own history or psychology; he was a mathematician anxious to get on with the job. And after all I too was a mathematician, and a mathematician meeting Ramanujan had more interesting things to think about than historical research. It seemed ridiculous to worry him about how he had found this or that known theorem, when he was showing me half a dozen new ones almost every day."[1]

[1] G. H. Hardy, *Ramanujan,* Cambridge University Press, 1940, p. 11.

INTERACTIONS OF DIVERSE DISCIPLINES

Ramanujan's discipline of mathematics is represented by 200 professional staff members at Planning Research Corporation. Here, the disciplines of 800 other professionals interact with mathematics and with each other on multidisciplined teams. These interactions—involving about 40 areas of knowledge in the classical sciences, the new behavioral, management, and computer sciences, most branches of engineering, and economics—form the most powerful tool yet devised for the solution of complex problems.

More than half of the professionals at Planning Research Corporation, in addition to their separate disciplines, are experienced systems analysts. They are currently using systems analysis to find practical solutions to problems in planning, programming, and budgeting for urban projects; in national defense and space exploration; and in the most complex computer systems problems faced by business and industry. This systems analysis capability can be applied to your problem. For further information, write to Mr. Stuart A. Krieger, Executive Vice President.

PLANNING RESEARCH CORPORATION

Home office: 1100 Glendon Avenue, Los Angeles, California 90024

An Equal Opportunity Employer. Candidates are invited to write to the Administrator for Professional Staffing.

LETTERS

Sirs:

Imre Tóth's article "Non-Euclidean Geometry before Euclid" [SCIENTIFIC AMERICAN, November, 1969] was fascinating and stimulating.... Since Dr. Tóth has demonstrated Aristotle's pioneering of non-Euclidean geometry, perhaps it is in order to point out that Aristotle held the equivalent of the steady-state theory of the universe and therefore was a forerunner of that cosmological theory. In his authoritative book *Aristotle: Fundamentals of the History of His Development,* Werner Jaeger points out:

"The doctrine that the world is eternal... was Aristotle's greatest innovation [and is found in his] dialogue *On Philosophy*. It was this work, now lost but much read in antiquity, that contained the two philosophical views then considered most characteristic of Aristotle: the adoption of the ether as the element of the heavens, and the assertion that the cosmos is indestructible and uncreated. The doxographers commonly mention the two together as his distinctive additions to Plato's cosmology, and this is correct."

This cosmological speculation required a mental quantum leap on the part of Aristotle analogous to the extraordinary one pointed out by Dr. Tóth regarding geometry.

It is also worth recalling that Aristotle founded the world's first proper university, its first real library (excepting those that we suspect existed in Sumer), its first comprehensive map collection and geographical study center, founded natural science, founded political science and initiated the studies of both religious experiences and psychological types.

ROBERT K. G. TEMPLE

London

Sirs:

The solution to the cryptarithm that appeared in "Mathematical Games" for the October 1969 issue is

$$\begin{array}{r} \text{SPIRO} \\ 7 \\ \hline \text{AGNEW} \end{array} = \begin{array}{r} 14076 \\ 7 \\ \hline 98532 \end{array}$$

It should be noted that 1407698532 can be viewed as 14/07/69, 14 July 1969, which was T-2 days in the *Apollo 11* countdown, and 8/5/32, August 5, 1932, which was astronaut Armstrong's second birthday. The numbers 0932, the time of liftoff, also appear in sequence. The sum of 9 plus 2 equals 11, 3 was the number of astronauts and 2 was the number of men to walk on the moon. The last three digits of the product, 532, was the time (EDT) at Cape Kennedy when it was 0932 hours GMT.

M. M. WILLIAMS

Senior Engineer
Kennedy Space Center
Cocoa Beach, Fla.

ADDENDUM

The illustration on page 102 of the article "The Origin of the Oceanic Ridges" (SCIENTIFIC AMERICAN, November, 1969) was adapted, with the kind permission of the publisher, from Figure 6 on page 82 of *The History of the Earth's Crust,* edited by Robert A. Phinney and published by the Princeton University Press (1968).

Scientific American, January, 1970; Vol. 222, No. 1. 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.

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.

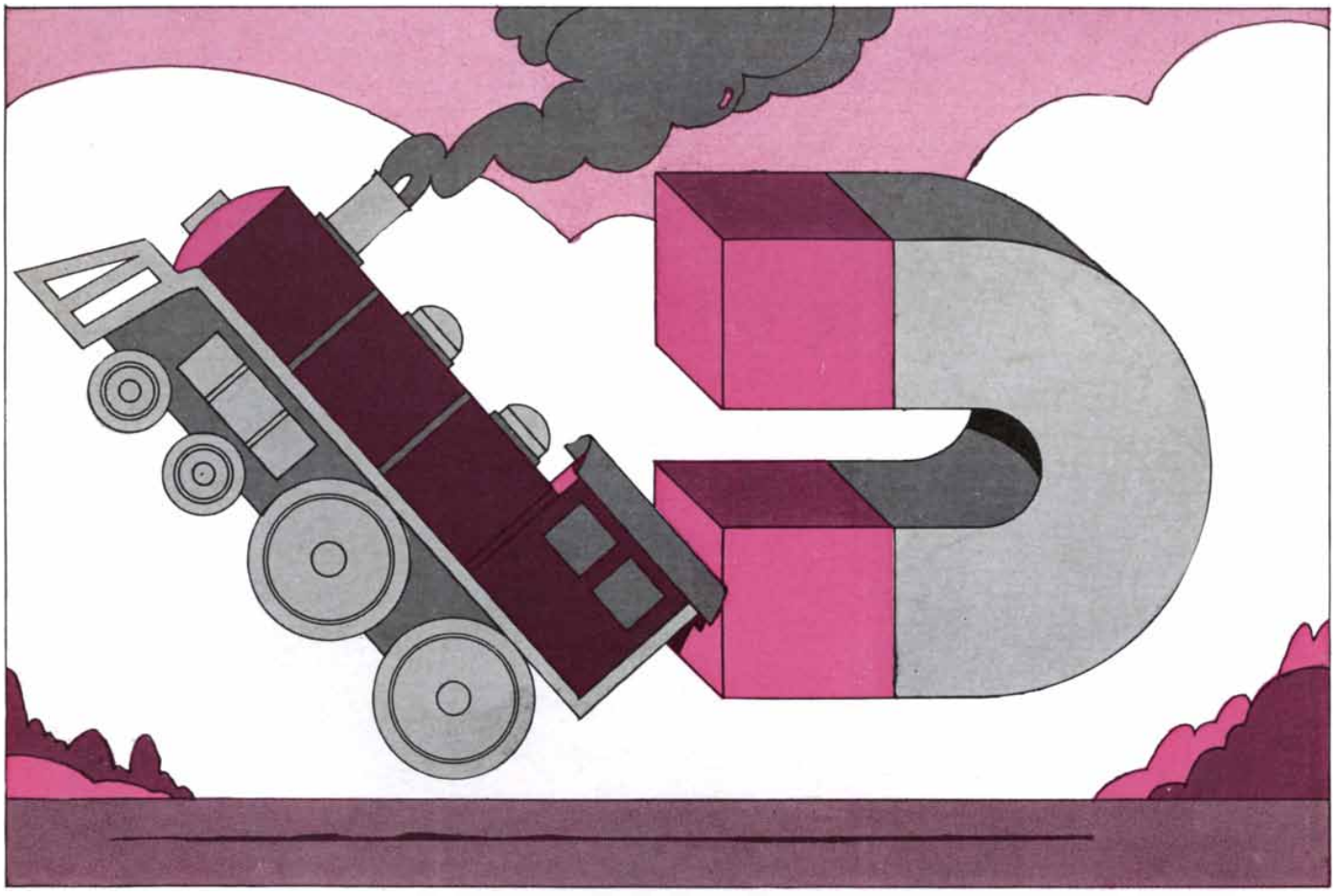
Change of address (or other subscription correspondence) should be addressed to Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Please notify us four weeks in advance of change. If possible, kindly furnish an address imprint from a recent issue. Send both old and new addresses or complete and mail Post Office Form 357B.

Please enter change of address ☐
Please enter subscription ☐
☐ 1 year, $10 ☐ 2 years, $18 ☐ 3 years, $25

NAME

NEW ADDRESS

OLD ADDRESS



Rare earths for better magnets

Scientists at Bell Laboratories have cast some of the most powerful small magnets ever made . . . from new materials containing rare earths. The new materials, alloys of cobalt, copper, and samarium or cerium, have the highest known intrinsic coercive force (field required to reduce intrinsic magnetization to zero). So, they make excellent permanent magnets.

It often requires very high magnetic fields to completely magnetize intermetallic compounds of samarium, cerium, and other rare-earth metals in certain crystal directions. While iron may require fields of hundreds of oersteds, and cobalt probably ten thousand (depending on grain orientation), compounds of rare-earth metals may need up to 200,000 oersteds. To students of magnetism, this indicates a material of high coercive force.

In practice, however, it is difficult to calculate coercive force accurately because the process of demagnetization in these alloys is not well enough understood. Predictions are often higher than what is realized. But we do know that very small grains tend to produce higher coercive force. Also, the better the grain alignment in a favorable magnetic-field direction, the higher the magnetic flux.

By taking a new approach toward the best grain size and alignment in pieces of samarium- or cerium-cobalt, E. A. Nesbitt and his colleagues at Bell Laboratories produced a magnet having a coercive force of at least 28,700 oersteds. First, they combined essentially nonmagnetic copper-samarium with a magnetic material, cobalt-samarium, into a new alloy possessing a solid mass of very fine grains. Then by cooling the melt rapidly in one direction, they produced long, thin crystals along which desirable magnetic properties tend to align. Finally, they annealed the material at about 400° C.

The highest coercive force is reached in a composition ranging from $Co_{3.5}Cu_{1.5}Sm$ to Co_3Cu_2Sm. Excellent permanent magnets can also be made by using cerium, which is cheaper than samarium.

Today, commercial permanent-magnet materials have intrinsic coercive forces below 5000 oersteds. The high forces achieved in the new materials permit practical strong magnets in small shapes, such as discs. Such shapes would be ideal for, say, miniature d-c motors.

From the Research and Development Unit of the Bell System—

Bell Labs

Dynamic range 10^{-98} to 10^{98}, nearly 200 decades. Observation of math operations on 3 displayed registers. Up to 32 more registers for data storage.

Complex and vector arithmetic simplified with coordinate transformation keys, rectangular-to-polar and vice-versa, in milliseconds.

Trig functions covering all quadrants and any size angle in degrees or radians.

Introducing the HP 9100B to give you a choice of basic calculators. Provides additional internal memory and programming capability.

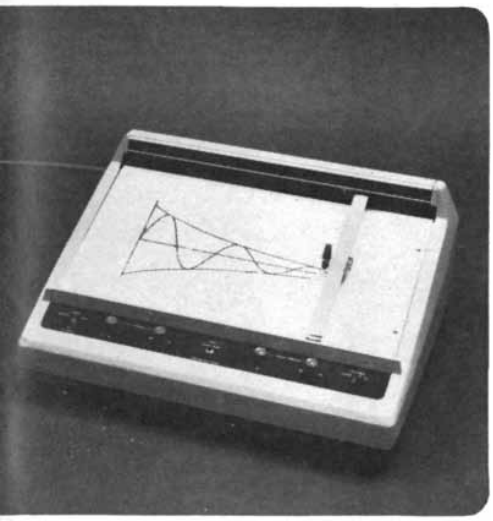
Program from the keyboard. Record and store up to 392-step programs on credit-card size magnetic cards for repeated use.

Branching and looping flexibility provided by "IF" keys expands programming capability. Single-key direct sub-routine call.

Edit programs easily. Single-step through programs to check and de-bug. Address an individual step and make corrections without re-entering the entire program.

The Emancipator...

start of the small computing system!



090/1

HEWLETT hp PACKARD

HP CALCULATOR SYSTEM 9100

It all starts with the HP 9100A calculator... and grows from there. In capability... not in size.

In fact, you can fit the entire HP System 9100 on your desk. It's the personal computing system that puts immediate answers to big computing problems right at your fingertips.

If a picture is worth a thousand numbers, add a plotter. See the solutions being plotted as fast as your problem is being solved.

Need printouts? Get the quiet printer that operates in an office or lab environment without disturbing you, or your neighbors.

You also get an extensive and growing library of applications oriented programs.

But the HP System 9100 is not resting on its laurels. Now you have a choice of basic calculators for your small computing system.

HP is adding the 9100B calculator for those of you who want even more memory and programming power.

The addition of 16 more storage registers doubles the programmable memory to 392 program steps. And, the ability to call subroutines directly gives you more efficient use of this extra memory.

Just pick the calculator that best suits your needs. Plug in the peripherals and you are ready to go. The computing power of your basic system can continue to grow to meet your changing requirements. Additions, like the upcoming memory extender, will be compatible with either calculator.

Stretch your computing dollar with the personal computing system that has learned to live on a small budget. Put this system to work for you now. Just call your local HP Calculator Salesman, he will have the HP System 9100 on your desk faster than you thought possible.

Or, write to Hewlett-Packard, P.O. Box 301, Loveland, Colorado 80537. In Europe: 1217 Meyrin-Geneva, Switzerland. Prices: HP 9100A Calculator $4400; HP 9100B Calculator $4900. Peripherals; HP 9120A Printer $975; HP 9125A X-Y Plotter $2475. Lease/rental programs start as low as $1.50/computing hour, based on average usage.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1920: "Papers by Prof. E. B. Wilson and Dr. Leigh Page read before the autumn meeting of the National Academy of Sciences led to a discussion of the announcement recently made in England that the results of the British eclipse expeditions to Brazil and West Africa had confirmed the existence of a deflection of the light of the stars passing by the sun of the same magnitude as that predicted by Einstein's generalized theory of relativity. The discussion developed the point of view, especially among the experimental physicists present, that it is not necessary to suppose that the deviation of the light observed is really a proof of the soundness of the theory of relativity. Several other causes, such as diffraction and refraction, might be operative to produce the small bending of the star rays seen. The impression prevailed that, so far as observations of any kind have yet gone, no one is compelled to adopt the difficult and obscure theory of relativity in place of other explanations of phenomena unless he has the type of mind that prefers it."

"The $50,000 prize put up by the Government of Australia for a flight from England to that continent has been won by Capt. Ross Smith and his brother Lieut. Keith Macpherson Smith, R.A.F., and Sergeants J. W. Bennett, A.F.M., M.S.M., and W. H. Shiers, A.F.M., their mechanics. They set out from Hounslow aerodrome the morning of November 12th in a Vickers-Vimy bomber and flew via Rome, Crete, the Mediterranean, Cairo, Baghdad, Delhi, Karachi, Calcutta, Rangoon, Singapore, Java and Bima Bay on the island of Sumbawa to Port Darwin at the extreme northern part of Australia, a distance of 10,500 miles, in 28 days, arriving December 10th. They caught up with M. Poulet and M. Benoist on their twin Le Rhône-motored Caudron biplane at Rangoon, and passed them in a race to Singapore. The Frenchmen left Paris October 14th. The Blackburn 'Kangaroo' was the third bi-motored plane in the contest. The other three entries—none of which completed the flight—were single-motored machines. The race has emphasized the advantage of multiple-motored machines such as were first advocated by Mr. Edwin Gould, who donated the Gould–SCIENTIFIC AMERICAN $10,000 prize for the first twin-motored airplane in 1911."

SCIENTIFIC AMERICAN

JANUARY, 1870: "There are probably few thinking men who do not foresee that sooner or later a ship canal must connect the Atlantic and Pacific. Which of the routes hitherto surveyed and discussed will be ultimately selected as most favorable to success in a work of this kind time will show; at present there is really too little knowledge of possible routes to form a correct and final judgment. Three routes have been much mooted, and our general knowledge of them obtained by former surveys is enough to give a tolerable idea of their feasibility. The Panama route involves only 28 miles of construction, but there are difficulties which, although not insurmountable, are of great magnitude. The Nicaragua route via the river San Juan and Lake Nicaragua involves only 16 miles of construction, but it involves the improvement of the river navigation and without doubt also that of the lake. The third route discussed, called the Tehuantepec route, is 130 miles in length, and there is probably less accurate knowledge in regard to it than there is to either of the others. The matter standing thus, the Government has acted wisely in dispatching a steamer to Aspinwall to make surveys and gain further light."

"During the year 1869 the extraordinary spectacle has presented itself of astronomers turning chemists. The telescope has been exchanged for the spectroscope, and mathematics has been laid on the shelf. Our observatories have become chemical laboratories. The physical conditions of the sun's atmosphere, its protuberances, and the source of its light and heat have been chiefly studied. All of the heavenly bodies have been brought down to earth for accurate analysis. No sooner was the computation of the time of the last total eclipse completed than the slate was thrown aside and preparations were made to photograph every stage of the obscuration and to study the light of the sun by means of the spectroscope. The chief preparations were chemical ones, and the most novel discoveries were in this department of science. We find hydrogen in the sun, and curious bands in the fixed stars and planets. A system of telegraphing to the nearest star is no more impossible now than the submarine cable would have appeared 50 years ago."

"A trial of a road steamer with rubber tires has recently been made in Paris. The tractile power was sufficient to draw a heavy omnibus with 50 passengers. *Engineering* states that on the report of the French Government engineers, leave has been granted to the road steamer to ply over two routes, several miles in length and including some busy parts of Paris. The engineers report it handier and more manageable than horses, and in no way dangerous to the public. The huge india-rubber tires save the machinery from jolting and the roads from ruts. The speed is that of a fast omnibus; the steamer went up the paved street beside the Trocadero, of which the gradients are 1 in 11 and even 1 in 9, without the least difficulty and came down again without any brake. In a wet grass field it was curious to observe how little the wheels sank into the saturated soil; in fact, the steamer obliterated, on retracing its circle, the deep ruts of the omnibus wheels. This circumstance has drawn the attention of artillery officers present at the experiment, suggesting to them an inquiry whether the system might not be advantageously applied to military transport in campaigning."

"Henry St. Claire Deville has conducted a series of experiments on the possible use of petroleum for fuel, and he has succeeded in inventing a furnace that satisfactorily accomplishes the object. This may be regarded as one of the most important inventions of the year."

"It will be gratifying to the advertising patrons and friends of SCIENTIFIC AMERICAN to learn that its present circulation is several thousand copies larger than at any previous time in its history. We are now printing a regular weekly edition of 40,000 copies, and subscriptions are flowing in from all sections of the country as they never came before. We confidently expect to run up our edition to 50,000 copies within a short time. Since the opening of the new volume we have increased the number of contributors to our columns, and shall labor earnestly to give all the practical and popular scientific intelligence of the day."

From the standard: New dimensions

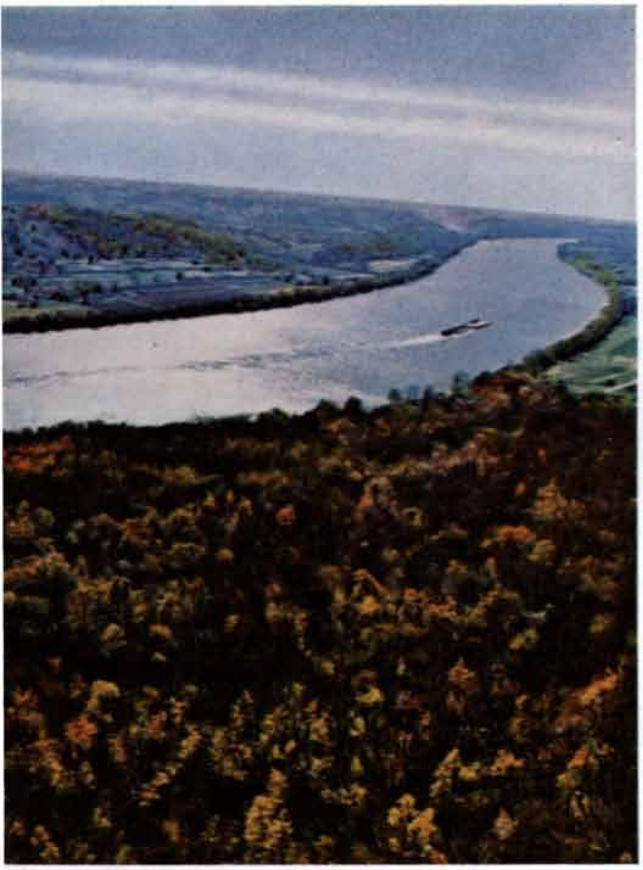
The starting point is General Time's video mapper, whose radar-interfaced "flying spot" scanner electronically provides geographical data simultaneously with target information.

Imaginative technology demands more. The challenge: To find, follow, place, hold and comprehend. The answer: New dimensions. *Portability* that provides space-sparing subsystems with plug-in, plug-out modules, multiple channels. *Bright displays* that take radar out of the dark and into the light, for signal visibility in ambient brightness. *Signal storage* that remembers an input signal long after its moment in time has passed. *Computer-interfacing* that provides accurate target tracking. And *high-resolution maps* that can be created anywhere, even by the untrained.

Maps. Mapping only *starts* with geography. The "flying spot" scanner reads—and writes—all sorts of space. Space is more volumes than we know and General Time is ready to work with you to write them. Adding the new dimensions that work for your imagination is all a matter of space and time. *The Big Time.*

GENERAL TIME
SPACE AND SYSTEMS DIVISION
135 South Main St., Thomaston, Conn. 06787
(203) 283-4323

The Ohio River Commission has been fighting and winning the battle against pollution for over 20 years. Although man-made pollutants have been reduced, increasing population and industrial growth create a never-ending challenge.



Turning the tide against pollution along the capricious Ohio River.

How can you analyze water quality every hour in an ever-changing river? The Ohio River Commission considered it vital. This story is another example of how IBM, its people or products often play a part in tackling today's problems.

David Dunsmore examines some of the 130 species of fish found in the Ohio. Control of pollution has helped reduce fish mortality in recent years.

"It's not how much information you gather on pollution that counts," says David Dunsmore, Sanitary Engineer of the Ohio River Commission (ORSANCO). "It's how fast you can evaluate it.

"Since 1965, our automatic monitoring system has been sending us enormous amounts of data from 14 locations along the river. But by the time we were able to do the paper work, the water conditions had changed.

"As a result, we asked IBM to come up with a data processing system that would allow us to evaluate water quality from these locations every hour. A tall order. But it would be a sure way to evaluate changes in the water when they happen.

"With the computer installed, we began to handle over a million water-quality measurements a year. In fact, the computer saved us so much time we were able to double the number of monitoring locations.

"Today, current river conditions can be appraised and trouble areas pinpointed so that downstream cities and industrial plants can be alerted to take protective measures.

"Right now, we're working on a computerized forecast procedure. This will let us predict the quality of Ohio River water three days in advance. We're confident this will be a significant weapon in the continuing fight against water pollution."

IBM®

Siemens

We bring Qualitätsware to America. This automated sequential X-ray spectrometer makes production control a more exact science.

X-ray spectrometry is one of the most important tools used in modern production control systems.

Until recently, however, the ideal X-ray spectrometer was not available. Industries like steel, glass, petroleum, chemical and aerospace had to settle for either a production control system or a laboratory unit.

The production control system could be programmed to handle only a few sample types. It wasn't accurate enough for many processes. Nor was it flexible enough to cope with the frequent changes necessary in the processes it was supposed to control.

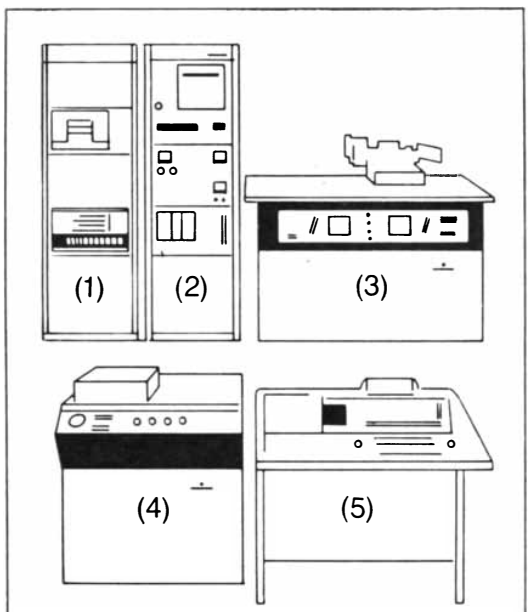
The manually-operated laboratory unit was too slow to be considered as part of the production system.

The Siemens automated sequential X-ray spectrometer system bridges this gap. It combines the versatility demanded of a laboratory unit with the speed and accuracy demanded of a production control system.

The automated X-ray spectrometer can handle up to 10 samples in each run. (Solids, liquids or powders.) Each sample can be analyzed for up to 128 element/matrix combinations.

An important feature is the asymmetrically located target in the X-ray tube. This feature makes the "target-to-sample" distance of Siemens equipment the shortest in its field. It's one reason why Siemens X-ray spectrometers have the lowest detection limits, from uranium (atomic no. 92) all the way down to fluorine (atomic no. 9).

In spite of its sensitivity, a Siemens automated X-ray spectrometer can be operated by production or laboratory personnel with no special technical training.



Basic components include (1) Digital computer. (2) Electronic panel. (3) X-ray generator. (4) Sequential spectrometer. (5) Teletypewriter.

After samples are placed in the unit, operation is rapid and completely automatic. Analytical results are printed out by the teletypewriter in percent concentration for each element in each matrix.

The base price of a system is $75,000. For complete technical details and an up-to-date list of the more than 50 users of Siemens X-ray spectrometers in the U.S., write to Mr. Dieter Meusel at Siemens, 186 Wood Avenue South, Iselin, N.J. 08830.

Siemens of West Germany. A worldwide company that sold 2.84 billion dollars worth of quality products last year.

THE AUTHORS

G. W. RATHJENS and G. B. KISTIAKOWSKY ("The Limitation of Strategic Arms") are respectively professor of political science at the Massachusetts Institute of Technology and professor of chemistry at Harvard University. They first worked together when Kistiakowsky was (from 1959 to 1961) special assistant for science and technology to President Eisenhower and Rathjens was a member of Kistiakowsky's staff. Rathjens was graduated from Yale University in 1946 and received his Ph.D. from the University of California at Berkeley in 1951. Kistiakowsky was born in Russia and came to the U.S. in 1926, a year after obtaining his doctorate from the University of Berlin. He began his association with Harvard in 1930. From 1957 to 1963 he was a member of the President's Science Advisory Committee. Rathjens and Kistiakowsky have both been associated with the U.S. Arms Control and Disarmament Agency, Rathjens as an official and Kistiakowsky as a member of its advisory committee.

LEO V. DICARA ("Learning in the Autonomic Nervous System") is an associate professor at Rockefeller University. His special area of interest is physiological psychology, the subject in which he obtained his Ph.D. from New York University in 1965. Within that area he works on the psychophysiology of the autonomic nervous system, with special emphasis on the instrumental and classical conditioning of visceral and glandular responses; neural and humoral factors involved in emotional behavior; psychosomatic medicine; electrical stimulation of the brain, and neural mechanisms in the regulation of food and water intake. DiCara took his bachelor's degree at the City University of New York in 1960. After receiving his doctorate he spent a year as a postdoctoral fellow at Yale University before joining Rockefeller University as a guest investigator.

ROBERT C. CHANAUD ("Aerodynamic Whistles") is associate professor of architectural engineering at the University of Colorado, where he is developing a graduate program in architectural acoustics and the control of environmental noise. He went to the university last year after a somewhat delayed period of graduate work at Purdue University, where he obtained his Ph.D. in mechanical engineering in 1967. For three years before going to Purdue he was employed by American Standard Inc., where he was supervisor of applied acoustics research. Chanaud was commissioned in the U.S. Coast Guard in 1954 after his graduation from the U.S. Coast Guard Academy. In 1958 he went to graduate school, obtaining his master's degree in engineering at the University of California at Los Angeles in 1961. His technical interests are in promoting the incorporation of acoustics in the design of buildings and other environmental facilities and in the prevention of excessive noise by machinery. He also enjoys oil painting, rock-climbing, skiing and the history of the American West.

JOSEPH B. LAMBERT ("The Shapes of Organic Molecules") is associate professor of chemistry at Northwestern University. He was graduated from Yale College in 1962, obtained his Ph.D. from the California Institute of Technology in 1965 and went to Northwestern as an assistant professor of chemistry the same year. His research interests include conformational analysis, nuclear magnetic resonance spectroscopy and organic reaction mechanisms. Lambert writes: "Of my many interests, hobbies and avocations two are major. As an armchair archaeologist I have visited many sites in Mexico, Egypt, Greece, Italy, France and Spain. My wife and I will be going to Guatemala, Honduras and other Central American countries in February to continue this pursuit. I also attempt to be a musician, both in the passive sense as an audiophile and in the active sense as a clarinetist. Lesser interests include the stock market, United Nations stamps, U.S. coins, most forms of literature, languages and travel."

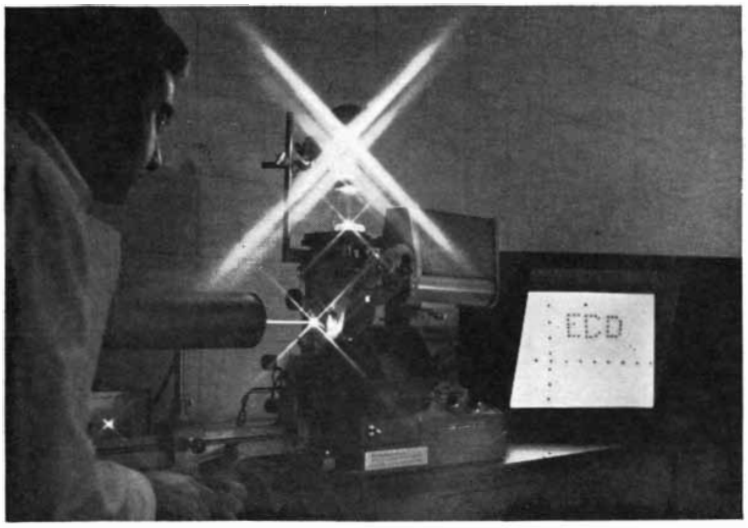
ELWYN L. SIMONS and PETER C. ETTEL ("Gigantopithecus") are at Yale University; Simons is professor of paleontology and curator in charge of vertebrate paleontology at the university's Peabody Musem of Natural History, and Ettel is a graduate student working with Simons. Since joining the Yale faculty some 10 years ago Simons has organized numerous fossil-hunting expeditions to Wyoming, Egypt and India in search of ancestral primates and other extinct vertebrates. These researches have disclosed what is by far the oldest-known skull of an ape. Simons has named the animal, which dates back some 30 million years and may be an ancestor of man, *Aegyptopithecus*. Simons holds a bachelor's degree from Rice University, a Ph.D. from Princeton University and a D.Phil. from the University of Oxford. Ettel was graduated from the University of Washington and holds a master's degree in biology from Yale.

SALVADOR E. LURIA ("The Recognition of DNA in Bacteria"), who shared the 1969 Nobel prize for physiology and medicine, is Sedgwick Professor of Biology at the Massachusetts Institute of Technology. Born in Italy and trained in medicine, he came to the U.S. in 1940 as a war refugee and worked at Indiana University and the University of Illinois for a number of years before going to M.I.T. in 1959. The award of the Nobel prize to him, Max Delbrück of the California Institute of Technology and Alfred D. Hershey of the Carnegie Institution of Washington last month cited them for "their discoveries concerning the replication mechanism and genetic structure of viruses." Luria has a number of interests aside from molecular biology, among them actions of protest against the war in Vietnam and efforts to keep science humanistic.

URSULA M. COWGILL ("The People of York: 1538–1812") is professor of biology at the University of Pittsburgh. When she moved there recently after a number of years as a research associate at Yale University, some 24 tons of laboratory equipment and her own belongings went with her; she writes that "if nothing else, this move has taught me why people remain in one place all their lives." Born in Switzerland, she was graduated from Hunter College in 1948, went to Kansas State University for her master's degree and obtained her Ph.D. from Iowa State University. Her professional interests include the geochemical history of lakes, biogeochemistry, physical and chemical limnology, historical demography and prosimian behavior. Her avocations include gourmet cooking and playing the classical guitar.

D. JAMES BAKER, JR. ("Models of Oceanic Circulation"), is assistant professor of oceanography at Harvard University. Following his graduation from Stanford University in 1958 he did graduate work in soft-X-ray physics at Cornell University, taking his Ph.D. there in 1962. He spent the next year measuring the equatorial current in the Indian Ocean as a postdoctoral fellow with the University of Rhode Island. The following year he studied photosynthesis at the University of California at Berkeley, beginning his association with Harvard in 1964 as a research fellow. His avocations include photography, travel and playing ragtime piano.

What's happening in ⊕ OVONICS



Reversible changes in the optical properties of amorphous semiconducting films provide a basis for new beam-addressable/beam-alterable mass memory systems

Using laser or electron beams to modify the structure of Ovonic memory films, ECD is now writing, reading and erasing readily detectable micron-size dots suitable for high-density data storage and printing applications.

Since first demonstrating the rapid and reversible switching effects in amorphous semiconductors,* considerable progress has been made in exploring the physics of the phenomena and evaluating various applications and device possibilities. While much of this preliminary work was confined to developing and testing discrete components, the body of scientific data derived from these efforts is now being applied to a number of more advanced systems concepts.

Of particular interest are those utilizing Ovonic memory films—amorphous materials having two or more stable molecular structures, one highly disordered and the others having some microcrystallinity.

These materials can be reversibly switched from one state to another by controlled energy absorption and will remain in either state indefinitely without holding power. As one would expect, reversible transformations in molecular structure result in corresponding reversible changes in physical properties—eg., transmissivity, reflectivity and resistivity—which can be sensed to determine the state of the memory film.

Thus any surface coated with such Ovonic materials could serve as the basic element for a two-dimensional data storage system possessing unique capabilities. A suitably modulated laser or electron beam could be used to write digital or analog information on the film surface. Stored data could be read out by detecting transmitted or reflected light patterns from the altered material. And the same energy beam set at a different power level could be used to erase data at will for correction or updating on the same film surface.

Accordingly, the experimental facilities shown in part above were established to evaluate the characteristics of such an alterable mass memory system. Results:

The wave length produced by an inexpensive argon ion laser—5164 Å—is suitable for inducing structural changes in Ovonic thin films. The mechanism being utilized is the change in refractive index and light scattering when a laser pulse is focused on a small area of the film.

Ovonic memory films have energy gaps ranging from the infrared to the visible. A shift in the 7000 Å absorption edge in a typical material results in a change in absorption and refractive index of light from a tungsten source. These effects cause a change of at least 10^2 in light transmitted through the switched areas. Such large changes in the films' optical properties permit a very high signal-to-noise ratio.

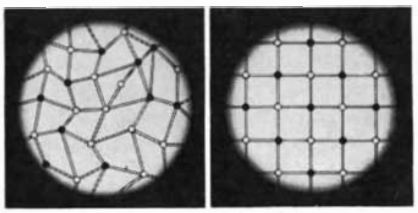
Switching between the two memory states is controlled by the intensity/time profile of the laser pulse. Operating at a peak power of 2 watts and a pulse width of 1 μsec—which is above the writing threshold—the laser writes data dots less than 2 μm in diameter, making bit densities in the order of $10^8/in^2$ possible. By changing beam energy, the same laser can be used to erase data dots and restore the film to its original disordered state.

The ability to record, store, erase and rewrite man-readable as well as machine-readable data on Ovonic films is evidenced by the "ECD" appearing on the screen above and in the microphotographs below.

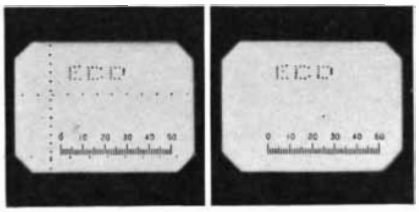
To read out such stored information visually, a film-coated substrate was illuminated with a tungsten lamp and the transmitted light pattern detected by a vidicon for display on the TV monitor.

Based on experience to date, this technique for producing rapid and reversible localized changes in the optical properties of thin Ovonic films could lead to the development of alterable mass memory systems having storage capacities in the order of 10^{12} bits. Additional possibilities also being investigated include analog storage.

The diagrams below depict characteristic difference in molecular structure between Ovonic amorphous semiconductors and crystalline semiconductors.



Photos show Ovonic memory film with dots written by a laser. At right: Same film after erasing some dots with the same laser. Scale = 10 μm/division.



Other on-going programs for applying Ovonic amorphous semiconductors include electrically alterable read-only memories, flat panel electroluminescent displays and non-impact printing systems. Career opportunities in Ovonics are open for qualified scientists and engineers. *A Greater Opportunity Employer!*

Energy Conversion Devices, Inc.

1675 W. Maple Road • Troy, Michigan 48084 • Telephone: 313/549-7300

*Covered by United States and foreign patents—issued and pending.

how to recall any of 1,000,000 pages within 30 seconds

Parts catalogs, engineering schematics, financial trend charts, customer accounts receivable, or whatever. DatagraphiX Micromation can reduce 200,000 pages of your computer's output to compact micro images that fit in one hand. Providing multiple economies for management information retention and retrieval. Translating computed data into easy-to-read report formats. Offering access to millions of facts within a matter of seconds from screen display inquiry stations. Providing hard copies on demand. And high volume production printing at 5,200 pages per hour on preprinted forms.

Instant communication of computer generated information improves decisions and profit margins. Many Micromation systems have earned back their cost within the first year. From the combined economies of paper consumables, rentals, manpower, time and $thousands in operations overhead. That's good business.

Compared to impact printing, Micromation is 27 times faster, takes 1/18th the computer time, slashes the cost of paper consumables by 7/8ths, and creates archival storage in 99% less space.

Only one company offers the complete family of machine systems; service centers; Kalvar dry film processing; all associated supplies; systems and software support; worldwide maintenance. Discover what Micromation can do for you. Contact our local office or National Sales Manager, James P. Whitfield.

DatagraphiX
micromation systems

Stromberg DatagraphiX Inc., a General Dynamics subsidiary. P.O. Box 2449, San Diego, Calif. 92112 (714) 283-1038 TWX: 910-335-2058

Established 1845 SCIENTIFIC AMERICAN January 1970 Volume 222 Number 1

The Limitation of Strategic Arms

The long-term prospects for the strategic-arms-limitation talks would be greatly enhanced by an early agreement to ban further tests of multiple independently targeted reentry vehicles (MIRV's)

by G. W. Rathjens and G. B. Kistiakowsky

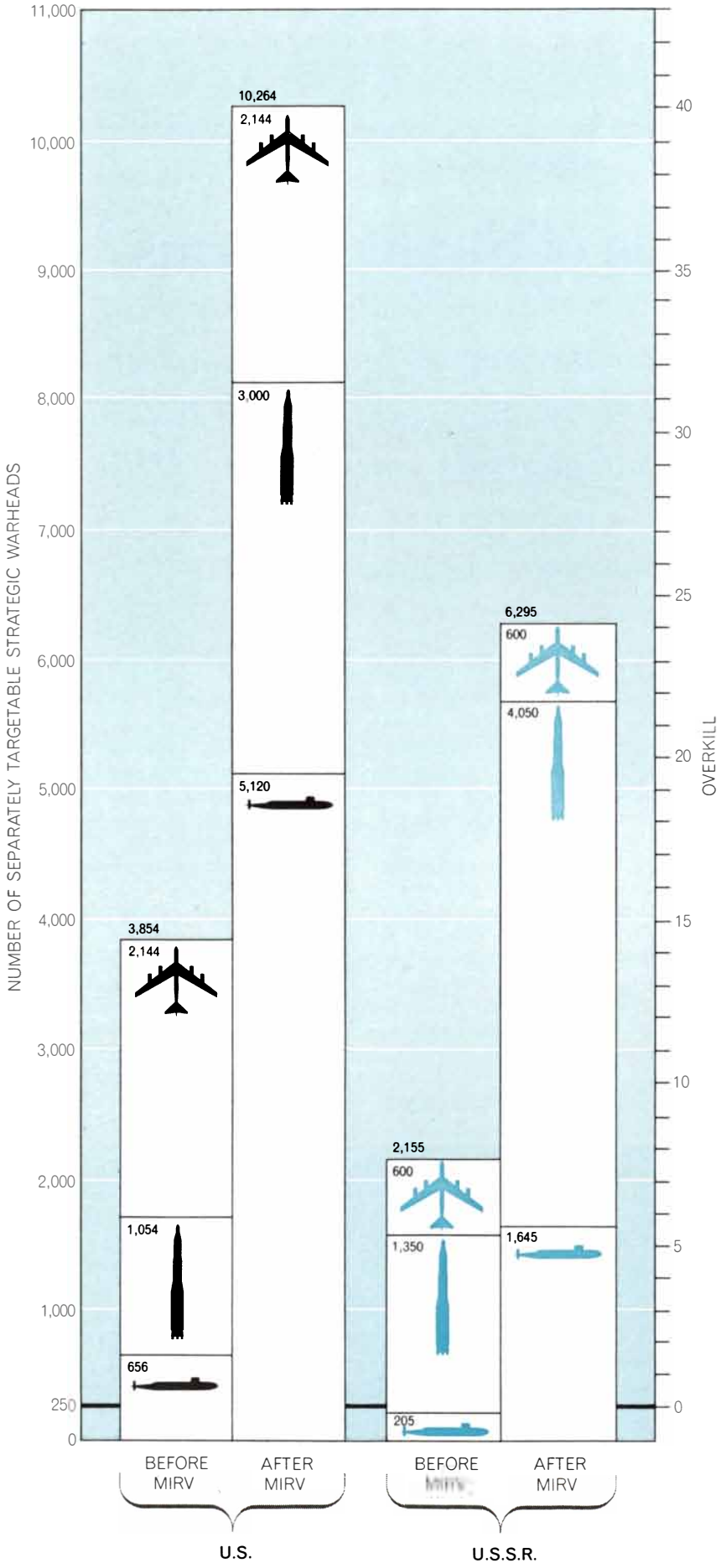
The preliminary phase of the strategic-arms-limitation talks ("SALT") between the U.S. and the U.S.S.R. was conducted in a convivial atmosphere and with a refreshing lack of familiar rhetoric. The road ahead for the negotiations nonetheless remains a steep and slippery one. The fact that the talks were delayed for as long as they were by both sides is not an encouraging sign. The initial unwillingness of the Russian leadership to negotiate because of the American involvement in Vietnam and the subsequent unwillingness of the American leadership to negotiate because of the Russian intervention in Czechoslovakia both reflect a failure to perceive the extraordinary and possibly fleeting nature of the opportunity presented at this particular juncture in the arms race and a failure to recognize that the strategic-arms confrontation can and should be largely decoupled from other sources of conflict between the two superpowers. More recent delays, first by the U.S. and then by the U.S.S.R., reinforce the view that on both sides there has been a fundamental failure in the ordering of priorities—a failure to recognize that the dangers to national security associated with arms-control agreements can be far less than those inherent in the ongoing arms race.

As the substantive phase of the arms talks is about to begin, it is still not obvious that policy-making circles of the two superpowers have consonant views about such basic questions as what objectives strategic forces serve, what relative roles offensive and defensive strategic forces play and what the desired effects of limitations on such forces are. If it should develop that there is no agreement on these points, it may not be possible to negotiate any meaningful limitation on strategic forces.

This article is written in the hope that by stimulating discussion of these questions the differences between the two powers may become more clearly understood and in time narrowed. Even if the talks fail to produce significant agreement, a better grasp of the issues involved will be in the ultimate interest of everyone.

A number of recent developments make the prospects for successful negotiations seem to be more favorable now than they might have been some years ago. Advances in the strategic reconnaissance capabilities of the superpowers (chiefly in the area of surveillance by artificial satellites) are steadily reducing the need for intrusive inspection to establish the degree of compliance with possible future agreements. Thus the thorny issue of verification may be less of a barrier to agreed arms limitation than it has been in the past. In addition the rapid growth of Russian offensive-missile forces has effectively erased a disparity with the U.S. that existed in the past, thereby making an arms-limitation agreement a more realistic possibility. Finally, there is the growing popular realization—at least in the U.S. and presumably also in the U.S.S.R.—that each side already has an enormous "overkill" capacity with respect to the other, and that further escalation in strategic-force levels would entail tremendous costs and new dangers at a time when both countries are confronted with a host of other pressing demands on their resources.

Although these developments would seem to favor successful negotiations, they are possibly outweighed by developments on the other side of the ledger. The most troublesome items are two emerging technical capabilities: multiple independently targeted reentry vehicles (MIRV's) and anti-ballistic-missile (ABM) defenses. It is frequently argued that the development and deployment of either (or particularly both) of these systems by one superpower could lead to a situation in which a decision to attempt a preemptive attack against the other's strategic forces might be considered rational. Indeed, some strategic planners contend that the threat is so great that offsetting actions must be started even before it is clear whether or not the adversary intends to acquire either a MIRV or an ABM capability. It is our belief that such arguments are largely fallacious and are made without real appreciation of the fact that a thermonuclear war between the superpowers, considering the vulnerability of the two societies, is a totally irrational policy choice. No combination of tactics and



weapons, offensive and defensive, could provide either power with sufficient assurance that at least a small fraction of its adversary's weapons would not be successfully delivered, thus inflicting in retaliation damage that would be clearly unacceptable.

We are confronted here, however, with a paradox that will haunt the rest of this discussion. Unilateral decisions regarding the development and procurement of strategic-weapons systems, and hence planning for arms-control negotiations, have been and will continue to be greatly influenced by a fundamentally simpleminded, although often exceedingly refined, form of military analysis. This approach, sometimes characterized as "worst-case analysis," invariably ascribes to one's adversary not only capabilities that one would not count on for one's own forces but also imputes to him a willingness to take risks that would seem insane if imputed to one's own political leadership. Thus the U.S. will react to Russian MIRV and ABM programs, and vice versa, whether or not national security demands it. Even if the reaction is totally irrational, it nonetheless becomes as much a part of reality as if the decision were genuinely required to preserve a stable strategic balance. We reluctantly accept the fact that in both the U.S. and the U.S.S.R. policy will be influenced excessively by those military planners and their civilian allies who persist in behaving as if a thermonuclear war could be "won," and in asserting that responsible political leaders on the other side may initiate it on that assumption.

The development of a strategic nuclear capability by lesser powers, particularly China, seems also destined to complicate efforts to curtail the strategic-

STRATEGIC BALANCE between the U.S. and the U.S.S.R. is shown at left in terms of the numbers of separately targetable strategic nuclear warheads already deployed and the numbers projected for 1975 if present plans to deploy multiple independently targeted reentry vehicles (MIRV's) go into effect. The symbols indicate the means of delivery; the numbers give the actual total of deliverable warheads in each category. The scale at right suggests the enormous "overkill" capacity possessed by each side in either circumstance; it is calibrated in units of 250—a highly conservative estimate of the number of nuclear warheads required to devastate the 50 largest cities on each side. The chart includes only strategic (that is, intercontinental) nuclear warheads, not tactical or intermediate-range nuclear weapons.

arms race between the superpowers. Here there are essentially two problems. First, what was said earlier about the unacceptability of nuclear war between the superpowers may be less applicable to conflicts between emerging nuclear powers, because their political leadership will be less knowledgeable about the effects of nuclear warfare and because the nuclear stockpiles involved will, at least initially, not be large enough to ensure the destruction of entire societies. Thus, with proliferation, the probability of thermonuclear war is likely to increase, and the superpowers will have a real basis for concern about their becoming involved. Second, a phenomenon not unlike the much discussed action-reaction effects of ABM defenses and MIRV's is likely to come into play. Nuclear proliferation may complicate Russian-American efforts to curtail the strategic-arms race even more than the objective facts warrant, as each superpower overreacts not only to the development of new centers of nuclear power but also to the other's reaction to them.

In fact, the rising threat of nuclear proliferation is already increasing the pressure in the U.S. (and probably in the U.S.S.R.) to develop defenses that might be effective at least for a few years against emergent nuclear powers. The enthusiasts talk about neutralizing completely the effects of such developments; the realists propose measures aimed at reducing the damage that might be inflicted in the unlikely event of a nuclear attack by a smaller power. Unfortunately the capabilities that might prove effective, for instance an ABM system adequate to cope with first-generation Chinese missiles, would probably lead the other superpower to expand or qualitatively improve its strategic forces.

The other major considerations that will have a bearing on the prospects for SALT are domestic. As the failure of American policy in Southeast Asia and its implications become apparent, it seems likely that there will be a sharp reaction in an important segment of American society, with the polarization of attitudes proceeding even further than it has in the past year or two. It will be a difficult time for arms-control negotiations. Indeed, the strategic-arms-limitation talks are likely to be a divisive factor in the same way that the recent debate on the Safeguard ABM system was.

The situation in the U.S.S.R., although less clear, seems no more promising. The controversy between China and the U.S.S.R. might lead one to expect that accommodation and cooperation with the West would be increasingly attractive to the Russian leadership. But that controversy, like the recent Russian difficulties in eastern Europe, is also likely to be a factor in reinforcing the trend toward orthodoxy and conservatism within the U.S.S.R., which is hardly a favorable augury for an arms-control agreement.

Thus for SALT to be successful will require not only that the two governments be sincere in approaching the talks but also that they be prepared to display leadership and steadfastness of purpose in dealing with domestic opposition. On both sides there will have to be a rejection of many of the premises on which military policy has been at least partially based for two decades, for example the importance of "superiority" in strategic strength, the concept of "winning" a thermonuclear war, and the view that one can build meaningful defenses against a thermonuclear attack. The leadership in each nation will be confronted with arguments about the great risks inherent in various kinds of agreement—barely feasible (or at least not provably unfeasible) developments that might be taken advantage of by an adversary. Such arguments will undoubtedly resemble those to which the Kennedy Administration had to respond, when in connection with the nuclear-test-ban treaty it was asserted that the U.S.S.R. might conduct nuclear tests behind the moon or behind the sun to our great disadvantage. If agreement is to be reached, such arguments will have to be judged for what they are: nightmares of people who have focused so narrowly on such problems that they simply lack the perspective for weighing the risks of agreement against the risks implicit in continuing the arms race without any agreed constraints.

In the case of the U.S. the President will have a special problem and a formidable challenge, perhaps the greatest faced by any American leader since President Wilson's effort at the end of World War I to gain acceptance for his views regarding the Treaty of Versailles and the League of Nations. Although most Americans, including probably a majority of those who supported President Nixon in his campaign for the Presidency, would support him in his efforts to reach an arms-control agreement, almost certainly the conservative wing of the President's political supporters will counsel him to exercise extreme caution in approaching SALT. In so doing this latter group will give unwarranted weight to the technical and military risks that might be involved in any agreement under consideration. It is equally certain that the military will attempt to influence him with similar arguments, both through its direct channels and through its Congressional allies.

It is inconceivable that any meaningful agreement can be reached if the views of these groups should prevail. They need not, of course. Exercising broader judgment, the President can reject such advice and, as suggested above, draw on very substantial nationwide support for an agreement. Should he choose to do so, he will be in a better position to make his decision politically acceptable than would have been the case for any of his recent predecessors, or for that matter for his opponent in the last election. There is almost certainly a sizable segment of the American body politic that could accept a decision by President Nixon to conclude a very far-reaching agreement as a result of SALT that would not accept a similar position were it offered by, say, a liberal Democratic president.

President Nixon's prospects for such an achievement will be enhanced if the SALT negotiators make substantial progress in the next few months. With momentum established as a result of some limited agreement, and with the prospects of broader agreements before them, both the American and the Russian leadership might well make the judgment that it would be worthwhile to expend the political capital that might be required to effect broader agreements. If, on the other hand, the talks bog down in procedural discussions or in defense of obviously non-negotiable positions, the political leadership in both the U.S. and the U.S.S.R. will be in a weakened position in dealing with those who are most skeptical and fearful of an agreement. Thus the importance of early limited agreement in connection with SALT cannot be overestimated.

In what areas might such limited agreement be immediately feasible? In order to answer this question we must first examine some of the technical realities of the present strategic balance. We believe that for the foreseeable future technological considerations will continue to make nuclear offensive forces dominant over nuclear defensive forces. In other words, we assert that, as has been the case since the initial deployment of thermonuclear weapons, it will be easier to destroy a technologically advanced society than to defend one. What can and should be done both in structuring strategic forces in the absence of agreement and in agreeing to limitations is critically

dependent on whether or not this judgment is correct. There is some dispute about its correctness in the U.S. For example, some assert that with recent developments in ABM technology it may be possible to offset the effects of an incremental expenditure on offensive capabilities by a similar or even lesser expenditure on defenses. Nonetheless, we share the prevailing view that defense of population, at least against a determined adversary with comparable resources, is essentially hopeless.

To facilitate discussion we shall now define two terms that have come to be applied to strategic forces and to their uses. By "damage limitation" we mean the prevention of damage to industry and population in a nuclear war or the reduction of such damage to below the levels that might be expected without the use of certain damage-limiting measures or systems. Antiaircraft or ABM defenses of cities would be categorized as being damage-limiting systems. The use of civil defense measures such as population shelters or evacuation of threatened cities would be regarded as damage-limiting measures. So would be attempts to limit the adversary's ability to inflict damage by preemptively attacking any component of his offensive strategic forces. By "assured destruction" we mean the destruction with high confidence of the adversary's society. Measures to achieve such destruction, or systems that might be used for the purpose, would be characterized as assured-destruction measures or systems. They include the use of offensive missiles and bombers against civilian targets, as distinguished from strictly military targets.

With these definitions we recast our earlier statement about the relative roles of offensive and defensive strategic weapons to assert: *In the superpower confrontation any attempt to build significant damage-limiting capabilities can be offset by changes in the adversary's assured-destruction capabilities.* To take a specific example, attempts to limit and reduce the damage to American society by deploying ABM defenses (including appropriate civil defense measures) can be offset by qualitative and quantitative improvements in the adversary's offensive capabilities at a cost to him certainly no greater than the cost of the damage-limiting measures taken. What is more, we believe that by and large such responses will occur, in spite of the fact that realistic security considerations do not necessarily require a response. Even a very large-scale and technically sophisticated American ABM system could not be counted on to prevent totally unacceptable destruction in the U.S. by a Russian attack—even by an attack launched in retaliation after the Russian forces had already been preemptively struck. Such an American ABM system would in no way make our strategic forces more useful as political instruments, and hence no Russian response would really be required to preserve the effectiveness of the U.S.S.R.'s assured-destruction forces. Because of fear, conservatism and uncertainty, however, it seems a foregone conclusion that a fully compensating buildup in Russian strength would follow.

There may, of course, be circumstances in which damage-limiting efforts will be effective. Each of the superpowers would temporarily be able to maintain a strategic posture that might greatly limit the damage to it in a conflict with a lesser nuclear power such as China. This will be particularly true if a preemptive, or "counterforce," attack against the lesser power's strategic nuclear forces is not excluded.

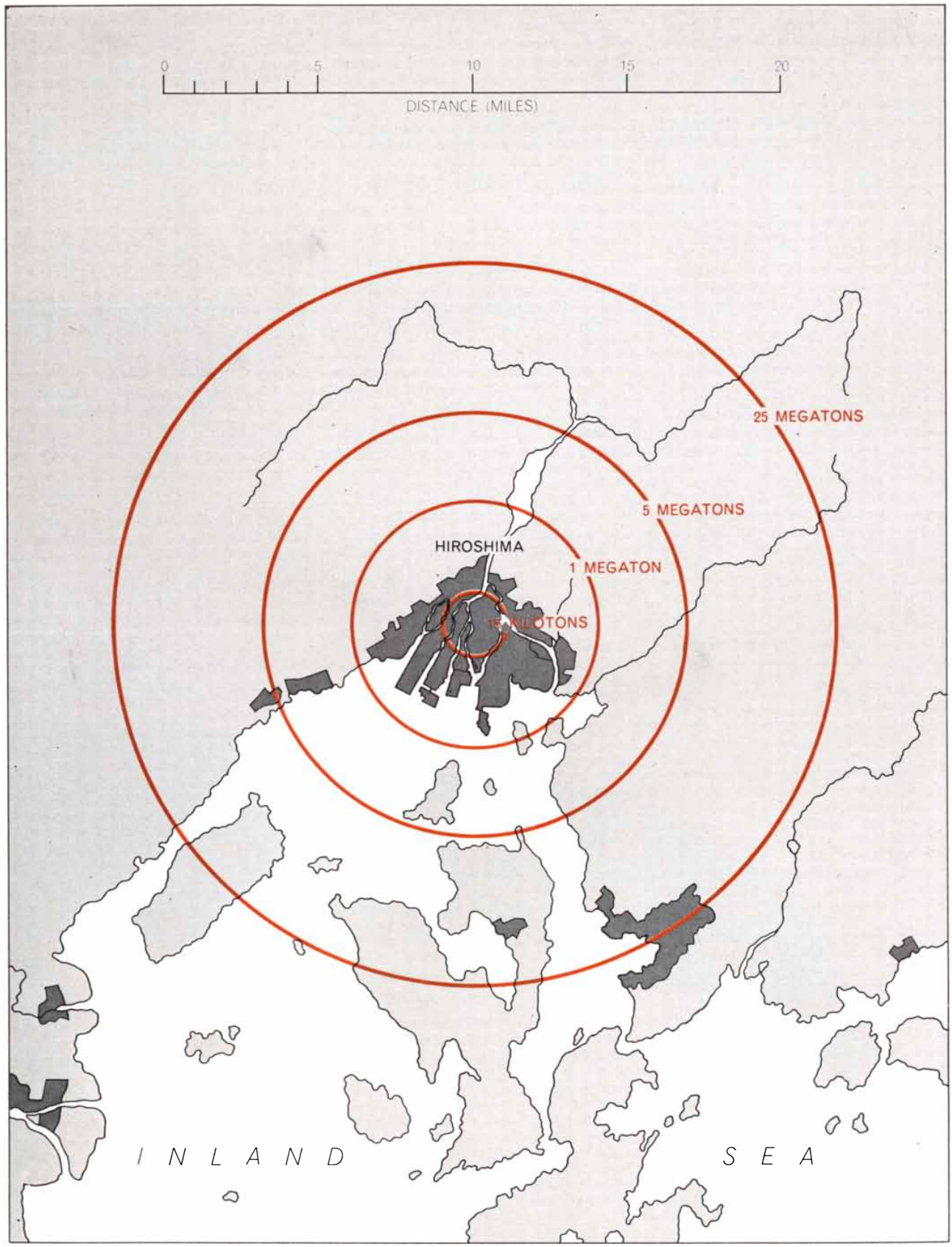
Moreover, if a nuclear exchange between the two superpowers should ever occur, parts of the strategic forces in being at that time probably would be used for active defense or in attacks on the strategic forces of the opponent. Thus they would be used in a damage-limiting role. Their effect would not be great, however, simply because the overkill capacity of each superpower's assured-destruction capabilities is so enormous. Both superpowers almost certainly now have the ability to destroy at least half of the adversary's population and three-quarters of his industrial capacity in spite of any damage-limiting measures that might be undertaken by the other. This situation has come about as a result of two factors. A strategic doctrine has developed, at least in the U.S., that has called for the maintenance of a very great assured-destruction capability under all conceivable circumstances. The doctrine has been one that could be easily implemented simply because thermonuclear weapons and strategic delivery systems are cheap in terms of the damage they can inflict on civilian targets.

This tremendous buildup of offensive forces means that the effectiveness of the last weapons used in destroying another society (in fact, the effectiveness of something like the last 90 percent of all weapons used) would be relatively small, since those already expended would have left so little to destroy. The amount of life and property saved by damage-limiting efforts would be dwarfed by the amount destroyed by weapons whose delivery could not be prevented.

We believe this situation will not change significantly in the near future. Any realistic approach to limitations on strategic armaments in the near future must almost certainly be in the context of the maintenance of very great assured-destruction capabilities. Agreements that would embody quite different strategic balances might result if any of several changes were to occur: technological breakthroughs that would lead to the dominance of the defense over the offense, the development of a high degree of trust between the U.S. and the U.S.S.R., the willingness of both nations to accept intrusive inspection, or an increased appreciation that strategic forces designed to inflict much lower damage levels would also serve effectively as a deterrent. We do not see any of these changes as short-term possibilities.

Because the assured-destruction, or damage-inflicting, capabilities of the two superpowers are so large and so varied, the present strategic balance is remarkably insensitive to either qualitative or quantitative changes in strategic forces. Even major changes in force levels, including the neutralization of entire systems (for example all bomber aircraft), would not be likely to have major effects on the damage levels one would expect each of the superpowers to suffer in a nuclear war. Worldwide radioactive fallout might be reduced significantly, but as far as the superpowers are concerned, cross-targeting with other systems would ensure that all major population and industrial centers would continue to be in jeopardy. When considered in the framework of the virtually certain collapse of an entire society, changes of a few percent in fatalities, which is all one might expect with foreseeable changes in strategic-force levels, are not likely to affect political decisions. Although it may have been correct some years ago to characterize the balance of terror as a "delicate" one, it is not so today, nor is it likely to be so in the foreseeable future. It will not be easily upset. Opponents of the Safeguard ABM decision have argued with some effect (although obviously not with complete success) that the U.S. deterrent was most unlikely to be in jeopardy at any time in the near future simply because of its diversity and because of the improbability of the U.S.S.R.'s being able to develop damage-limiting capabilities and tactics that would effectively neutralize all the deterrent's components.

We have argued so far that one general premise on whose acceptance a successful SALT outcome depends is



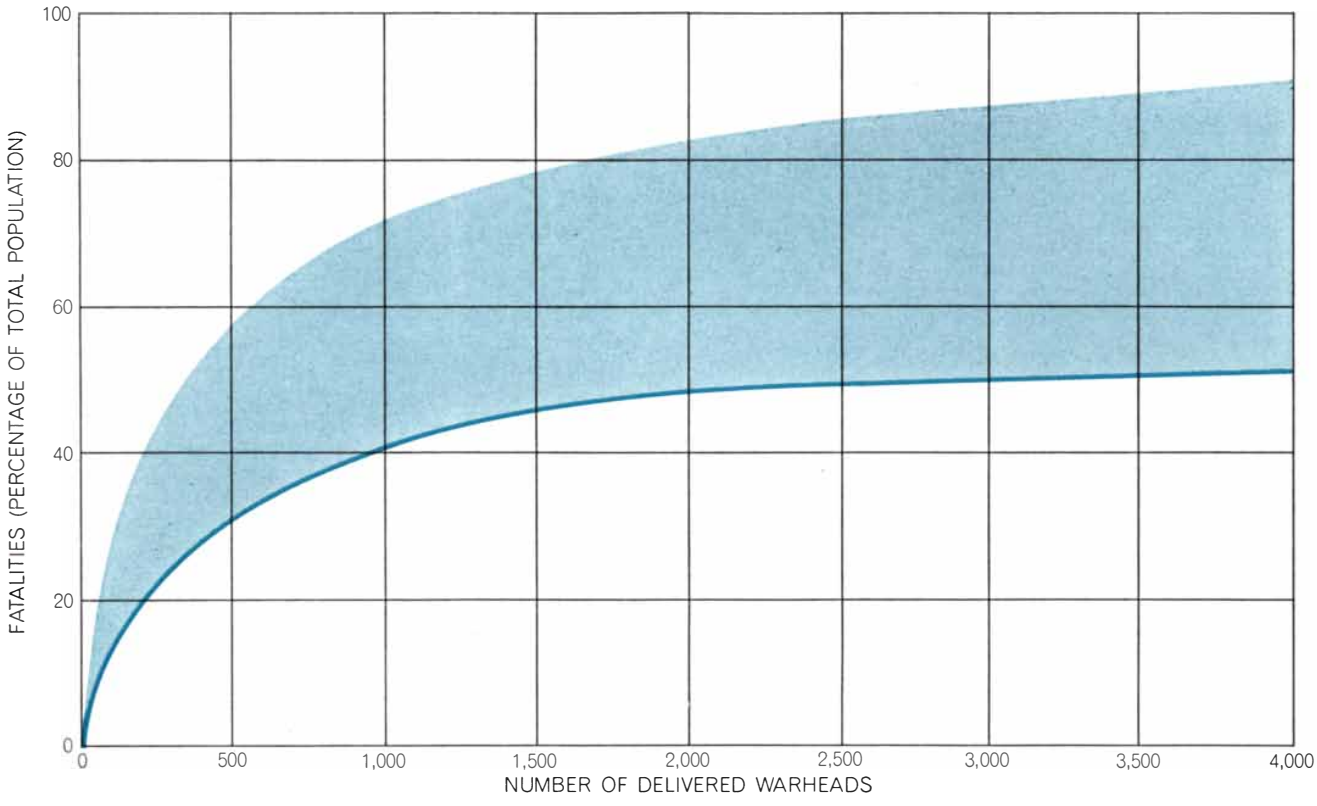
RELATIVE DESTRUCTIVENESS of several currently deployed thermonuclear weapons is illustrated here in relation to the damage caused by the nuclear bomb that was exploded over Hiroshima on May 8, 1945. The colored circles superposed on the map denote each weapon's "lethal area": the area within which the number of survivors equals the number of fatalities outside the circle. For a perfectly uniform population distribution the lethal area times the population density gives the total number of people killed in the explosion. At present most of the strategic warheads deployed by the U.S. and the U.S.S.R. are in the megaton range or larger. Even after MIRVing all the strategic warheads on both sides will exceed the estimated 15-kiloton explosive yield of the Hiroshima bomb.

that the offense will continue to dominate the defense for the foreseeable future. A second technical generalization that may be equally important is: *The uncertainty about the effectiveness of damage-limiting capabilities will be considerably greater than about assured-destruction capabilities.* This statement can be supported by a number of arguments. First, the characteristics of the target against which assured-destruction capabilities would be used (population and industry) will be known with some precision and will change only slowly with time. On the other hand, the characteristics of the systems (and the environment) against which damage-limiting capabilities must operate (adversary's warheads, delivery vehicles and launch facilities) will be generally less well known and more susceptible to rapid variation, both in quality and in number, at the option of the adversary. Second, some of the damage-limiting systems (such as ABM defenses, antiaircraft defenses and under some circumstances antisubmarine warfare, or ASW, systems) must function at the time chosen by the adversary for his offensive, whereas for assured destruction there is a much bigger "time window" during which performance will be acceptable. The effectiveness of submarine-launched missiles in destroying cities will not depend much on the instant of launch. Third, damage limitation generally will involve the use of more intimately coupled systems (for example the radars, computers and missiles of an ABM system), inviting the possibility of "catastrophic" technical failures. All these factors tend to make the advance estimates of the effectiveness of assured-destruction systems far more reliable than estimates of damage-limiting systems.

The inherent uncertainty in effectiveness that characterizes the performance of damage-limiting systems has been of profound importance in the Russian-American strategic-arms race. Each side has reacted to the development, or even the possible development, by the other of damage-limiting capabilities by greatly strengthening its offensive forces—to the point of overreaction because of the conservative assumption that the adversary's damage-limiting forces will be far more effective than they are in fact likely to be. For example, the uncertainty about the possible deployment and effectiveness of a large-scale Russian ABM defense has provided the primary rationale for the U.S. decision to introduce MIRV's into both land-based and sea-based missile forces, the net effect being a severalfold increase in the number of warheads these forces will be able to deliver. Barring unforeseeable technical developments, we must expect that the great uncertainty that characterizes the performance of damage-limiting systems will continue, and we must base our approach to SALT on that assumption.

If one accepts the judgments we have made about the relative effectiveness of defense and offense, about the insensitivity of assured-destruction capability to changes in force levels and about the uncertainty that characterizes damage-limiting efforts, one is led to some possibly useful generalizations about the forthcoming substantive phase of SALT.

First, the level of damage that each of the superpowers can inflict on the other is not likely to be altered significantly in the near future. Measures that might possibly be agreed on could change the level of damage that each side could inflict on the other by at most



FUTILITY of seeking to mitigate the consequences of a full-scale nuclear exchange between the two superpowers by negotiating modest reductions in strategic-force levels or by resorting to moderately effective "damage-limiting" measures is illustrated in this graph, in which the expected fatalities in the U.S.S.R. are plotted as a function of the number of U.S. megaton-range warheads delivered. The solid curve indicates the immediate, easily calculable fatalities; the shading represents the fact that the total fatalities would probably be much larger. In either case, because of the very large number of deployed weapons, the effects of small changes in the total of delivered weapons would be negligible. The expected effects of a Russian attack against the U.S. would be similar.

a few percent. Therefore the problem of the reduction in damage in the event of war should probably be given low priority as a short-term negotiation objective. More realistic objectives of the negotiations could be to lower the level of tension between the superpowers and so reduce the probability of nuclear war.

Second, apart from possible worldwide fallout effects and domestic political considerations, neither side need be much concerned about the possibility of modest, or even substantial, expansions in the strategic offensive forces of the other side, nor about precise limitations on those forces, as long as the other side does not have a damage-limiting capability. Because of the large overkill capacities discussed above, even large increases in strategic forces will have little military effect.

Third, measures to constrain the introduction or improvement of damage-limiting systems, particularly those whose performance is expected to be highly uncertain, merit high priority. The introduction or improvement of damage-limiting capabilities by either side is likely to result, as we have noted, in an excessive reaction by the other. Because of the insensitivity of the strategic balance to modest changes in force levels, a move toward the development of a narrowly circumscribed damage-limiting capability by one side could in principle be tolerated without undue concern by the other. Such a move might be perceived, however, as an indicator of the adversary's intent to develop an across-the-board damage-limiting capability. (Witness Secretary of Defense Laird's public reaction to a possible Soviet SS-9 MIRV capability.) This, coupled with the fact that a development of damage-limiting capabilities can be offset rather quickly and cheaply, virtually ensures a reaction. The overall effect of such an action-reaction cycle on the ability of each side to inflict damage on the other is likely to be small, but the expenditures of both sides on strategic armaments are likely to be much increased, as will be the tensions between them.

Fourth, owing to the large uncertainty that characterizes the effectiveness of damage-limiting systems and tactics, the two superpowers will face a very troublesome dilemma if, on the one hand, they try to develop effective damage-limiting capabilities with respect to emerging nuclear powers and, on the other, they attempt to limit the strategic-arms race between themselves. With a few exceptions, such as a deployment of Russian intermediate-range ballistic missiles (IRBM's) in Siberia, the measures that could have long-term effectiveness against a third country's nuclear strength would appear to the other superpower to foreshadow an erosion in its own assured-destruction, or deterrent, capability. This creates an authentic problem of conflicting desires. We would hope that in efforts to deal with this problem the usefulness of damage-limiting capabilities with respect to the lesser nuclear powers would not be overrated. Although such damage-limiting capabilities probably would be effective in reducing damage in the event that a lesser power attempted a nuclear attack against one of the superpowers, we question whether either superpower would ever be willing to take action against a lesser power on the assumption that damage-limiting efforts would be 100 percent effective, that is, on the assumption that "damage denial" with respect to a lesser power could be achieved. Considering one's inability to have high confidence in the effectiveness of damage-limiting measures, and considering the effects of even a single thermonuclear weapon on a large American or Russian city, we doubt that efforts to develop damage-limiting capabilities with respect to the smaller powers would materially increase the options the superpowers would have available for dealing with these powers.

With this background in mind one would be in a good position to evaluate the relative desirability of limiting various strategic systems if each were unambiguously useful only for damage limitation or assured destruction. Unfortunately many existing or prospective strategic systems may play several roles, a factor that greatly complicates the problem.

Of all the ambiguous developments now under way none is more troublesome than MIRV. The development of a MIRV capability may facilitate the maintenance of an assured-destruction capability by providing high assurance that ABM defenses of industry and population can be penetrated. Given sufficient accuracy, reliability and yield, however, MIRV's may also make it possible for a small number of missiles to destroy a larger number of fixed offensive facilities, even if they are "hardened" against the effects of nuclear weapons.

Although the effectiveness of a given missile force in a damage-limiting preemptive attack against an adversary's intercontinental ballistic missile (ICBM) force might be much increased through the use of such MIRV's, it does not necessarily follow that the deployment of the MIRV's would make such a strike more likely. As we have noted, in the context of a confrontation between superpowers such an attack would surely be irrational, no matter how severe the crisis, simply because no responsible political leader could ever have high confidence in the effectiveness of the attack and in the effectiveness of the other damage-limiting measures that would be required to keep the damage from a retaliatory response down to acceptable levels. Although MIRV's are not likely to have much actual effect on the willingness or ability of nations to use strategic nuclear forces to attain political objectives, we must accept the fact that arms policies will, to a substantial degree, be based on the assumption that they might be so used.

Beyond that, there is the problem of the impact of MIRV's on events if a crisis should ever escalate to the point where limited numbers of nuclear weapons will have been employed by the superpowers against each other. At some point in the process of escalation it is likely that one or both powers would initiate counterforce attacks against the other's remaining offensive forces. Such an attack would probably come earlier if one or both sides had counterforce-effective MIRV's than if neither did.

Because of what we regard as unwarranted, but nevertheless real, concern about MIRV's being used in a preemptive counterforce attack, and because of more legitimate concern that once a thermonuclear exchange has begun MIRV's may make further escalation more likely, MIRV development may well have a critical impact on the outcome of SALT, and for that matter on the force levels of the two sides independent of the talks. It is generally, although not universally, accepted that the tests of MIRV's have not yet gone far enough for one to have confidence that their reliability and accuracy would be sufficient to assure their effectiveness in a counterforce role against hardened ICBM's. On the other hand, the MIRV principle is now demonstrated, and the expectation is common that with perhaps the second generation of such systems, if not with the first, MIRV's will be effective as counterforce weapons.

If no constraints are put on the development of MIRV's, it is likely that each superpower will go ahead with such development and (in the case of the U.S. at least) an early deployment program. This will be regarded as particularly urgent if ABM deployment

continues, or even if there continues to be evidence of significant research and development that might later lead to ABM deployment. Assuming that MIRV programs do continue, each superpower will perceive in the other's deployment a possible threat to its fixed-base ICBM's and will react to counter that threat. The U.S. has already begun to do so in deciding to go ahead with an active ABM defense of Minuteman sites: the Safeguard program. Acceleration in the U.S.S.R.'s missile-launching submarine program and a possible mobile-ICBM program are plausible reactions to the U.S. MIRV programs.

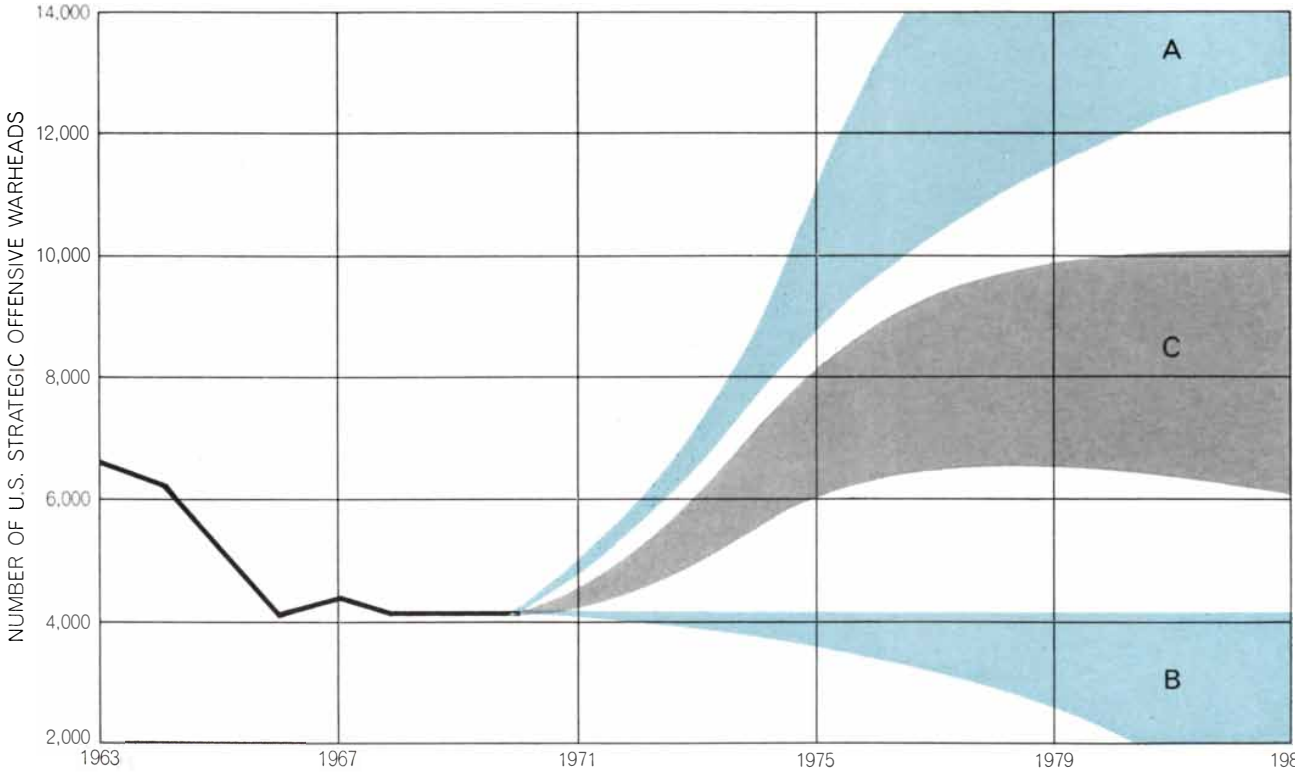
We anticipate that in the absence of agreements the technological race will go much further. It seems likely that the arguments to "do something" about the vulnerability of fixed ICBM's will increase in tempo and will carry the day in both the U.S. and the U.S.S.R. Superhardening alone will be perceived to be a losing game, considering how easily any moves in that direction could be offset by further improvements in missile accuracy. A defense of the Safeguard type will probably also be judged to be a losing proposition. A very heavy defense with components specifically optimized for the defense of hardened ICBM's might be one response. There is likely to be even further reliance on mobile systems: missile-launching submarines, new strategic bombers and, in the case of the U.S.S.R., probably mobile ICBM's. It is conceivable that fixed ICBM's may be given up altogether, although the arguments we have advanced against the acceptability of attacking them preemptively would still be valid.

It is also likely in the absence of agreements that one or the other of the superpowers will deploy ABM systems that will provide more extensive and effective defense of population and industry than either the present Russian defenses around Moscow or the projected Phase II of Safeguard. Defense against a Chinese missile capability may be the rationale, but it is to be expected that the other superpower will respond to any such deployment both by emulation and by increasing its strategic offensive capabilities.

Whereas the strategic-forces budget of the U.S. now amounts to about $9 billion per year (excluding some rather large items for nuclear warheads, research and development, command and control, communications and intelligence activities), outlays for strategic systems could well double by the mid-1970's. Continuing large expenditures on strategic systems are probably also to be expected in the U.S.S.R.

As we have stated, there appears to be no basis for expecting SALT to lead to significant reductions in the assured-destruction capabilities of the superpowers. Therefore other objectives must command our attention. The most important objective is of course to reduce the probability that a thermonuclear exchange will ever take place.

The major factors affecting that probability are likely not to be simply technical but to be largely political. They involve the degree of tension that will exist between the superpowers based on international political considerations, on domestic politics in each country and in an important sense on the strategic-arms race itself. We believe that in contrast to some previous eras, when the motivations for continuing arms races were largely political and economic conflicts, the strategic-arms race now has a life of



PROJECTED EFFECTS associated with three possible outcomes of the strategic-arms-limitation talks are expressed in the graphs on these two pages in terms of the number of U.S. strategic offensive warheads (*left*) and the U.S. budget for strategic forces (*right*). With no agreement (*A*) the number of weapons and the strategic-forces budget are likely to grow with no obvious limit. A SALT agreement that included a prohibition on the development and deployment of MIRV's (*B*) could lead to stability in strategic forces and a reduction in the budget to a level required to maintain them. With an agreement that did not constrain MIRV's (*C*) there would certainly be an increase in the strategic-forces budget for a few years as the composition of these forces changed, probably accompanied by the replacement of some fixed-base offensive missiles by mobile systems (either land-based or sea-based) or possibly by

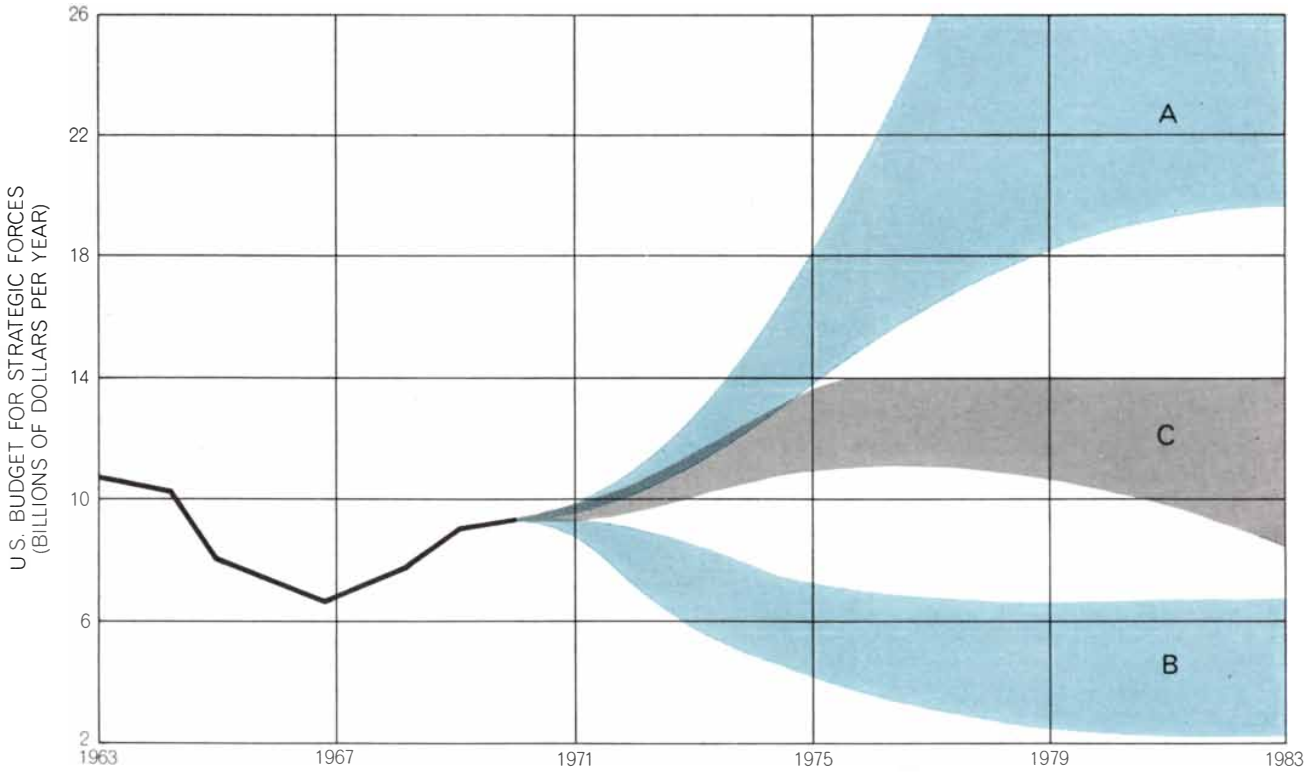
its own. For instance, the strategic-weapons programs of each superpower are more dependent on the programs of the other than on the levels of tension between the two countries. If this race can be attenuated, it would have a number of effects that would result in a diminution of tensions and hence in a reduction in the risk of war. That is perhaps the major reason for the urgency of a serious SALT effort. Keeping budgets for strategic forces at low levels is desirable in its own right in that significant resources, both financial and intellectual, will be freed for more constructive purposes. More important, in the U.S. lower military budgets will diminish the role of what President Eisenhower termed the military-industrial complex: those who have a propensity for, and in some cases obviously a vested interest in, the acquisition of more armaments and in exciting and maintaining an often unwarranted attitude of alarm and suspicion regarding an adversary's intentions. Lower military budgets in the U.S.S.R. would almost certainly have a similar desirable effect.

A poorly designed agreement could of course prove to be a vehicle for increasing suspicion and tension. Venturing into the realm of unprovable value judgments, however, we assert that it is not beyond the wit of man to design agreements that would result in there being less objective cause for concern than if the strategic-arms race continues unabated. In general, it would seem that any understanding that slowed the rate of development and change of strategic systems would have an effect in the right direction.

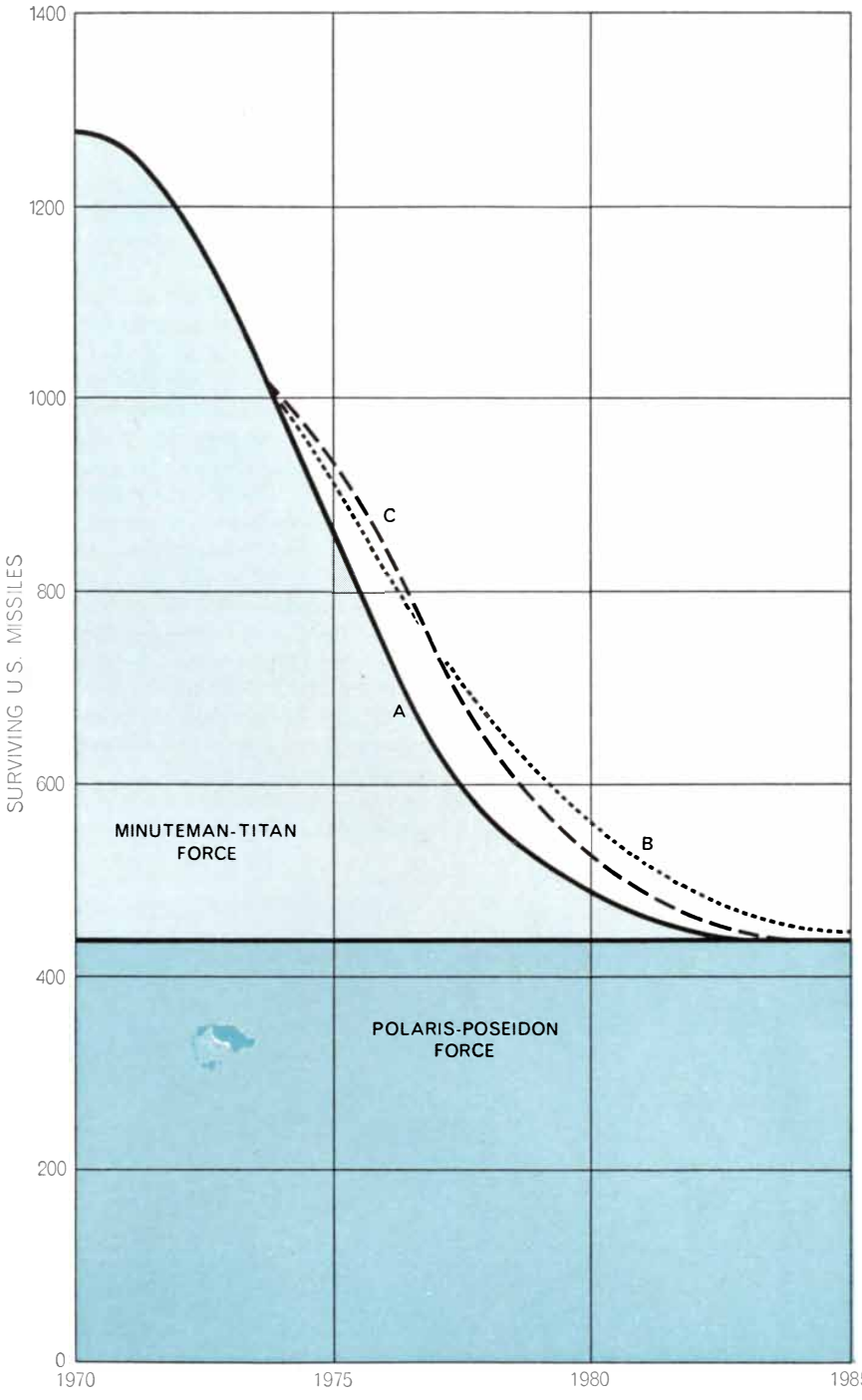
Beyond affecting the probability of a nuclear exchange's beginning, one would like to see strategic forces structured so that there would be at least some possibility that, if an exchange started, it would not have to run its course. A necessary but of course not sufficient condition for this is that there be no particular advantage to be gained from precipitate launch of more nuclear weapons after a few have been dispatched. By this criterion vulnerable ICBM's would seem to be the quintessence of undesirability. If both sides have them, each will recognize that if they are withheld, they may be destroyed.

Whether or not MIRV development and deployment will be controlled may not be a question for the SALT negotiators to consider, because of the inability of one side or the other to decide in a timely fashion the position it wishes to take on the issue. The rate of MIRV development is so rapid that the question may thus be settled before the substantive phase of the talks is well advanced. If such development is still in doubt, however, either because the talks get to such substantive issues very quickly or because of a moratorium on MIRV testing, MIRV limitation should be an issue of the highest priority.

The arguments for preventing deployment of MIRV's advanced enough to be effective counterforce weapons are persuasive. They have been made at great length elsewhere (for example in public hearings before committees of the Senate and the House of Representatives). We simply summarize here by pointing out that if MIRV deployment is prevented, it may be possible to freeze the strategic balance at something approximating its present level. Most of the incentive to defend hardened ICBM's or to replace them with mobile systems will



"superhardening" and heavy specialized ABM defense of missile sites. Assuming under case *C* that a large-scale ABM defense of population is prohibited, there would be little military rationale for either side to acquire large additional numbers of offensive warheads. Nonetheless, the numbers might increase significantly with the implementation of present plans to deploy MIRV's. Future Russian strategic-forces levels would probably display similar trends, but budget projections would differ somewhat. The Russian budget for strategic weapons is possibly at an unprecedentedly high level now, considering the present rapid rate of growth in their strategic systems. Thus in case *B* the drop in the strategic-forces budget for the U.S.S.R. might be sharper than for the U.S., and in the two other cases there would be a less pronounced increase. Estimates are in constant-value 1969 dollars.



DIMINISHING UTILITY of fixed-base intercontinental ballistic missiles (ICBM's) as a component of the U.S. "assured-destruction" forces would result from further development and deployment of MIRV's, even in the event of a SALT agreement that freezes the number of missiles on both sides. In preparing this graph it was assumed that in a preemptive, or counterforce, strike against the U.S. the U.S.S.R. would target its SS-9 missile force (estimated to be frozen at 280 missiles) at the U.S. Minuteman-Titan force. The numbers of surviving U.S. ICBM's are based on the assumption that each SS-9 will carry one 25-megaton warhead in 1970, three five-megaton warheads in 1975, nine 500-kiloton warheads in 1980 and 25 50-kiloton warheads in 1985; delivery accuracies are assumed to improve by a factor of two every five years. Curve *A* assumes that no additional measures are taken to protect the already "hardened" U.S. ICBM force. Curve *B* assumes that the blast resistance of the ICBM sites is improved by "superhardening" so that by 1972 they can withstand three times the overpressure sustainable in 1970. Curve *C* assumes full operational capability (and a generous estimate of performance) of the Safeguard ABM system by 1978. It is apparent that neither superhardening nor active defense (unless many times more effective than Safeguard) is likely to extend the period of invulnerability for U.S. ICBM's by very much. (The number of surviving submarine-launched missiles is based on the assumption that a third of the Polaris-Poseidon force is destroyed in port by the Russian preemptive attack.)

have been reduced, if not eliminated.

The arguments for continuing MIRV testing and then deployment because MIRV's may someday be required to penetrate an adversary's ABM defenses are not convincing. There is little doubt that currently designed U.S. MIRV's could be deployed on a time scale short compared with that required for deployment of any significant Russian ABM defenses. Accordingly there is no need for any MIRV deployment pending firm evidence that the U.S.S.R. is beginning the construction of such defenses. And there is no need for further research and development tests unless a counterforce capability is intended. For similar reasons the U.S.S.R. should also abstain from further multiple-warhead tests and deployment, which it can do at no great risk to its security.

Essential to the survival of an agreement not to test MIRV's would be a prohibition of large-scale ABM deployment. If ABM systems were deployed, the pressures to deploy MIRV's and to test them frequently in order to maintain confidence in their reliability would be overwhelming. Furthermore, there would undoubtedly be great domestic pressures to develop and test more sophisticated penetration aids. Under such circumstances neither side could have any confidence that the other was not developing counterforce-effective MIRV's. An ABM freeze would be a logically required companion measure to any agreement prohibiting MIRV's.

Assuming that ABM deployment and MIRV testing are both frozen, the other important component of a strategic-arms-limitation agreement would be an understanding to maintain something like parity in ICBM-force levels by freezing these levels or preferably reducing them, and if necessary permitting replacement of fixed-base ICBM's by mobile systems whose levels could be verified by unilateral means. In the absence of such a measure there would be the possibility of one side's gaining such a superiority in missile strength that, with improved accuracies and even without MIRV's, would enable it to knock out a large fraction of its adversary's forces by delivering a counterforce attack against them. The reasons for concern about such a possibility have been identified above: the probability of arms-race escalation and the reduction in whatever small chance there may be of a nuclear exchange's being terminated short of running its suicidal course.

If the development of MIRV's that are perceived by the adversary to have counterforce capability cannot be pre-

vented (and we are pessimistic about preventing it), the relative importance of some of the measures discussed above will be changed materially. A prohibition on large-scale ABM deployment would still be desirable, but it would be less important; it would not in this case prevent the MIRV genie from escaping the bottle. Moreover, continuing development and deployment of MIRV's would make a large-scale ABM defense unattractive simply on cost-effectiveness grounds.

A provision permitting the replacement of fixed ICBM's by mobile systems would seem virtually unavoidable because of concern about the vulnerability of the ICBM's to counterforce attack. Indeed, in the interest of stabilizing arms at low levels, and to minimize concern about damage-limiting strikes, agreements could probably include measures that would enhance the viability of mobile systems. An area of agreement that would seem to merit most serious consideration would be prohibition on certain improvements in antisubmarine-warfare capabilities. Actually the possibility of breakthroughs in antisubmarine warfare is extremely remote. It is probable that through noise reduction, extension of missile range and other techniques the gap between ASW capability and the capability of the missile-launching submarine to escape detection and destruction will widen rather than narrow. Yet it seems likely from recent debate in the U.S. that the present American leadership, and presumably the leadership of the U.S.S.R. as well, would be reluctant to rely solely on a missile-launching submarine force for deterrence, given the possibility of further ASW development by its adversary. Constraints on ASW such as a limitation on the number of hunter-killer submarines would increase the acceptability to both sides of relying more heavily on missile-launching submarines for deterrence.

Similar arguments might be made for limitations on or curtailment of air defense. Such moves would seem less realistic on three counts. First, compliance with limitations on air-defense capabilities could probably not be verified with unilateral procedures as well as could limitations on ASW systems, or for that matter on ABM systems. Intelligence on short-range antiaircraft systems is likely to be poorer than on hunter-killer submarines, specialized ASW aircraft or large-sized components of ABM systems. Second, the overlap between tactical and strategic antiaircraft capabilities is considerable, and neither superpower is likely to be willing to greatly reduce tactical antiaircraft capabilities in the context of SALT. ASW capabilities (except for destroyers) would, on the other hand, have little role other than attack against an adversary's missile-launching submarines. This is far truer now than it was a few years ago because the realization is more widespread that a major war involving large antishipping campaigns is extremely unlikely. Third, neither the U.S. nor the U.S.S.R. is likely to have enough confidence in bombers to rely much on them in a missile age even if air defenses are constrained, whereas both superpowers obviously are prepared to rely heavily on submarine-launched missiles.

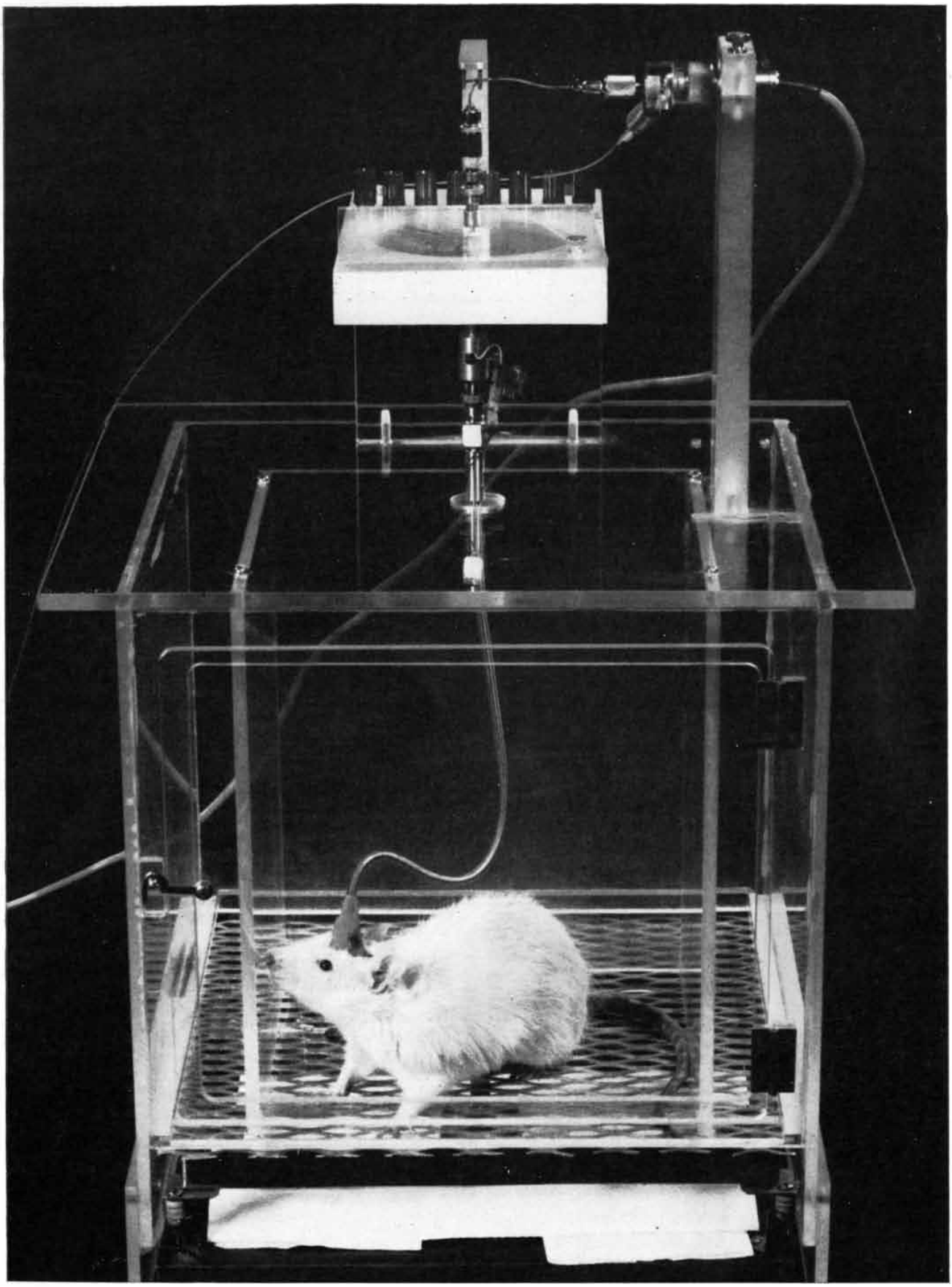
Finally, if counterforce-effective MIRV's were a reality, and if as a consequence both sides were to place reliance very largely on mobile systems, additional offensive weapons on one side could not be used effectively to limit the other side's ability to retaliate. Considering this fact and the fact that since strategic-force levels are already at least an order of magnitude larger than is rationally required for deterrence, there would be little incentive for either side to acquire additional offensive capabilities. Also in this situation it would hardly matter if either side were to introduce new assured-destruction systems such as, for example, small mobile ICBM's that could not be easily counted.

Even this incomplete discussion shows that the strategic balance between the superpowers is likely to be very different depending on whether or not MIRV development and ABM deployment are allowed to continue. Both possibilities will have a serious impact on future strategic postures, but with respect to ABM deployment nothing much is going to happen overnight. Dealing with the issue of MIRV development, although perhaps no more important, is far more urgent. That is why it is the watershed issue for SALT. If counterforce-effective MIRV's (and large-scale ABM deployment) can be stopped, the present strategic balance of force levels may endure for some time. If such MIRV's are deployed, the balance will unavoidably change in qualitative ways. How large an escalation in the arms race will result will depend on whether agreement to constrain or cut back other strategic systems could still be negotiated.

We have attempted here to present an objective analysis of the prospects for various agreements to limit strategic armaments. In so doing we are aware that many of our readers will be dismayed that our discussion has been in the context of each superpower's preserving the capability of destroying the other. This has been so not because we ourselves favor the continuing retention of huge stocks of thermonuclear weapons but because we have tried to be realistic. The distrust that exists between the U.S. and the U.S.S.R. will induce both to preserve the capability of destroying the other; such a capability, as we have noted, is unfortunately easier to attain than an effective defense of one's own society, whether or not there are agreements on strategic armaments. Both superpowers will preserve this capability because they see it as the only effective deterrent to the war that neither wants or could win.

The most that can reasonably be expected of the forthcoming talks is a move toward a strategic balance where (1) uncertainties about the adversary are reduced and with them some of the tensions; (2) each side can inflict a level of damage on the other sufficient to destroy its society but neither feels a need to maintain a great overkill capability as a hedge against possible damage-limiting efforts by the other; (3) there will be an improved chance that a thermonuclear exchange, should one begin, would be terminated short of running its course, and (4) the levels of expenditure on strategic armaments are lower, so that larger fractions of the resources available to each society can be used for more constructive endeavors.

We believe that the realization of these objectives would be a tremendous accomplishment and one that is possible without the solution of the deep-seated political problems of the Russian-American confrontation. To go further will require dealing with those problems. We do not believe, however, that the superpowers can afford to delay attacking the strategic-arms race while trying to solve political differences. Regrettably the situation with respect to technical developments (MIRV's, ABM defenses and nuclear proliferation), and quite possibly with respect to domestic politics as well, will probably make strategic-arms-limitation negotiations less likely to be successful several years hence than now. Time is of the essence, and we write with a feeling of urgency. Although our tone is pessimistic, we do not despair. We are convinced that latent public support for an agreement could be exploited by effective political leadership on both sides to reverse the trends we have lived with for two decades.



VISCERAL RESPONSES of active rats were measured with this experimental setup. The necessary tubes and wires (in this case including a plastic catheter to sense blood pressure in an abdominal artery) are led from the rat's skull through a protective steel spring to a mercury connector, a fluid swivel that permits free movement. The platform is wired to record the rat's activity.

Learning in the Autonomic Nervous System

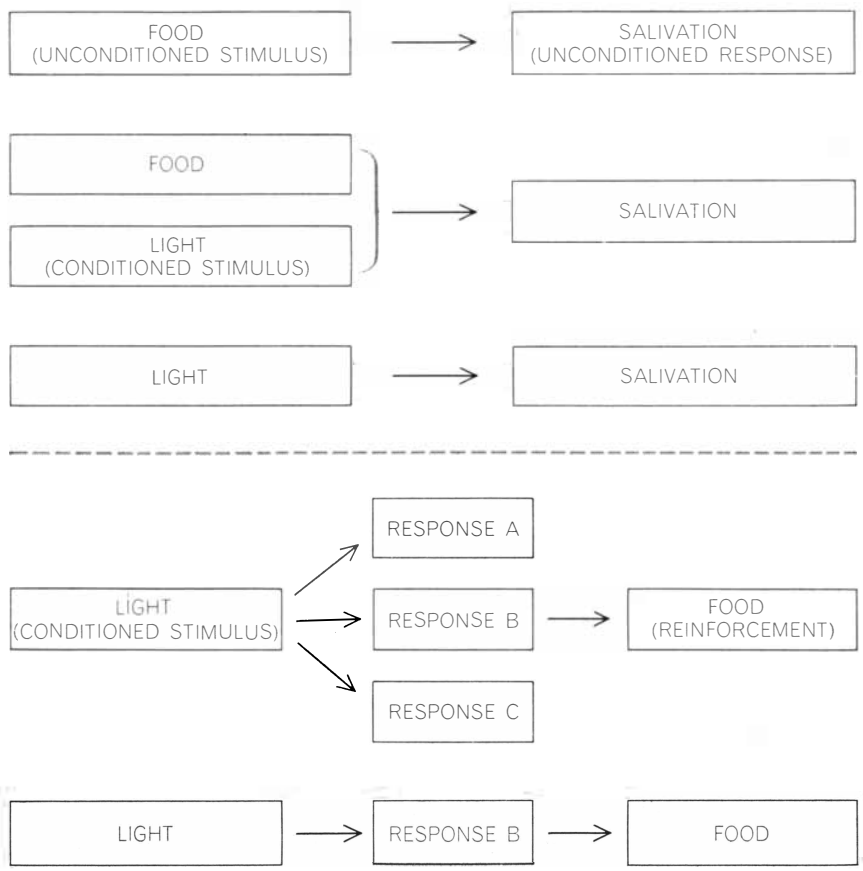
It has long been assumed that body functions such as heartbeat and intestinal contraction were involuntary and could not be influenced by learning. Recent experiments indicate that this is not the case

by Leo V. DiCara

The heart beats and the stomach digests food without any obvious training, effort or even attention. That may be the basis of a curious prejudice against the visceral responses—the responses of glands, of cardiac muscle and of the smooth muscle of the alimentary canal and blood vessels—and against the autonomic nervous system, which controls them. Such responses are assumed to be quite different from, and somehow inferior to, the highly coordinated voluntary responses of skeletal muscles and the cerebrospinal nervous system that controls them. A corollary of this attitude has been the assumption that visceral responses can be "conditioned" but cannot be learned in the same way as skeletal responses. It turns out that these long-standing assumptions are not valid. There is apparently only one kind of learning; supposedly involuntary responses can be genuinely learned. These findings, which have profound significance for theories of learning and the biological basis of learning, should lead to better understanding of the cause and cure of psychosomatic disorders and of the mechanisms whereby the body maintains homeostasis, or a stable internal environment.

Learning theorists distinguish between two types of learning. One type, which is thought to be involuntary and therefore inferior, is classical, or Pavlovian, conditioning. In this process a conditioned stimulus (a signal of some kind) is presented along with an innate unconditioned stimulus (such as food) that normally elicits a certain innate unconditioned response (such as salivation); after a time the conditioned stimulus elicits the same response. The other type of learning—clearly subject to voluntary control and therefore considered superior—is instrumental, or trial-and-error, learning, also called operant conditioning. In this process a reinforcement, or reward, is given whenever the desired conditioned response is elicited by a conditioned stimulus (such as a certain signal). The possibilities of learning are limited in classical conditioning, because the stimulus and response must have a natural relationship to begin with. In instrumental learning, on the other hand, the reinforcement strengthens any immediately preceding response; a given response can be reinforced by a variety of rewards and a given reward can reinforce a variety of responses.

Differences in the conditions under which learning occurs through classical



TWO TYPES OF LEARNING are classical conditioning and instrumental learning. Classical conditioning (*top*) begins with an unconditioned stimulus. The conditioned stimulus that is paired with it comes to substitute for it in producing the unconditioned response. In instrumental learning (*bottom*) a conditioned stimulus is presented along with an opportunity to respond in various ways. The correct response is reinforced, or rewarded. After several reinforcements the stimulus serves as a signal to perform the learned response.

conditioning and through instrumental learning have been cited to show that the two processes are two distinct phenomena that operate through different neurophysiological mechanisms. The traditional belief has been that the involuntary and inferior visceral responses can be modified only by the correspondingly inferior type of learning—classical conditioning—and not by the superior and voluntary instrumental learning, which has been thought to modify only voluntary, skeletal responses.

Not all learning theorists accepted this distinction. For many years Neal E. Miller of Rockefeller University has held that classical conditioning and instrumental learning are not two basically different phenomena but rather two manifestations of the same phenomenon under different conditions—that there is, in fact, only one kind of learning. To support such a position he had to show that instrumental training procedures can produce learning of any visceral responses that can be acquired through classical conditioning, and the demonstration had to be very clear and convincing in the face of the ingrained belief that such learning is simply not possible.

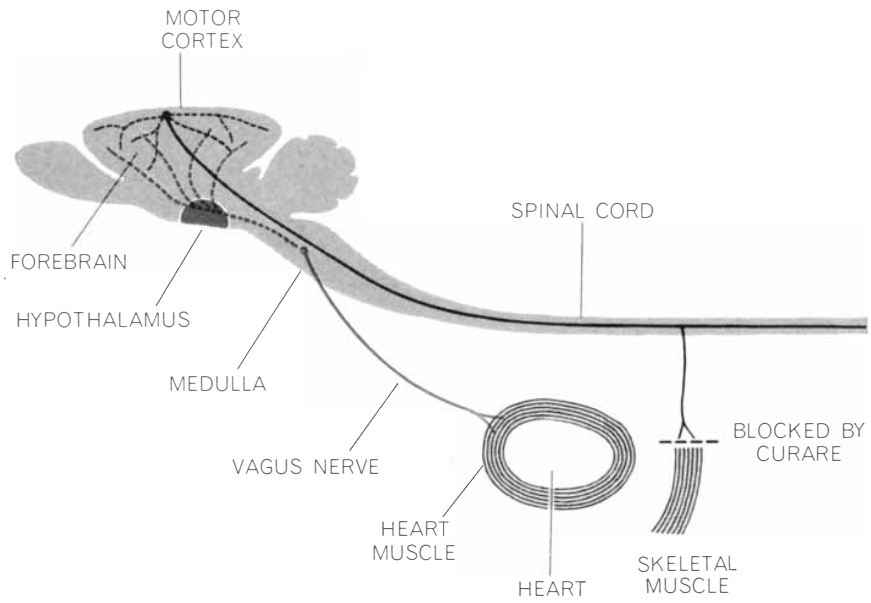
Research on the instrumental modification of visceral responses comes up against a basic problem: most such responses can be affected by voluntary activities such as the tensing of muscles or changes in the rate or pattern of breathing. It is therefore hard to rule out completely the possibility that the experimental subject has not directly learned to control a visceral response through the autonomic system but rather has learned to execute some subtle and undetectable skeletal response that in turn modifies the visceral behavior. (A skilled disciple of yoga, for example, can stop his heart sounds by controlling his rib cage and diaphragm muscles so that pressure within the chest is increased to the point where the venous return of blood to the heart is considerably retarded.)

To guard against the contamination of experimental results by such "cheating," careful controls and detailed statistical analysis of data are required. The primary control Miller and I apply in our animal experiments is paralysis of the subject's skeletal muscles. This is accomplished by administering a drug of the curare family (such as *d*-tubocurarine) that blocks acetylcholine, the chemical transmitter by which cerebrospinal nerve impulses are delivered to skeletal muscles, but does not interfere with consciousness or with the transmitters that mediate autonomic responses. A curarized animal cannot breathe and must therefore be maintained on a mechanical respirator. Moreover, it cannot eat or drink, and so the possibilities of rewarding it are limited. We rely on two methods of reinforcement. One is electrical stimulation of a "pleasure center" in the brain, the medial forebrain bundle in the hypothalamus, and the other is the avoidance of or escape from a mildly unpleasant electric shock.

Utilizing these techniques, we have shown that animals can learn visceral responses in the same way that they learn skeletal responses. Specifically, we have produced, through instrumental training, increases and decreases in heart rate, blood pressure, intestinal contractions, control of blood-vessel diameter and rate of formation of urine. Other investigators have demonstrated significant instrumental learning of heart-rate and blood-pressure control by human beings and have begun to apply the powerful techniques developed in animal experiments to the actual treatment of human cardiovascular disorders.

After Miller and his colleagues Jay Trowill and Alfredo Carmona had achieved promising preliminary results (including the instrumental learning of salivation in dogs, the classical response of classical conditioning), he and I undertook in 1965 to show that there are no real differences between the two kinds of learning: that the laws of learning observed in the instrumental training of skeletal responses all apply also to the instrumental training of visceral responses. We worked with curarized rats, which we trained to increase or to decrease their heart rate in order to obtain pleasurable brain stimulation. First we rewarded small changes in the desired direction that occurred during "time in" periods, that is, during the presentation of light and tone signals that indicated when the reward was available. Then we set the criterion (the level required to obtain a reward) at progressively higher levels and thus "shaped" the rats to learn increases or decreases in heart rate of about 20 percent in the course of a 90-minute training period [*see illustration on page 34*].

These changes were largely overall increases or decreases in the "base line" heart rate. We were anxious to demonstrate something more: that heart rate, like skeletal responses, could be brought under the control of a discriminative stimulus, which is to say that the rats could learn to respond specifically to the light and tone stimuli that indicated when a reward was available and not to respond during "time out" periods when they would not be rewarded. To this end we trained rats for another 45 minutes at the highest criterion level. When we began discrimination training, it took the



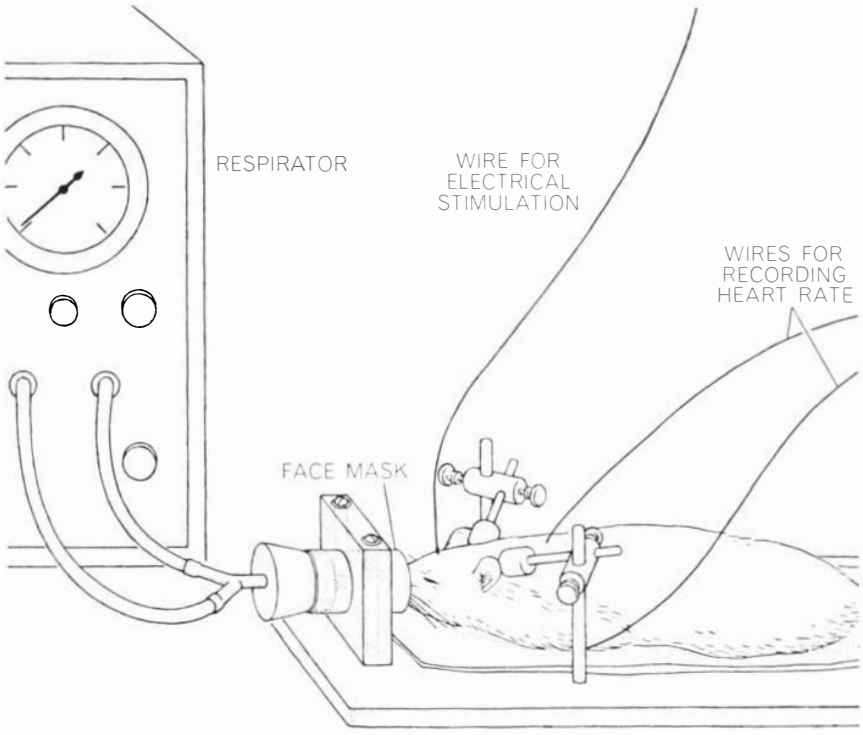
CURARE paralyzes skeletal muscles. It ensures, for example, that a change in heart rate has been controlled by autonomic impulses from the vagus nerve and not by cerebrospinal impulses to skeletal muscles. The two nervous systems are not completely separate: visceral responses have representation at higher brain centers in the cortex (*broken lines*).

rats some time after the beginning of each stimulus period to meet the criterion and get the reward; by the end of the training they were changing their heart rate in the rewarded direction almost immediately after the time-in period began [*see illustration on page 35*].

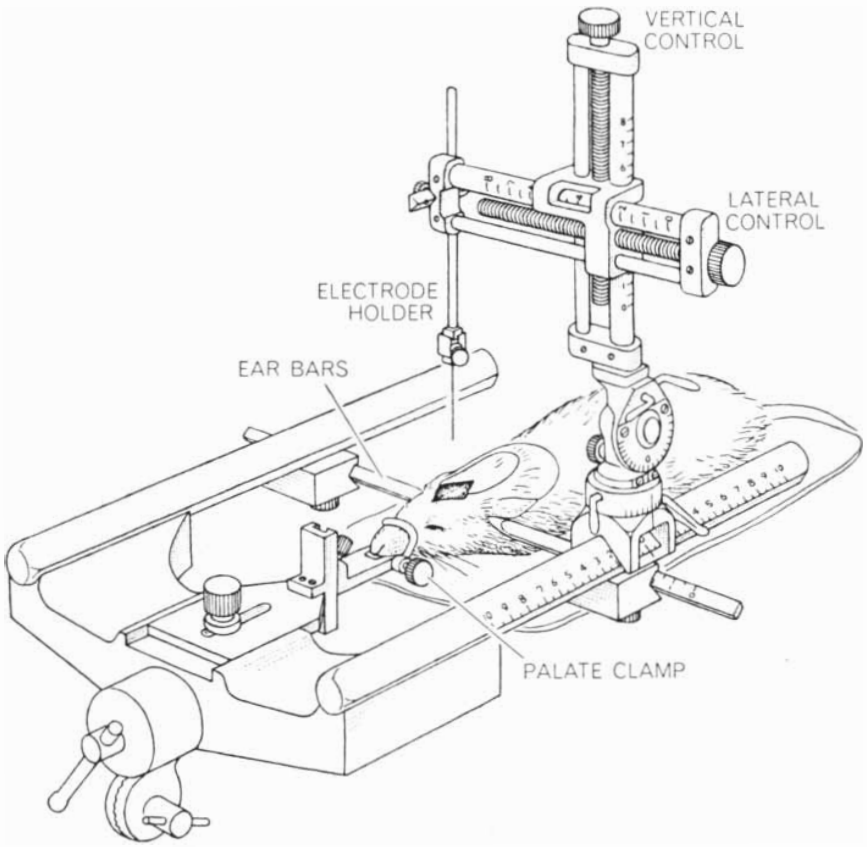
In skeletal instrumental training discrimination is also learned between a positive stimulus, response to which is rewarded, and a negative stimulus, response to which is not rewarded. Our animals learned to respond with the proper visceral behavior to one stimulus (such as a light) and not to respond to another (such as a tone). Moreover, once an animal has learned to discriminate between positive and negative cues for a given skeletal response, it is easier for it to respond similarly with a different response for the same reward. We found that this phenomenon of transfer also appeared in visceral training: rats that showed the best discrimination between a positive and a negative stimulus for a skeletal response (pressing a bar) also showed the best discrimination when the same stimuli were used for increased or decreased heart rate.

Two other properties of instrumental training are retention and extinction. To test for retention we gave rats a single training session and then returned them to their home cages for three months. When they were again curarized and tested, without being reinforced, rats in both the increase group and the decrease group showed good retention by exhibiting reliable changes in the direction for which they had been rewarded three months earlier. Although learned skeletal responses are remembered well, they can be progressively weakened, or experimentally extinguished, by prolonged trials without reward. We have observed this phenomenon of extinction in visceral learning also. To sum up, all the phenomena of instrumental training that we have tested to date have turned out to be characteristic of visceral as well as skeletal responses.

The experiments I have described relied on electrical stimulation of the brain as a reinforcement. In order to be sure that there was nothing unique about brain stimulation as a reward for visceral learning, Miller and I did an experiment with electric-shock avoidance, the other of the two commonly used rewards that can conveniently be administered to paralyzed rats. A shock signal was presented to the curarized rats. After it had been on for five seconds it was accompanied by brief pulses of mild



CURARIZED RATS cannot breathe and must be fitted with a face mask connected to a respirator. Such usual instrumental-learning rewards as food and water cannot be used.



REWARD for visceral learning is either electrical stimulation of the brain or avoidance of electric shock. For brain stimulation an electrode implanted in the brain of an anesthetized rat is guided to a "pleasure center" in the hypothalamus with the aid of a stereotactic device.

shock delivered to the rat's tail. During the first five seconds the animal could turn off the shock signal and avoid the shock by making the correct heart-rate response; failing that, it could escape the shock by making the correct response and thus turning off both the signal and the shock.

In the course of a training session we mixed shock trials with "safe" trials and "blank" trials at random. During a safe trial we presented a different signal and did not administer a shock; during a blank trial there was no signal or shock. For half of the rats the shock signal was a tone and the safe signal a flashing light; for the other half the stimuli were reversed. The rats that were rewarded for increasing their heart rate learned to increase it and those that were rewarded for decreasing the rate learned to decrease it. In part the learning represented a general change in base line, as indicated by the trend of the heart rate during blank trials. Beyond this, however, the rats clearly learned to discriminate. As their training progressed, the shock signal began to elicit a greater change in the rewarded direction than the blank trials did. Conversely, the safe signal elicited a trend in the opposite direction—toward the base line represented by the data for the blank trials [*see illustration on page 36*].

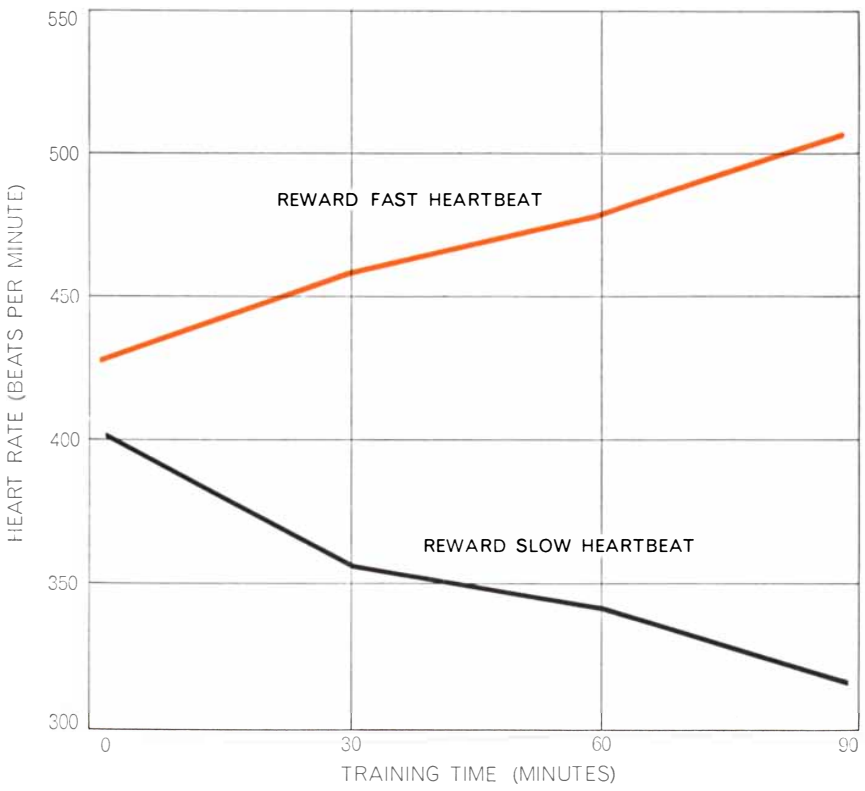
At this point we had shown that instrumental learning of visceral responses follows the laws of skeletal instrumental training and that it is not limited to a particular kind of reward. We also showed that the response itself is not limited: we trained rats to raise and lower their systolic blood pressure in much the same way. These results were all obtained, however, with animals that were paralyzed. Would normal, active animals also learn a visceral response? If so, could that response be shown to be independent of skeletal activity? We designed a special experimental cage and the necessary equipment to make possible the recording of various responses of active rats [*see illustration on page 30*], and we established that heart-rate and blood-pressure changes could be learned by noncurarized animals. The heart-rate learning persisted in subsequent tests during which the same animals were paralyzed by curare, indicating that it had not been due to the indirect effects of overt skeletal responses. This conclusion was strengthened when, on being retrained without curare, the two groups of animals displayed increasing differences in heart rate, whereas any differences in respiration and general level of activity continued to decrease.

We noted with interest that initial learning in the noncurarized state was slower and less effective than it had been in the previous experiments under curare. Moreover, a single training session under curare facilitated later learning in the noncurarized state. It seems likely that paralysis eliminated "noise" (the confusing effects of changes in heart action and blood-vessel tone caused by skeletal activity) and perhaps also made it possible for the animal to concentrate on and sense the small changes accomplished directly by the autonomic system.

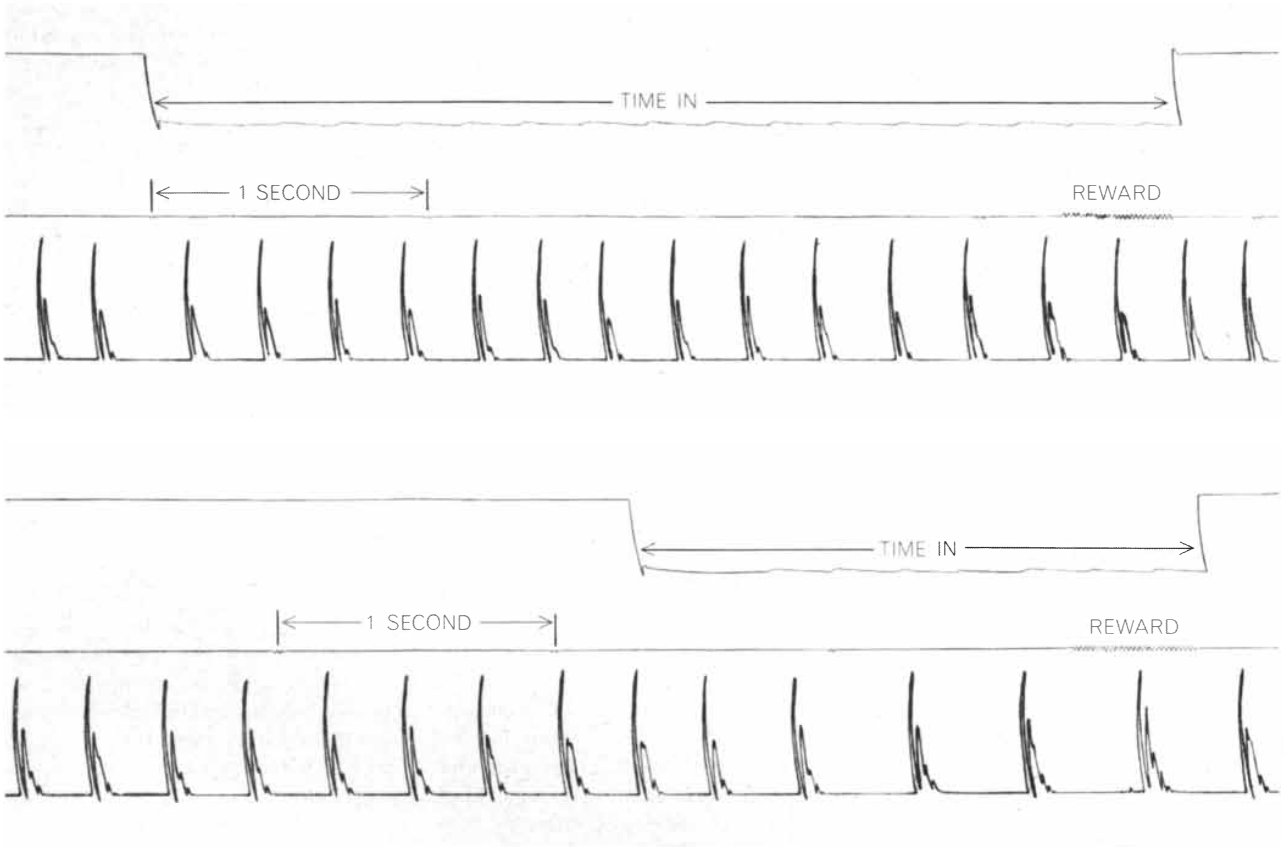
In all these studies the fact that the same reward could produce changes in opposite directions ruled out the possibility that the visceral learning was caused by some innate, unconditioned effect of the reward. Furthermore, the fact that the curarized rats were completely paralyzed, which was confirmed by electromyographic traces that would have recorded any activity of the skeletal muscles, ruled out any obvious effect of the voluntary responses. It was still possible, however, that we were somehow inducing a general pattern of arousal or were training the animals to initiate impulses from the higher brain centers that would have produced skeletal movements were it not for the curare, and that it was the innate effect of these central commands to struggle and relax that were in turn changing the heart rate. Such possibilities made it desirable to discover whether or not changes in heart rate could be learned independently of changes in other autonomic responses that would occur as natural concomitants of arousal.

To this end Miller and Ali Banuazizi compared the instrumental learning of heart rate with that of intestinal contraction in curarized rats. They chose these two responses because the vagus nerve innervates both the heart and the gut, and the effect of vagal activation on both organs is well established. In order to record intestinal motility they inserted a water-filled balloon in the large intestine. Movement of the intestine wall caused fluctuations in the water pressure that were changed into electric voltages by a pressure transducer attached to the balloon.

The results were clear-cut. The rats rewarded (by brain stimulation) for increases in intestinal contraction learned an increase and those rewarded for decreases learned a decrease, but neither



HEART-RATE CHANGES are shown for rats rewarded for increasing the rate (*color*) and for decreasing it (*black*). Animals were curarized and rewarded with brain stimulation.



ELECTROCARDIOGRAMS made at the beginning and at the end of an extra period of training demonstrate discrimination. At first the rat takes some time after the onset of stimulus ("time in") to respond (by slowing its heartbeat) and earn a reward (*top*). After 45 minutes of discrimination training the rat responds more directly: it slows its heartbeat soon after time-in period begins (*bottom*).

group showed an appreciable change in heart rate. The group that was rewarded for increases in heart rate learned an increase and the group rewarded for decreases learned a decrease, but neither heart-rate group showed an increase in intestinal contraction [*see illustrations on page 38*]. Moreover, the heart-rate and intestinal learning were negatively correlated: the better the response being rewarded was learned, the less change there was in the unrewarded response. These results showed that the instrumental learning of two visceral responses can occur independently of each other and that what is learned is specifically the rewarded response. They ruled out the possibility that the learning was mediated by a general reaction such as arousal.

There was still a remote possibility to be eliminated: The central impulses I mentioned might be initiated selectively toward muscles that affect the intestines when intestinal changes are rewarded and toward muscles that affect heart rate when heart-rate changes are rewarded. Miller and I therefore trained curarized rats to increase or decrease their heart rate and then tested them in the noncurarized state for transfer of learning. We reasoned that if heart-rate changes were not directly learned under curare but rather were mediated by the learning of central impulses to skeletal muscles, movement of such muscles would betray the fact if the learning was transferred to the noncurarized state. We found that learned increases and decreases of about 10 percent did transfer independently of muscle movement: the differences between the two groups in heart rate were too large to be accounted for by the differences between them in respiration or general level of activity.

The strongest argument against attempts to explain visceral learning as a response to skeletal movement or central motor impulses is this kind of specificity. As more and more different visceral responses are recorded and the learning of them is shown to be specific, it becomes harder to think of enough different voluntary responses to account for them all. We have shown, for example, that curarized rats can learn to make changes in the dilation and constriction of blood vessels in the skin and to make these vasomotor changes independently of changes in heart rate and blood pressure. Indeed, the rats can be trained to make these changes specific to a single structure: they can dilate the blood vessels in one ear more than those in the other ear! This could not be the result of heart-rate or blood-pressure changes, which would affect both ears equally. We also obtained instrumental learning in the rate of urine formation by the kidneys, independent of blood pressure or heart rate. The increases and decreases in the amount of urine produced were achieved by specific changes in the arteries of the kidneys that resulted in an increase or decrease in the blood flow through the kidneys.

In addition to buttressing the case for instrumental learning of visceral responses, these striking results suggest that vasomotor responses, which are mediated by the sympathetic division of the autonomic nervous system, are capable of much greater specificity than was believed possible. This specificity is compatible with an increasing body of evidence that various visceral responses

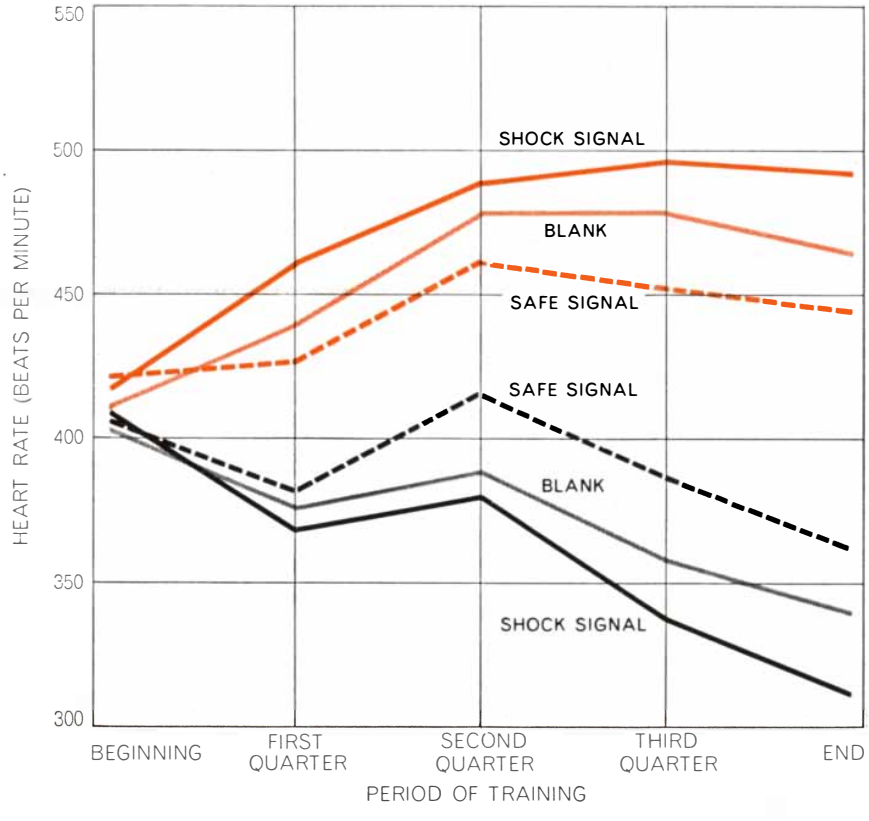
have specific representation at the cerebral cortex, that is, that they have neural connections of some kind to higher brain centers.

Some recent experiments indicate that not only visceral behavior but also the electrical activity of these higher brain centers themselves can be modified by direct reinforcement of changes in brain activity. Miller and Carmona trained noncurarized cats and curarized rats to change the character of their electroencephalogram, raising or lowering the voltage of the brain waves. A. H. Black of McMaster University in Canada trained dogs to alter the activity of one kind of brain wave, the theta wave. More recently Stephen S. Fox of the University of Iowa used instrumental techniques to modify, both in animals and in human subjects, the amplitude of an electrical event in the cortex that is ordinarily evoked as a visual response.

We are now trying to apply similar techniques to modify the electrical activity of the vagus nerve at its nucleus in the lowermost portion of the brain. Preliminary results suggest that this is possible. The next step will be to investigate the visceral consequences of such modification. This kind of work may open up possibilities for modifying the activity of specific parts of the brain and the functions they control and thereby learning more about the functions of different parts of the brain.

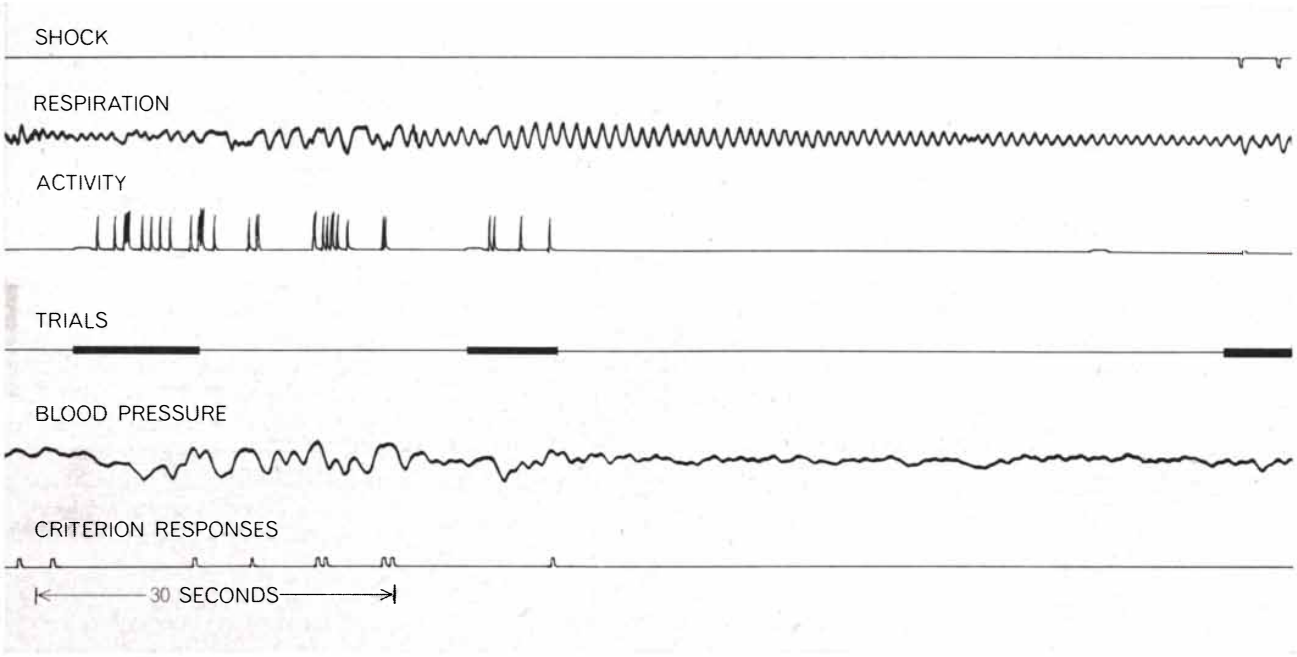
Controlled manipulation of visceral responses by instrumental training also makes it possible to investigate the mechanisms that underlie visceral learning. We have made a beginning in this direction by considering the biochemical consequences of heart-rate training and specifically the role of the catecholamines, substances such as epinephrine and norepinephrine that are synthesized in the brain and in sympathetic-nerve tissues. Norepinephrine serves as a nerve-impulse transmitter in the central nervous system. Both substances play roles in the coordination of neural and glandular activity, influencing the blood vessels, the heart and several other organs. Alterations in heart rate produced by increased sympathetic-nerve activity in the heart, for example, are accompanied by changes in the synthesis, uptake and utilization of catecholamines in the heart, suggesting that it may be possible to influence cardiac catecholamine metabolism through instrumental learning of heart-rate responses. This would be important in view of the possible role of norepinephrine in essential hypertension (high blood pressure) and congestive heart failure; it might also help to establish the role of learning and experience in the development of certain psychosomatic disorders.

Eric Stone and I found that the level of catecholamines in the heart varies with heart-rate training. After three hours of training under curare, rats trained to increase their heart rate have a significantly higher concentration of cardiac catecholamines than rats trained to decrease their heart rate. Experiments are now under way to determine how long such biochemical differences between the two groups persist after training and whether the heart-rate conditioning has long-range effects on the heart and on the excitability of the sympathetic nerves. When we examined the brains of rats in the two groups we found a similar biochemical difference: the animals trained to increase their heart rate had a significantly higher level of norepinephrine in the brain stem than rats trained to decrease heart rate. Brain norepinephrine helps to determine the excitability of the central nervous system and is involved in emotional behavior. We have therefore started experiments to see whether or not changes in sympathetic excitability obtained by cardiovascular instrumental training are related to changes in the metabolism of norepinephrine and, if so, in which areas of the brain these metabolic changes are most apparent.



DISCRIMINATION is demonstrated by these curves for rats that were trained to increase (*color*) and decrease (*black*) heart rate and were rewarded by avoidance of shock. The results for blank trials (no signal or shock) show "base line" learning. The results for shock-signal and safe-signal trials show discriminating responses to more specific stimuli.

Is the capacity for instrumental learning of autonomic responses just a useless by-product of the capacity for cerebrospinal, skeletal-muscle learning? Or does it have a significant adaptive function in helping to maintain homeostasis, a stable internal environment? Skeletal responses operate on the external environment; there is obvious survival value in the ability to learn a response that brings a reward such as food, water or escape from pain. The responses mediated by the autonomic system, on the other hand, do not have such direct effects on the external environment. That was one of the reasons for the persistent belief that they are not subject to instrumental learning. Yet the experiments I have described demonstrate that visceral responses are indeed subject to instrumental training. This forces us to think of the internal behavior of the visceral organs in the same way we think of the external,



POLYGRAPH RECORD, a small portion of which is reproduced, records a free-moving rat's respiration, activity and systolic blood pressure. It also shows when trials took place, whether the blood-pressure increase met the criterion and whether, not having met criterion, the animal received an electric shock. This record was made by an animal being tested as in the illustration on page 30.

observable behavior of the skeletal muscles, and therefore to consider its adaptive value to homeostasis.

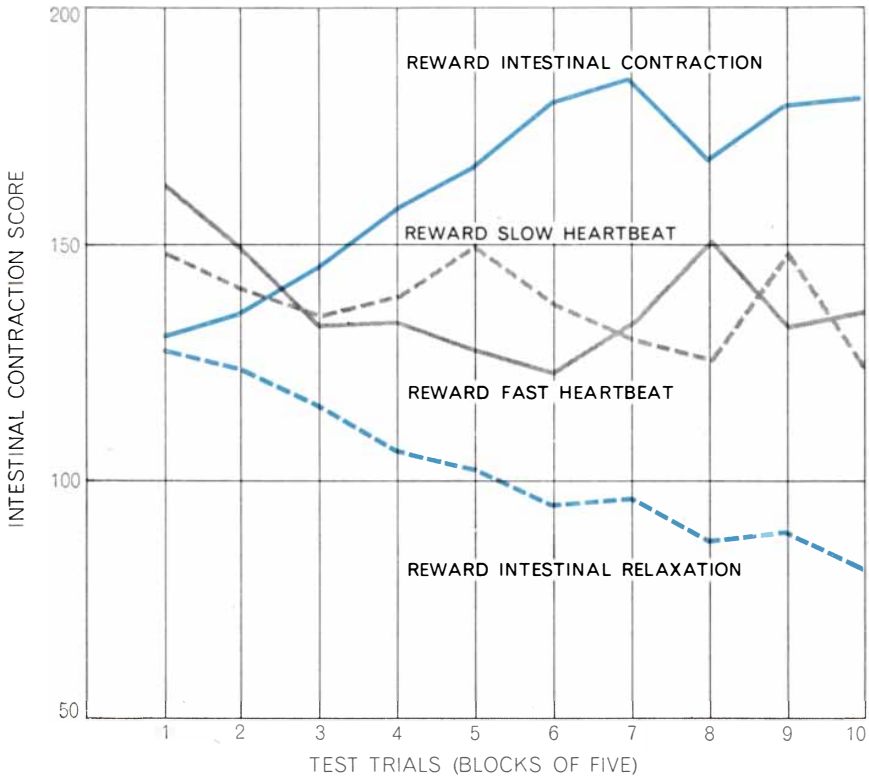
In a recent experiment George Wolf, Miller and I found that the correction of a deviation from homeostasis by an internal, glandular response (rather than by an external response such as eating or drinking) can serve as a reward to reinforce learning. We injected albino rats with an antidiuretic hormone (ADH) if they chose one arm of a *T*-shaped maze and with a control solution (a minute amount of isotonic saline solution) if they chose the other arm. Before running the maze each rat had been given an excess of water through a tube placed in the stomach, so that the antidiuretic hormone was maladaptive: it interfered with the kidney response that was necessary to get rid of the excess water and restore homeostasis, whereas the control solution did not interfere. The rats learned to select the side of the maze that ensured an injection of saline solution, so that their own glandular response to the excess water could restore homeostasis. Then we did the same experiment with rats that suffered from diabetes insipidus, a disorder in which too much urine is passed and it is insufficiently concentrated. These rats had been tube-fed an excess of a highly concentrated salt solution. Now the homeostatic effects of the two injections were reversed: the ADH was adaptive, tending to concentrate the urine and thereby get rid of the excess salt, whereas the control solution had no such effect. This time the rats selected the ADH side of the maze. As a control we tested normal rats that were given neither water nor concentrated saline solution, and we found they did not learn to choose either side of the maze in order to obtain or avoid the antidiuretic hormone.

In many experiments a deficit in water or in salt has been shown to serve as a drive to motivate learning; the external response of drinking water or saline solution—thus correcting the deficit—functions as a reward to reinforce learning. What our experiment showed was that the return to a normal balance can be effected by action that achieves an internal, glandular response rather than by the external response of drinking.

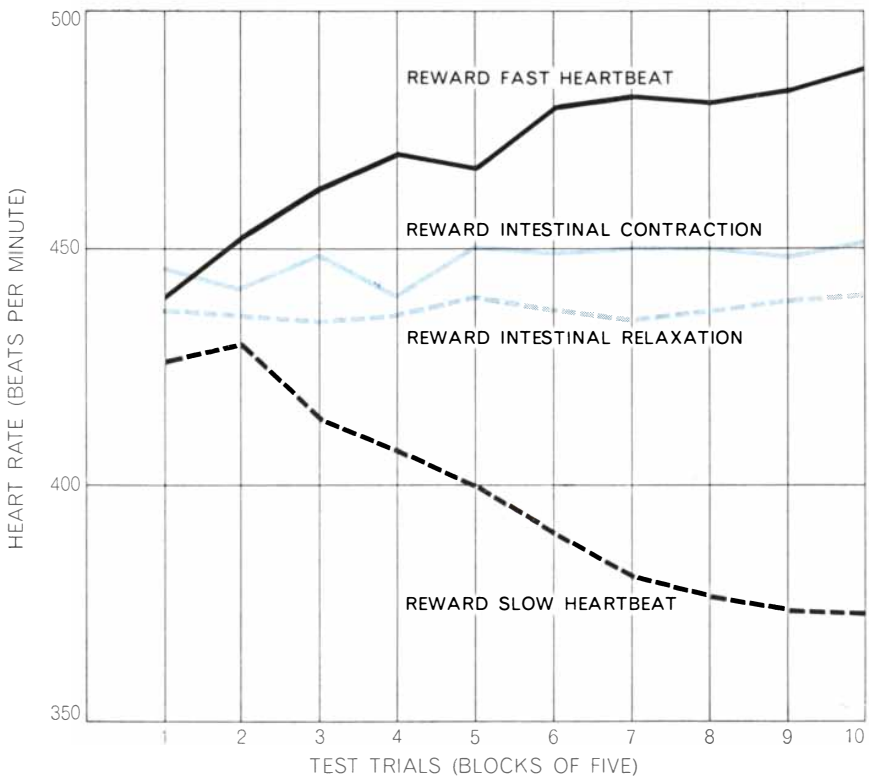
Consider this result along with those demonstrating that glandular and visceral responses can be instrumentally learned. Taken together, they suggest that an animal can learn glandular and visceral responses that promptly restore a deviation from homeostasis to the proper level. Whether such theoretically possible learning actually takes place depends on whether innate homeostatic mechanisms control the internal environment so closely and effectively that deviations large enough to serve as a drive are not allowed. It may be that innate controls are ordinarily accurate enough to do just that, but that if abnormal circumstances such as disease interfere with innate control, visceral learning reinforced by a return to homeostasis may be available as an emergency replacement.

Are human beings capable of instrumental learning of visceral responses? One would think so. People are smarter than rats, and so anything rats can do people should be able to do better. Whether they can, however, is still not completely clear. The reason is largely that it is difficult to subject human beings to the rigorous controls that can be applied to animals (including deep paralysis by means of curare) and thus to be sure that changes in visceral responses represent true instrumental learning of such responses.

One recent experiment conducted by David Shapiro and his colleagues at the Harvard Medical School indicated that human subjects can be trained through feedback and reinforcement to modify their blood pressure. Each success (a rise in pressure for some volunteers and a decrease for others) was indicated by a flashing light. The reward, after 20 flashes, was a glimpse of a nude pinup picture. (The volunteers were of course male.) Most subjects said later they were not aware of having any control over the flashing light and did not in fact know what physiological function was being



INTESTINAL CONTRACTION is learned independently of heart-rate changes. Contractions are increased by rats rewarded for increases (*colored line*) and decreased by rats rewarded for decreases (*broken colored line*). The intestinal-contraction score does not change appreciably, however, in rats rewarded for increasing or decreasing heart rate (*gray*).



SPECIFICITY of learning is shown by this graph and the one at the top of the page. Here the results for heart rate rather than intestinal contraction are shown for the same animals. Rats rewarded for changing their heart rate change it in the appropriate direction (*black lines*). Rats rewarded for intestinal changes do not change heart rate (*light colored lines*).

measured, and so they presumably had not exerted any voluntary effort (at least not consciously and deliberately) to modify the response.

Whatever is actually being learned by such subjects, the extent of learning is clearly less than can be achieved in animals. In one of our experiments the average difference in blood pressure between the two groups of curarized rats was 58 millimeters of mercury. Shapiro's two human groups, in contrast, yielded a comparable difference of about four millimeters. Clearly curarized rats do better than noncurarized people, but that is not really surprising. The difference between the noncurarized rats and the noncurarized human subjects is much smaller [*see bottom illustration on opposite page*].

The curare effect here is in line with what is seen in experiments with a single species. What does it mean? I mentioned above that initial training under curare facilitated further training in the noncurarized state. Perhaps the curare keeps the animal from being confused (as it may be in the noncurarized state) when a small change in the correct direction that is produced by direct control of the visceral response is obscured by a larger change in the opposite direction that is accomplished through skeletal activity and is therefore not rewarded. It is also possible that the curare helps to eliminate variability in the stimulus and to shift the animal's attention from distracting skeletal activity to the relevant visceral activity. It may be possible to facilitate visceral learning in humans by training people (perhaps through hypnosis) to breathe regularly, to relax and to concentrate in an attempt to mimic the conditions produced by curarization.

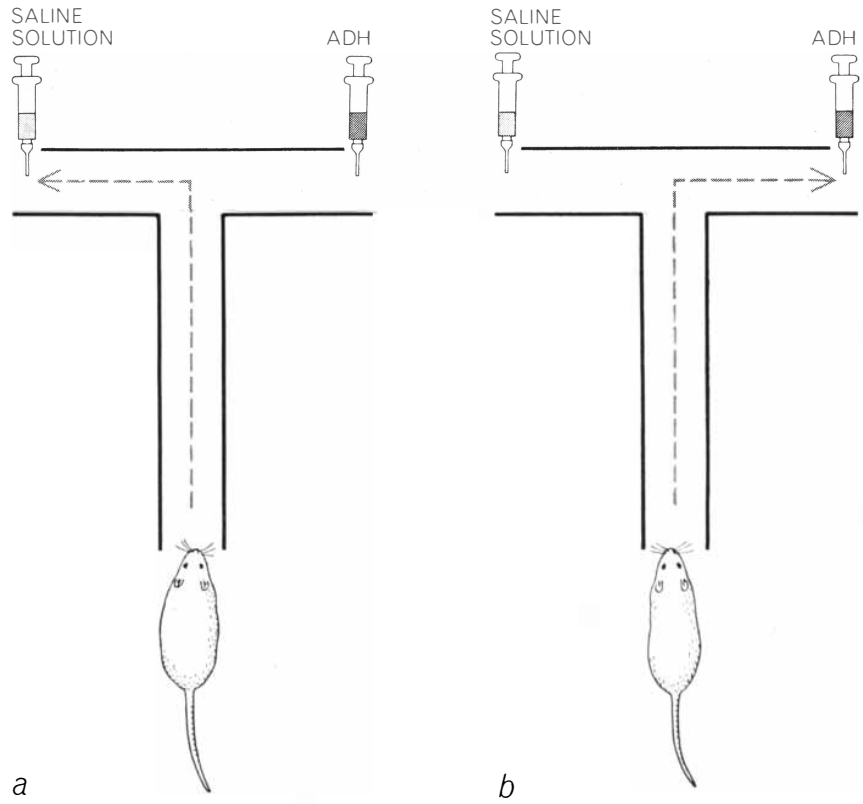
The evidence for instrumental learning of visceral responses suggests that psychosomatic symptoms may be learned. John I. Lacey of the Fels Research Institute has shown that there is a tendency for each individual to respond to stress with his own rather consistent sequence of such visceral responses as headache, queasy stomach, palpitation or faintness. Instrumental learning might produce such a hierarchy. It is theoretically possible that such learning could be carried far enough to create an actual psychosomatic symptom. Presumably genetic and constitutional differences among individuals would affect the susceptibility of the various organ systems. So would the extent to which reinforcement is available. (Does a child's mother keep him home

from school when he complains of headache? When he looks pale?) So also would the extent to which visceral learning is effective in the various organ systems.

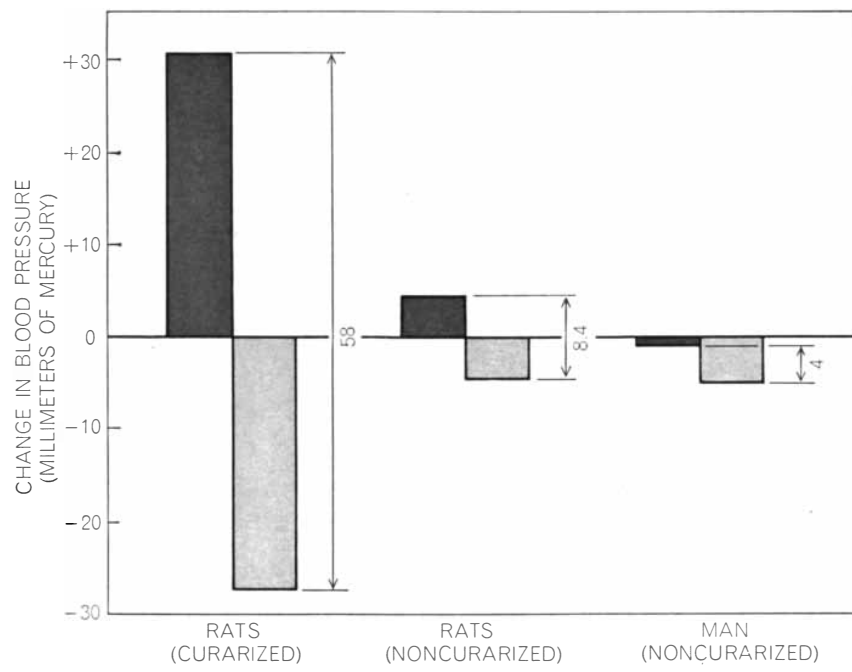
We are now trying to see just how far we can push the learning of visceral responses—whether it can be carried far enough in noncurarized animals to produce physical damage. We also want to see if there is a critical period in the animal's infancy during which visceral learning has particularly intense and long-lasting effects. Some earlier experiments bear on such questions. For example, during training under curare seven rats in a group of 43 being rewarded for slowing their heart rate died, whereas none of 41 being rewarded for an increase in heart rate died. This statistically reliable difference might mean one of two things. Either training to speed the heart rate helps a rat to resist the stress of curare or the reward for slowing the heart rate is strong enough to overcome innate regulatory mechanisms and induce cardiac arrest.

If visceral responses can be modified by instrumental learning, it may be possible in effect to "train" people with certain disorders to get well. Such therapeutic learning should be worth trying on any symptom that is under neural control, that can be continuously monitored and for which a certain direction of change is clearly advisable from a medical point of view. For several years Bernard Engel and his colleagues at the Gerontology Research Center in Baltimore have been treating cardiac arrhythmias (disorders of heartbeat rhythm) through instrumental training. Heart function has been significantly improved in several of their patients. Miller and his colleagues at the Cornell University Medical College treated a patient with long-standing tachycardia (rapid heartbeat). For two weeks the patient made almost no progress, but in the third week his learning improved; since then he has been able to practice on his own and maintain his slower heart rate for several months. Clark T. Randt and his colleagues at the New York University School of Medicine have had some success in training epileptic patients to suppress paroxysmal spikes, an abnormal brain wave.

It is far too early to promise any cures. There is no doubt, however, that the exciting possibility of applying these powerful new techniques to therapeutic education should be investigated vigorously at the clinical as well as the experimental level.



VISCERAL RESPONSE that adjusts the internal environment can serve as a reward to reinforce learning. Rats "loaded" with water (*a*) learned to choose the side of a *T*-maze that resulted in an injection of a control solution rather than one of antidiuretic hormone (ADH), which would interfere with water excretion. (The arms associated with each reward were changed at random.) Rats loaded with salt (*b*), on the other hand, for whom the hormone would induce the proper kidney response, learned to pick the ADH-associated arm.



COMPARISON of blood-pressure learning in rats and humans rewarded for increasing (*dark gray bars*) and for decreasing (*light gray*) blood pressure shows that the difference between curarized and noncurarized subjects is greater than the difference between species.

AERODYNAMIC WHISTLES

They are represented not only by policemen's whistles and flutes; they can also be found in oil burners and in rocket engines. Their frequency and intensity are governed by three feedback mechanisms

by Robert C. Chanaud

The sound of aerodynamic whistles is familiar as the resonant note of an organ pipe, the shrill peep of a teakettle and the mellow tone of a flute. How are these sounds produced? In such nonaerodynamic devices as a drum, a violin and a loudspeaker sound is generated when a mechanical system vibrates and disturbs the air. In an aerodynamic whistle the vibrating system is the air itself. Not all aerodynamic whistles whistle in the usual sense of the word. They include, for example, a telephone wire hissing in the wind.

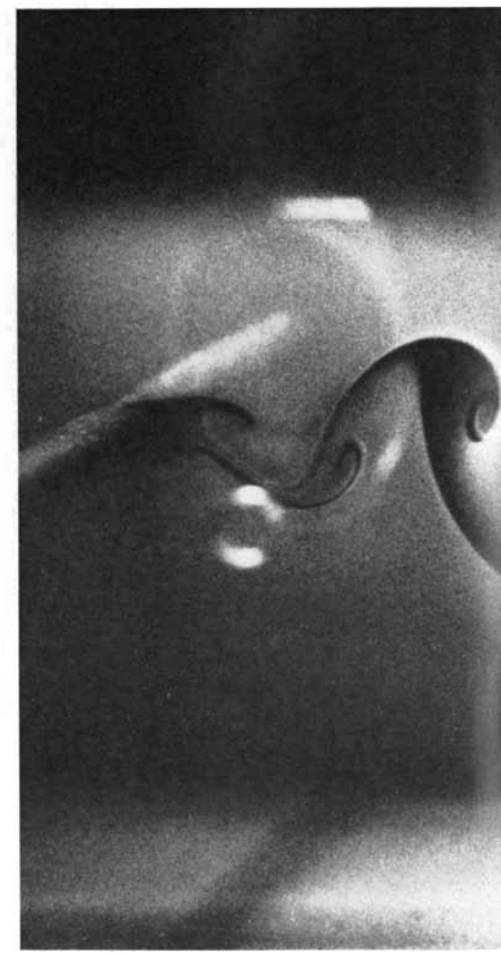
Aerodynamic sound generation has been the subject of experiment and theoretical study for more than a century. In the course of these investigations novel whistles have been discovered and mathematical descriptions have been developed (notably by Vincenz Strouhal of Czechoslovakia and by Lord Rayleigh of Britain). More recent investigation has identified the feedback mechanisms that determine the frequency and intensity of aerodynamic whistles.

Current research in aerodynamic whistles, including my own at the University of Colorado, has been stimulated not only by scientific curiosity but also by important practical considerations. Many machines and structures of modern technology generate whistling sounds that are annoying and even capable of damaging the ear. Such sounds can better be controlled if the generating process is understood. Aerodynamic whistles also serve constructive purposes: they can measure the rate of flow of fluids in manufacturing processes and function as amplifiers in "fluidic" control systems. In oil burners whistles can make combustion more efficient by vaporizing the fuel and evenly mixing it with air.

Clearly aerodynamic whistles can take many forms. Nonetheless, all aerodynamic whistles work in basically the same way. In every whistle a steady flow of fluid must be established. Below a certain speed the flow is laminar, or smooth and stable. Above that speed some disturbance can cause the stream to form periodically spaced vortexes that give rise to oscillations in the surrounding fluid. If the frequency of the oscillations is between 50 and 20,000 cycles (the range of human hearing), a sound is heard. If the frequency is higher or lower, ultrasonic or subsonic acoustical fields are produced.

This is only a partial description of how whistles work. It neglects the fact that the disturbance amplified by the fluid instability may occur only intermittently. How then does an aerodynamic whistle produce a prolonged, steady tone? Here the concepts of modern control theory can be used to describe the whistle mechanism in simple terms. In the language of control theory an aerodynamic whistle is a self-maintained oscillator, analogous to a public-address system that squeals when too much sound from the loudspeaker is picked up by the microphone, reamplified and then fed back to the speaker.

The basic elements of such a system are (1) a means of amplification and (2) a means of feeding part of the amplified energy back to sustain and control the process. In an aerodynamic whistle a small disturbance in the stream flowing through the whistle is amplified into a large one by the instability of the stream, which permits steady energy to be converted to oscillatory energy. Part of the energy of the amplified disturbance is fed back upstream, where the flow is most unstable, and if it has the appropriate frequency and amplitude, it joins the original disturbance in maintaining the process. After a few cycles of this kind the feedback controls the input completely. At this point the frequency is determined not by the original disturbance but by the period of the feedback cycle [*see bottom illustration on page 42*].



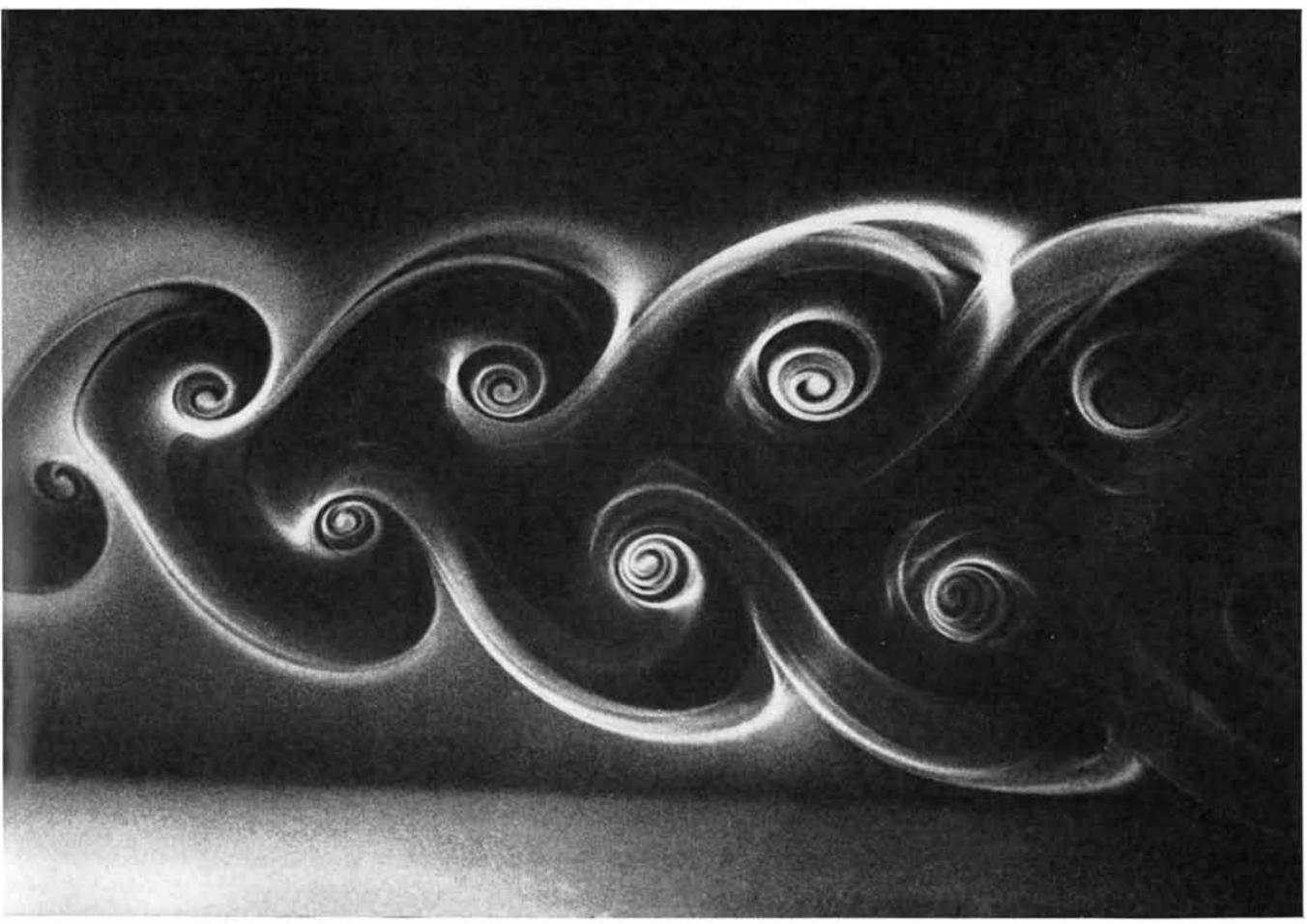
VORTEX PATTERN is generated by a cylinder in a stream of air in a wind tunnel. This is one of the commonest whistle mecha-

In an aerodynamic whistle there is a limited amount of energy in the stream, so that for a given set of conditions the sound reaches a steady amplitude. This steady state is achieved in the course of several feedback cycles. Each time a cycle is completed the amplitude of the sound increases. The rate of increase declines, however, until it reaches zero. At that point virtually all the available energy contained in the steady flow has been diverted into amplifying the original disturbance.

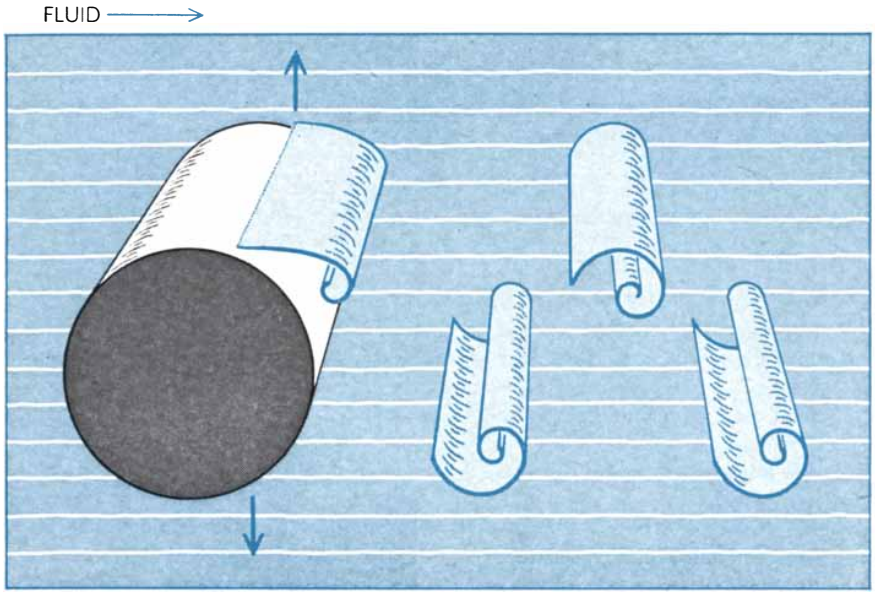
Aerodynamic whistles can be divided into three classes according to the means of feedback. If the whistle's feedback consists primarily of hydrodynamic oscillations (that is, incompressible vortex motion), I call it a Class I or hydrodynamic whistle. If the feedback consists of the sound waves generated by the whistle and fed directly back to the region of instability, it is a Class II or acoustic whistle. Class III whistles are distinguished by the fact that feedback is accomplished by sound waves reflected back to the region of instability by some ancillary structure.

Any classification scheme for aerodynamic whistles is somewhat arbitrary, for two reasons. First, a whistle mechanism can be so complex that it may operate in several classes; the classifications below apply to normally observed operation. Second, the names given the elements of a whistle are only symbolic descriptions applied to the device so that it can be discussed and investigated. They do not correspond to conveniently self-contained "black boxes" such as the components of a public-address system. Each of the components of a whistle is physically intertwined with the others.

Class I whistles are the most widely encountered, perhaps because so many of them occur naturally. This category includes telephone wires, tree limbs and aeolian harps singing in the wind. (The aeolian harp is an ancient Greek instrument consisting of a set of strings stretched over a sounding box and set in motion by the wind or the breath.) This kind of Class I whistle, called an aeolian-tone generator, basically consists of a long, thin cylinder in a stream of air or some other fluid. Above a certain speed there will develop behind the cylinder two symmetrically placed vortexes that are stable and steady. If the speed of flow increases above a second threshold and one of the vortexes is disturbed by a sound pressure wave, the vortex will oscillate around its stable position and ultimately break away from the cylinder and move downstream. The breaking away of this vortex causes the opposite vortex to become unstable, and it too breaks away. Another vortex forms in place of the first one and it in turn becomes unstable. The feedback appears to be entirely hydrodynamic: each vortex gives rise to instability in the other directly, without any intervening agent such as a sound wave. As a result of the influence of one vortex on the other a chain of alternating vortexes soon stretches downstream from the cylinder. As the vortexes develop they gener-



nisms. The cylinder at left makes the flow of air (which is visible because of smoke particles in it) unstable, so that alternating vortexes develop that swirl downstream toward the right. In a whistle such vortexes produce a sound in the surrounding air called an aeolian tone. The photograph was made by Gary Koopmann at the U.S. Naval Research Laboratory in Washington.



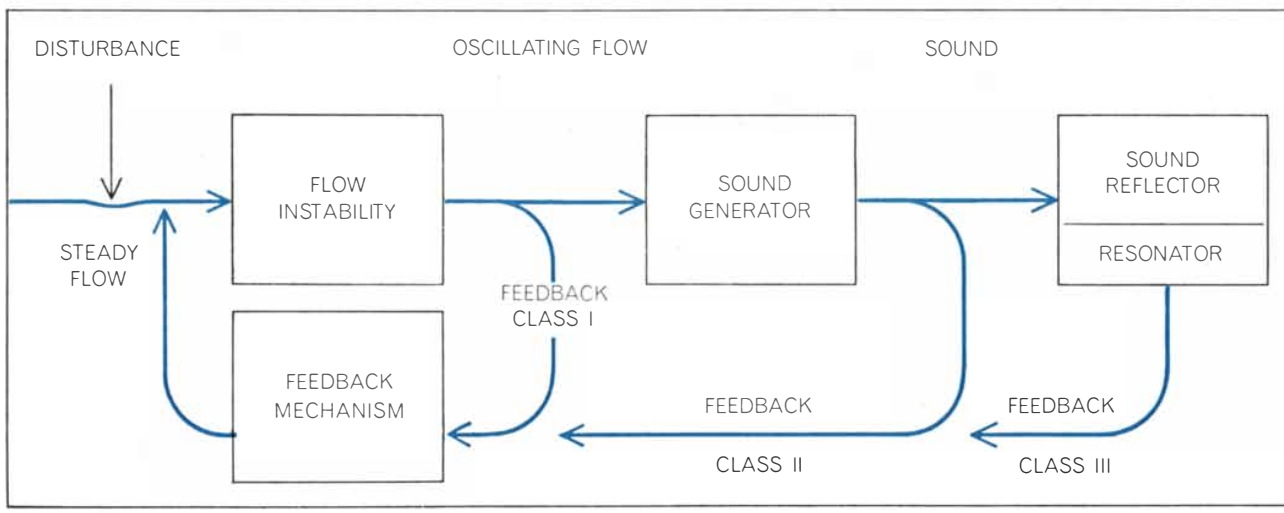
VORTEX DEVELOPMENT begins when the flow around the cylinder moving from left to right (*arrow*) reaches a threshold speed. At that threshold vortexes at right are formed and are shed alternately from the top and bottom of the cylinder. Vertical arrows indicate that sound field produced by moving vortexes travels at right angles to their path.

ate a sound field with a maximum at right angles to their path [*see illustration above*].

The only other type of Class I whistle appears to be the vortex whistle. This whistle can consist of a pipe with air flowing through it. If the air enters the pipe tangentially to the wall or encounters a set of appropriately designed blades in the pipe, it will begin to swirl. When this swirling flow encounters the open end of the pipe (or a widened section of the pipe), the helical flow begins to precess, or rotate around the axis of the pipe, at a definite frequency. The interaction with the exit of the pipe produces a sound field [*see top illustration on opposite page*]. This mechanism may seem quite different from that of the aeolian-tone generator, but when the precessing flow is viewed in cross section along the axis of the pipe, it resembles the vortex pattern that forms behind a cylinder.

The sound of Class I whistles is a by-product of vortex development; indeed, the vortexes can develop without generating any audible sound at all. A whistle is produced only when the frequency falls in the audible range and the flow speed is high enough. Even then the intensity of the sound is usually low. Sometimes the process of sound generation in an aeolian-tone generator makes the cylinder itself vibrate, as when a telephone wire "gallops" in the wind. This motion can contribute to the sound, but it is not essential to its production.

The precise nature of the feedback in both the aeolian-tone generator and the vortex whistle has resisted efforts to observe or analyze it. Today, after almost a century, we do not know much more about the aeolian tone than Strouhal and Lord Rayleigh did. In 1878 Strouhal observed that no sound was emitted by the flow around a cylinder until a given flow speed had been reached. Above that speed a sound was generated whose frequency was directly related to the speed of the fluid and the diameter of the cylinder. The frequency, Strouhal found, was generally higher for smaller cylinders and lower for larger ones. In fact, the relationship could be described in terms of a constant that is the product of the sound frequency



FEEDBACK DIAGRAM shows how aerodynamic whistles produce sound. At upper left a small disturbance impinges on a steady flow of fluid. The disturbance is amplified by the instability of the flow, represented by the upper box at left. As the disturbance moves through the surrounding air it is translated by the various sound-generating processes (*box in middle*) into acoustical vibrations. The lower box at left represents the feedback mechanisms that return part of the energy from the unstable flow to the unstable region of the stream so that the original disturbance is reinforced. If this feedback energy consists of part of the unstable flow itself, the whistle can be placed in Class I. If the feedback consists of the sound itself acting on the flow, the whistle is a Class II whistle. In a Class III whistle the feedback loop is established either by a reflecting surface or by a resonator, represented by the box at right.

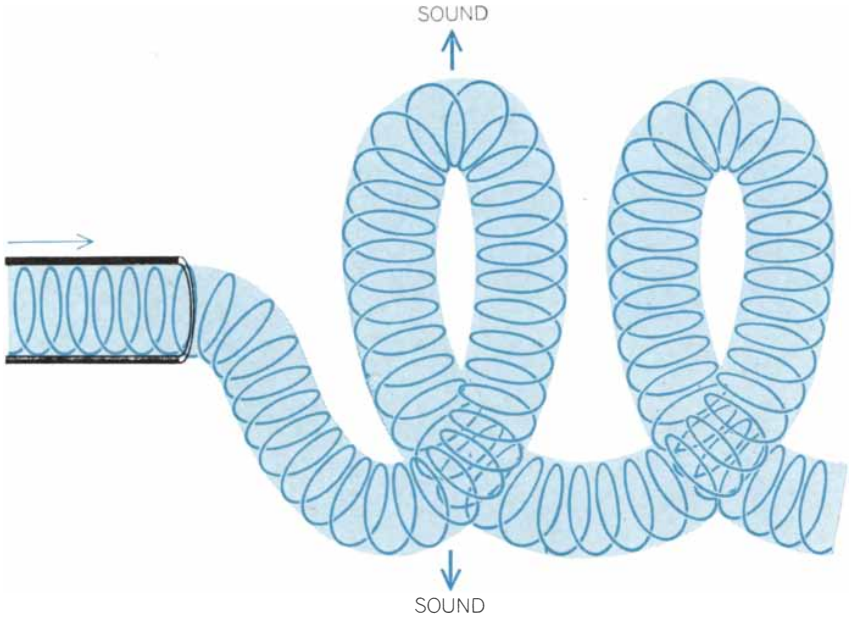
times the diameter of the cylinder divided by flow speed. This number is now called the Strouhal number, and it can be used to describe all whistles.

With sufficient experimental data the behavior of Class I whistles can be predicted, and this can make them useful as flowmeters. The frequency of the sound produced by an aeolian-tone whistle or a vortex whistle is almost directly proportional to the flow speed. Therefore by measuring this frequency one can monitor the rate of flow through a pipe. The precession of helical flow, however, is not always helpful. It can be a serious problem in the combustion chamber of a solid-propellant rocket. Unless it is suppressed the combustion energy will amplify the vortex and the rocket engine will be destroyed.

Class II whistles are more numerous than those of Class I. Some of these whistles have been discovered only recently, and it seems likely that more will be found as the search for whistles that can be adapted to practical purposes is continued. Some of this research has been preventive. Several kinds of Class II whistle can be generated accidentally in jet-aircraft engines. These oscillations are so intense that they can cause metal fatigue and engine failure. Through an understanding of the feedback loop in such whistles ways have been found to disrupt them.

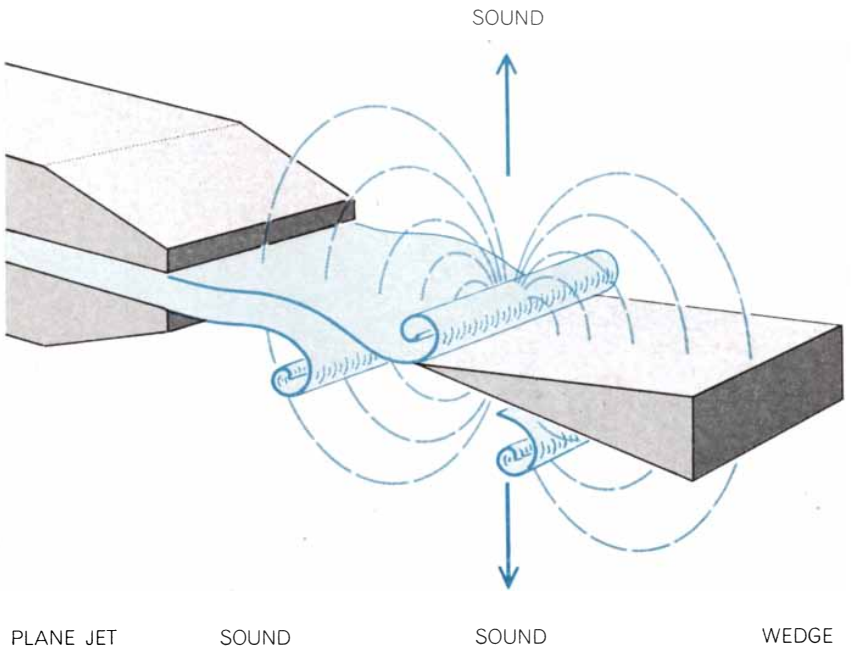
One of the oldest and best-known of the Class II whistles is called the edge tone. The edge tone, which can be generated by flows at both low speeds and supersonic ones, generally has a pure, intense sound that can be painful to the ear. An edge tone is produced when a jet of air emerging from a slit encounters an object downstream. The sheared jet flow is unstable; any disturbance will cause vortex development and hence cause a force to be exerted on the downstream object. The reaction force exerted by the object on the fluid then generates a sound field.

The lines of fluid motion associated with the edge-tone sound field resemble the pattern of iron filings around a magnet. As the sound is propagated back toward the slit, where the jet is more unstable, it reinforces the instability by causing a lateral displacement of the jet that gives rise to vortexes downstream; these vortexes encounter the object (generally a sharp wedge) and cause further sound emission. The sound field propagates back to the orifice and the cycle begins again [*see bottom illustration on this page*].

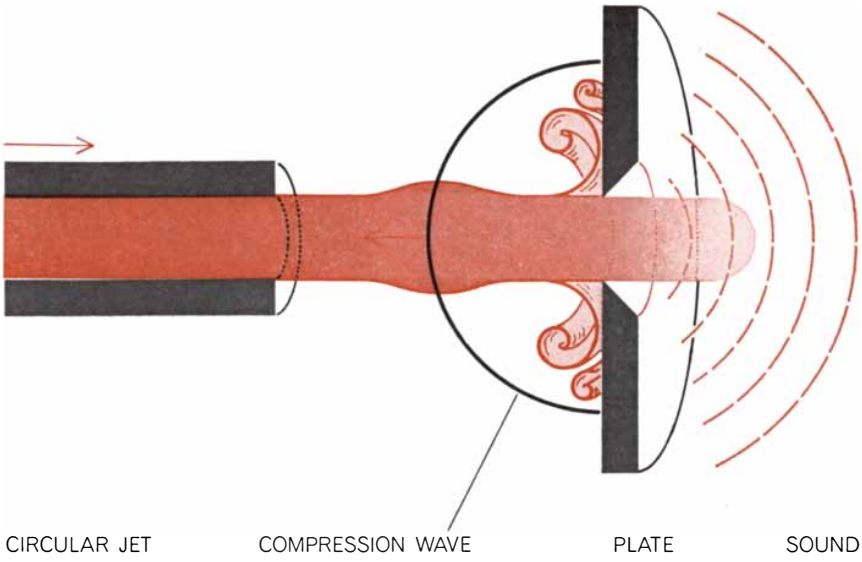


VORTEX WHISTLE produces sound by generating a precessing spiral of air. The air (*color*) swirls through the pipe at left following a helical path. When it leaves the pipe, the interaction of the pipe with the precessing flow of air creates sound (*vertical arrows*). Air follows a helical path because it enters tangentially or encounters a set of blades.

Two other whistles in this class—hole tones and ring tones—are generated by a round jet impinging on a round edge or a circular ring. The teakettle whistle is a good example of the hole tone. Such a whistle consists of two holes separated by a small cavity. A whistle sounds when the jet formed at the first hole impinges on the second hole. Like the edge tone, the stream instability causes vortexes to form that generate sound when they encounter the object. The air in the second hole vibrates much like the diaphragm of a loudspeaker. Part of the sound gen-



EDGE TONE is generated when a stream of air (*color*) issues from the plane (flat) jet at left and strikes a wedge at right. Instabilities in the flow produce vortexes that create the sound field whose streamlines can be seen at center and at right. Part of sound field spreads back toward the left and shears emerging jet flow, thus creating another disturbance that then develops into a vortex pattern as it impinges on wedge at right. The vortexes produce a sound field in the surrounding air (*indicated by solid arrows*), completing the cycle.



HOLE TONE, like the sound made by a teakettle whistle, is generated when flow of air (*color*) from a jet at left impinges on a round hole in a plate at right. Vortexes form between the plate and the nozzle and create a sound or compression wave (*semicircular line*). This wave sets up disturbances (*indicated by vertical arrows*) in the flow at nozzle, which move downstream toward the right. The disturbances alter the flow rate as air passes through the plate, causing vibrations. Because of the vibrations in the airflow a sound field (*indicated by broken semicircular lines*) is produced. Meanwhile vortex pattern continues to generate pressure waves that disturb the stream of air flowing from the circular jet.

erated by this diaphragm of air travels outward. The rest travels back toward the hole from which the jet issues. Unlike the edge tone, the sound causes slight changes in flow speed that give rise to vortex rings resembling rings of cigarette smoke. These vortexes travel downstream, impinge on the second hole and cause more disturbance in the flow through the hole to complete the feedback loop [*see illustration above*].

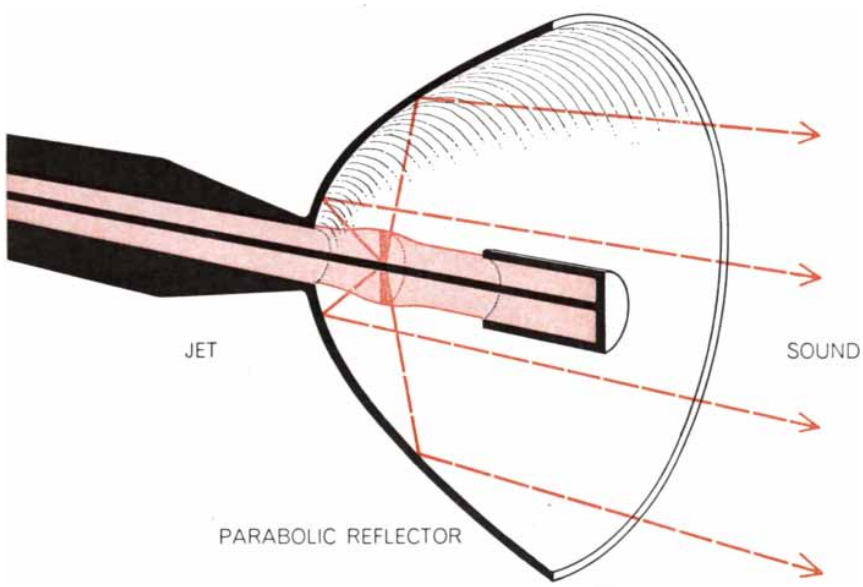
When the second hole in a hole-tone whistle is replaced by a small ring, the weaker ring tone is generated. If the diameter of the cavity between the two holes in the hole-tone generator is reduced to the diameter of the holes, thus forming a straight pipe, there may be a whistling sound called a jet tone. Its mechanism is very similar to that of the hole tone. Human whistling, in which sound is produced at an orifice formed by the mouth, also seems similar to the hole tone, but the mechanism of this whistle has not been studied thoroughly enough to classify it.

The observation of supersonic jet flows has led to the discovery of another Class II whistle called the choked-jet tone. It consists of a high-pressure stream of air flowing through a narrow passage. The intense sound produced by this whistle results from the fact that when air enters a restriction such as a nozzle at a pressure higher than atmospheric pressure, it cannot flow through the nozzle faster than the speed of sound. As a consequence the air cannot return to atmospheric pressure until after it has escaped from the nozzle. When the flow emerges, it suddenly accelerates to supersonic speed and then readjusts to subsonic speed by compression through a shock wave. The process creates a series of diamond-shaped cells of alternate supersonic and subsonic flow.

Such a pattern of cells can be seen in the exhaust of a rocket engine. The shock front at the head of certain cells is so unstable that small disturbances can cause it to oscillate and produce sound. The sound then propagates outward and creates a disturbance at the nozzle that is amplified in the jet to complete the feedback loop. A particularly good photograph of the sound from a choked-jet tone has been made by M. G. Davies of the University of Liverpool [*see bottom illustration on page 46*].

If Strouhal's observations applied, it could be anticipated that as the flow speed in a Class II whistle is increased the frequency of the whistle would gradually rise. This has been found to be true, but at a certain flow rate the continuous rise is interrupted and the frequency jumps abruptly upward. It then resumes a steady rise with increasing flow speed. This phenomenon, called a frequency jump, can be reversed by decreasing the flow rate. On the way down, however, the pitch will fall abruptly at a flow rate different from that at which it originally jumped up. The complete graph of frequency v. flow speed forms a loop and is analogous to the graph of the hysteresis loop in magnetic circuits.

Most Class I and Class II whistles can



STEM JET can create intense, high-pitched tone when air (*color*) from jet at left flows into the cavity at right at supersonic speeds. If the cavity is mounted at the correct distance from the jet, a standing shock wave (*solid color at center*) develops in front of the cavity. A disturbance in the flow can cause a moving shock wave in the cavity that can escape and collide with the standing wave, making it jump suddenly upstream to the left, thereby generating a strong sound pulse (*broken lines*). When the wave leaves the cavity, pressure drops and the standing wave falls back, driving another shock wave into the cavity. The cycle then starts again. The parabolic reflector attached to the jet focuses the sound field.

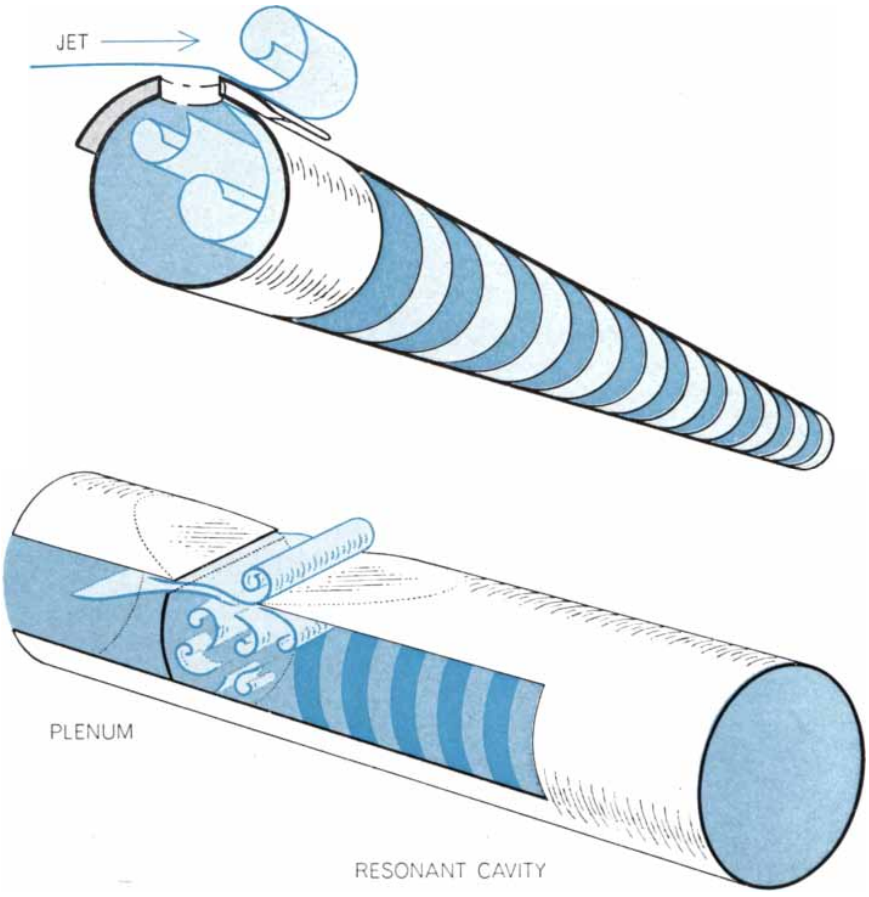
be made so that they can be blown with the mouth. Because the frequency depends almost linearly on flow speed, and because it is difficult to maintain a precise flow speed with the mouth, these whistles have never resulted in highly developed musical instruments. They had to be modified to Class III whistles before they were able to produce a constant frequency.

Class III whistles can be distinguished from the other kinds by the fact that a resonant or reflecting structure controls the feedback. A common example in this class of whistles is the flute. The flute whistles when a jet of air from the mouth is blown across a hole in the side of the instrument. The jet impinges on the opposite edge of the hole to create an edge tone. The edge tone, however, makes the column of air in the tube of the instrument resonant at a frequency that is determined by the length and diameter of the tube. The reflected sound waves in the column of air are sufficiently intense to override the normal edge-tone feedback, and thus the frequency of the tone is the resonant frequency of the tube. In a recorder or an organ pipe a resonant tube also controls the frequency. Instead of a round hole, however, a sharp wedge establishes the jet tone by interfering with a jet of air blown across it [*see illustration at right*].

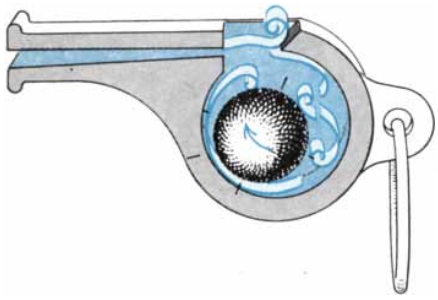
Since the frequency of the tone of an organ pipe or a woodwind is controlled not by the speed of the airflow, as it is in a Class I or Class II whistle, but by the resonant modes of the tube, the flow speed can be altered considerably without affecting the pitch of the instrument. It is this fact that enables organ pipes and woodwinds to function effectively as musical instruments. In order to change pitch, pipes of various lengths can be added to an instrument, as they are in an organ. The pitch of a flute or a recorder is changed by covering or uncovering holes so that the effective length of the tube changes. Because of the dominance of the resonant cavity, consecutive musical notes, each of a constant but different frequency, can easily be blown. Making tube lengths and hole spacings that will produce harmonically related notes is still an art, and it is likely to remain so for some time. When the jet, because of a speed increase, can no longer amplify the first resonance of the tube, it is said to be overblown. The instrument then switches from the first resonance to a second one through a frequency jump.

Police whistles belong in Class III. The Metropolitan Police of London use a small version of the organ pipe. The American police whistle, however, has a cylindrical cavity containing a ball that rotates so that a warbling tone is generated. The controlling element in the feedback for this whistle is still unknown. It may be controlled by acoustical resonance within the cavity; it may also be controlled by the fluctuating recirculating flow inside the cavity. When the jet is deflected inside the cavity, some flow enters that later must reappear at the nozzle exit. This flow may deflect the stream of air and thereby maintain the feedback cycle. The warbling occurs when the rotating ball blocks the hole and stops the tone [*see top illustration on next page*].

The Class III whistles most useful in industry are descendants of a whistle developed by Sir Francis Galton in 1883 to test hearing ability. The Galton whistle consists of a ring-shaped jet that produces sound when it impinges on the edge of a resonant cavity set coaxially in front of it. The sound can be varied from low frequencies and intensities to high ones. In a modification of the Galton whistle made by Julius Hartmann of Denmark in 1919 a circular jet is substituted for a ring-shaped one. The Hartmann whistle generates a tone by directing a supersonic flow of air into a cavity. If the cavity is located at the correct distance from the nozzle, a traveling shock wave is formed within the cavity. When the traveling wave impinges on the standing shock wave in the jet and immediately in front of the cavity, it causes the standing wave to jump. The jump gives rise to a new wave in the cavity and to sound emission similar to the shock motion in the choked-jet tone. If the airflow is subsonic or even laminar, a Hartmann whistle will still produce a tone, but in these circumstances



WOODWINDS are Class III whistles. The flute (*top illustration*) voices when air is blown across hole on its side. This flow of air establishes a Class II edge tone at right that causes the air column in the flute barrel to vibrate (*alternating light and dark bands*). The sound energy produced is fed back to the edge tone by the resonant column of air in the barrel. Since the barrel of the flute has certain preferred frequencies, it is these at which both the air column and the edge tone vibrate. The same principles govern feedback in the organ pipe (*illustration at bottom*). In this instrument the edge tone is produced by air escaping at low pressure into the barrel from the plenum, or pressure chamber, shown at left.



AMERICAN POLICE WHISTLE sounds when air is blown through the mouthpiece and creates an edge tone in the slot at top. According to one description of how this whistle works, part of the flow from the mouthpiece represented by swirling lines travels around the inner surface of the cavity and returns to the slot, where it reinforces the edge tone. The air could carry the ball with it (*as indicated by arrow*) so that the slot is periodically blocked. This would explain the whistle's rapidly varying tone.

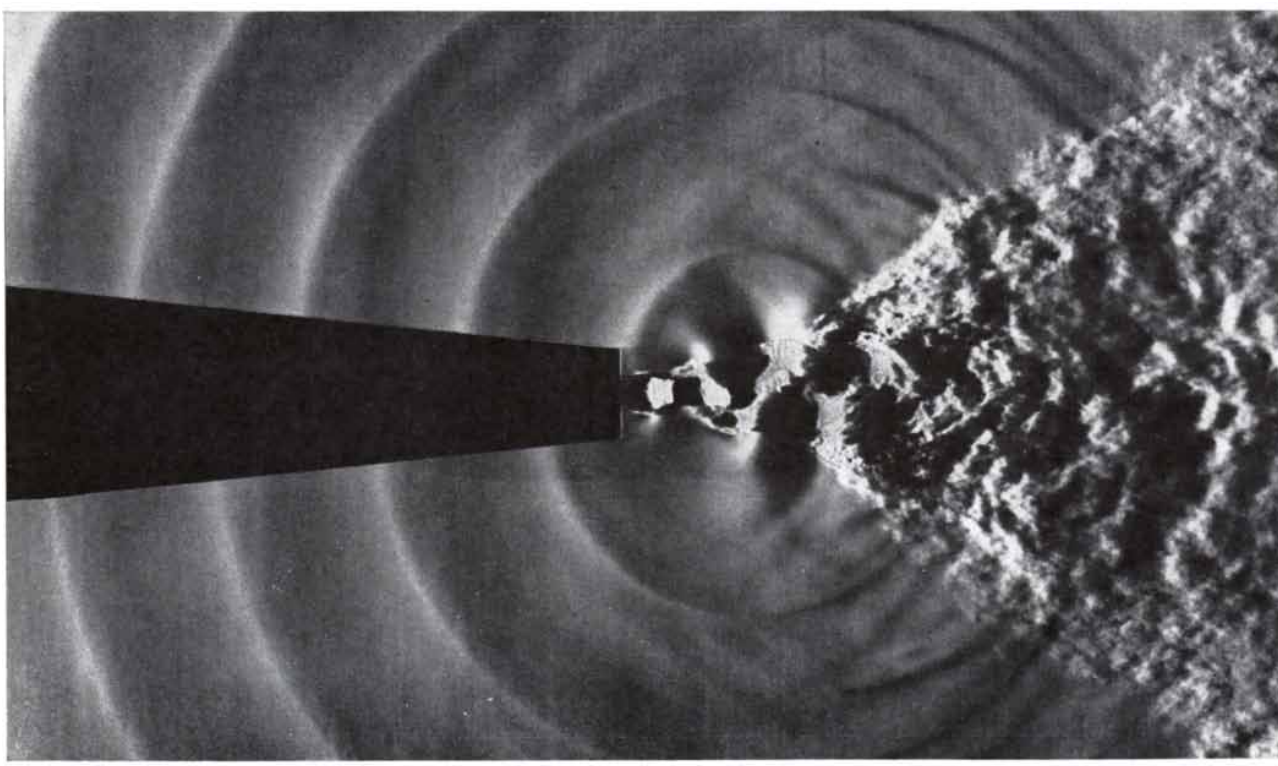
the amplifier is simply the jet instability.

Another variation on the Galton whistle is the stem jet. The cavity of this device is supported by a rod projecting from the nozzle, and a parabolic reflector fitted around the nozzle focuses the sound. In supersonic operation this jet is similar to the Hartmann whistle in that the jumping of the exterior shock wave generates the sound. The effect of the stem on the flow field is quite large, however, and higher sound levels result [*see bottom illustration on page 44*].

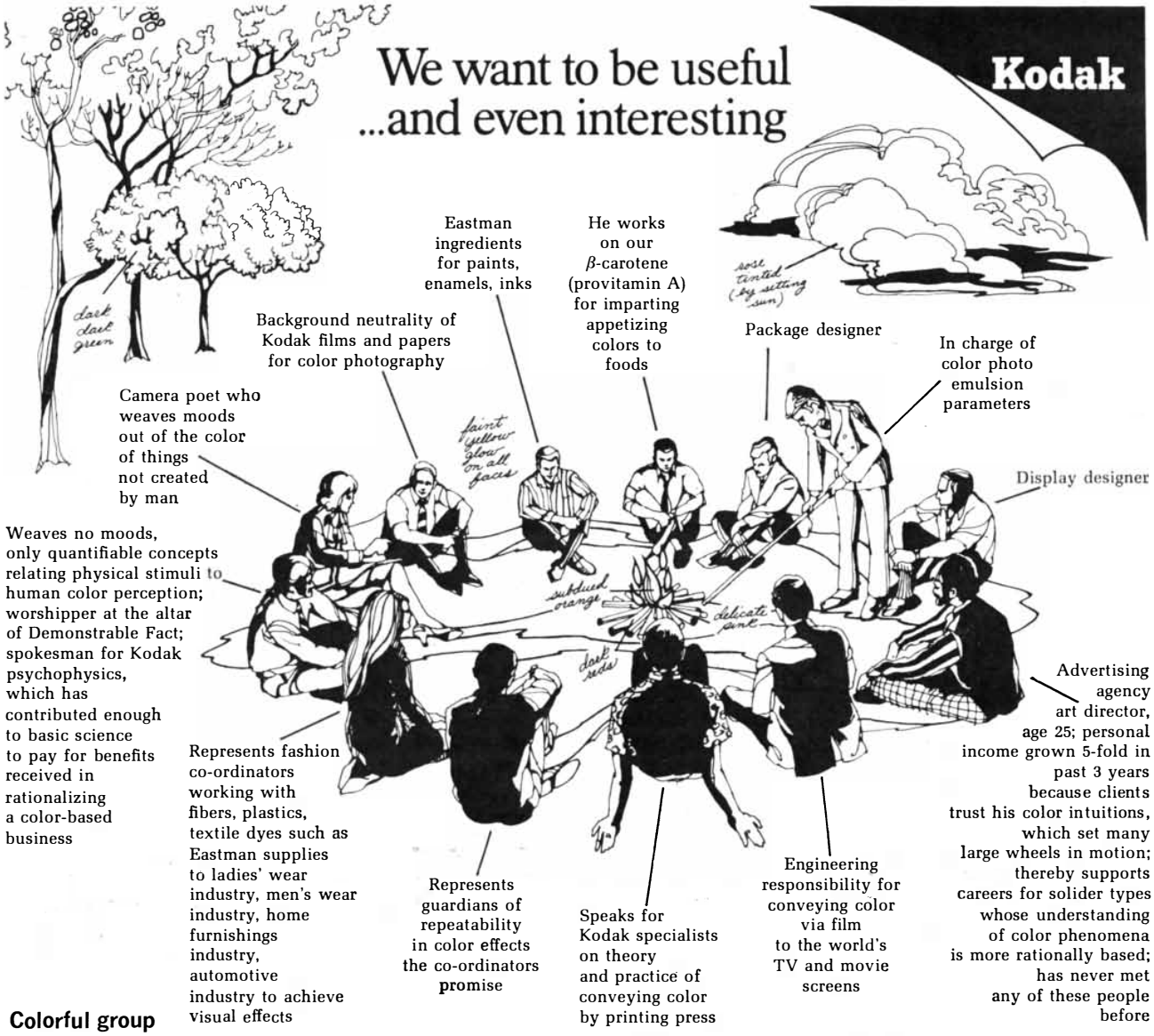
The Galton whistle, the Hartmann whistle and the stem jet have all been adapted to practical ends. The Galton whistle was once used as a steam-locomotive whistle. Instead of having a ring-shaped jet of steam impinge on the edge of one big cavity, several smaller chambers of different lengths were assembled to form a supersonic "pipes of Pan" that produced harmonically related sounds. Although this "chime" whistle was pleasant to hear, it was a failure in sounding a strident warning of the train's approach. Today Hartmann whistles and stem jets control combustion by altering chemical-reaction rates and vaporize liquid fuel so that it burns more efficiently in a boiler. They also emulsify liquid mixtures and coagulate smoke and dust. Sonic energy generated by these whistles can hasten drying, clean surfaces, and test rocket materials and components. There are mechanical sirens that can generate sounds intense enough for these purposes, but because whistles have no moving parts they are simpler to construct and maintain.

Not all aspects of the supersonic Class III whistles are understood. The amplifying mechanism is still somewhat obscure, particularly with regard to the role played by the jet instability. Although vortexes must develop in the jet as a consequence of the jet's being disturbed by the strong sound field, they are far weaker than the vortexes found in the subsonic jet whistles.

The detailed study of aerodynamic whistles not only has satisfied scientific curiosity and provided some novel solutions to practical problems but also has opened avenues to the understanding of aerodynamic sound generation. The mechanism of whistles is intimately related to the mechanisms that create the sounds of jet-aircraft engines and air-moving fans. Whistles, although very complex, are still easier to analyze, and hypotheses of sound generation can be more readily tested with them. Further study of whistles should lead to deeper knowledge of sound generated by fluids and perhaps to cures for the myriad noises that are bombarding mankind with ever increasing intensity.



CHOKED-JET TONE is produced when a stream of air at a pressure higher than atmospheric pressure spurts from the plane jet at left. Because air cannot flow through the nozzle faster than sound, it cannot return to atmospheric pressure until it has escaped. Once outside, it decompresses at supersonic speeds, creating the dark cells of expanding air and the light cells of compressed air in the turbulent flow at right. When the shock fronts that separate the cells move in response to a disturbance, they generate sound. These sound waves, which can actually be seen as alternating semicircular ripples surrounding the jet, propagate back to disturb the nozzle flow, creating further disturbances in the jet. This photograph was made by M. G. Davies of University of Liverpool.



Colorful group

We take counsel in preparation for the annual meeting of the 29-member Inter-Society Color Council in New York on April 13 and 14. ISCC, founded in 1931, brings together principal societies interested in the optics, chemistry, and psychology of color with associations of professionals in the *use* of color. For particulars, address ISCC's Secretary, Ralph M. Evans, whose address is Photographic Technology Division, Eastman Kodak Company, Rochester, N.Y. 14650.

That's an asymptote, Sammy

Familiar KODAK CAROUSEL *Slide Trays take 80 slides arranged in a circle. Loaded with Inquiry Slides created by Biological Sciences Curriculum Study (P. O. Box 930, Boulder, Colo. 80301), they are now moving out to high schools in gratifying numbers. Very gratifying.*

The United States is one of the few nations without a ministry of education. What shall be taught to its youth is decided by thousands upon thousands of persons, each of whom has a right to his particular shade of opinion. Such an uncoordinated state of affairs is not necessarily deplorable.

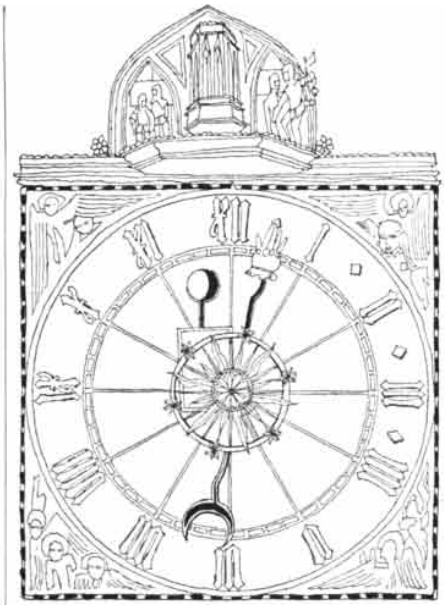
Plainspoken straight-thinkers want the teacher to sit up there as an authority figure belting out uncontroverted, opinion-free facts and meting out fair punishment for failure to fire them accurately back on signal.

Missionaries for the scholarly way of life demand the schools send them ever more converts. Let the unconvertible become used-tire salesmen, or something.

In between sit some who foresee countless hordes learning painfully to think like Charles Darwin, only to face employers with little need and much fear of Charles Darwins.

In there pitching is BSCS. It describes itself as "an essentially autonomous organization of high school biology teachers, science educators, school administrators, and college biologists concerned with the improvement of biological education." Friendly to textbook publishers and others commercially involved with education (like us), BSCS nevertheless counters the tendency to leave the content of education to be decided in combat among sales managers. In addition to its well-established textbook program, BSCS now ventures forth with an initial 20 sets of Inquiry Slides in sequences of 6 to 15 slides, at various levels in various biological topics. A KODAK EKTAGRAPHIC Projector puts them on the blackboard. There teacher and class, employing thought, chalk, opinion, and normal roomlight, interact with data and questions presented in bold, colorful graphics and labeled coordinates awaiting curves to be drawn in by reasonable individual and group hypotheses. Next slide, bearing further data, may confirm or refute the predictions. As in life. Thinking like Darwin becomes less painful. Less painful also for the teacher not to have to feel all that authoritative.

SCIENCE AND



The CBW Statement

President Nixon's November announcement concerning chemical and biological weapons renounced germ warfare and the first use of lethal and "incapacitating" chemical weapons. The statement did not, however, change U.S. policy on two major weapons currently in routine use in Vietnam: tear gas and chemical defoliants.

With regard to biological warfare the renunciation was unilateral and unequivocal. The President indicated that biological-warfare research would be confined to defensive measures and that the U.S. stockpile of bacteriological weapons would be destroyed. In spite of a widespread feeling that such weapons are undependable and potentially uncontrollable, the Joint Chiefs of Staff and the Department of Defense had long maintained that the "option" of "retaliation in kind" was essential for U.S. security. Last fall that position was apparently overruled by Secretary of Defense Melvin R. Laird, so that there was nearly unanimous support in the National Security Council for the new policy enunciated by President Nixon.

With regard to chemical warfare the President referred to the 1925 Geneva Protocol, which prohibits the first use of "asphyxiating, poisonous or other gases" and "analogous" materials. The protocol was signed on behalf of the U.S. but has never been ratified by it, although some 80 countries have now acceded to it, including all the major powers except the U.S. and Japan. The U.S. position has been that it would not initiate the use of lethal chemical agents, but both the Department of State and the Department of Defense have resisted any formal pledge to that effect. President Nixon affirmed the no-first-use policy for lethal agents, extended it to include chemical agents that incapacitate rather than kill and asked the Senate to formalize the policy by ratifying the 1925 protocol.

White House sources immediately defined out of the protocol both tear gas and defoliants. The Administration was challenged on both counts. Over the years many of the protocol's signatories have interpreted it as including tear gas; moreover, although the Department of Defense classifies the "super" tear gas CS as a riot-control agent rather than an incapacitating agent, its use in Vietnam to force enemy troops into the open seems to contradict that designation. As for defoliants, opposition to their use on ecological grounds was strengthened last fall by reports that such chemicals can cause malformations in experimental animals. Last month the UN General Assembly approved, over objections by the U.S., a resolution declaring that the protocol prohibits the use of "any chemical agents," including tear gas and herbicides.

The DDT Ban

The insecticide dichlorodiphenyltrichloroethane (DDT) is on the way out in the U.S. In November the Federal Government sharply curtailed applications of the pesticide and ordered that its use be virtually ended by December 31, 1970. Acting on the basis of recommendations made by a commission on pesticides appointed by the Department of Health, Education, and Welfare, Secretary of Agriculture Clifford M. Hardin ordered immediate notice of cancellation of "registrations" (permission to market) for DDT intended for house and garden pests, for shade-tree and tobacco pests and for aquatic areas. All other applications except for "prevention or control of human disease and other essential uses for which no alternative is available" are to stop by the end of this year.

The move against DDT came at the end of a year in which a number of state and foreign governments had taken similar action. The moves were based primarily on the fact that DDT and related chlorinated hydrocarbons do not break

down easily. They persist in the environment and are poorly metabolized and excreted by animals. Instead they build up, particularly in fatty tissues, and are concentrated as they progress up the food chain. Particularly large concentrations of DDT are therefore found in predatory fishes and birds—and sometimes in man.

The Federal order is expected to cut DDT applications in the U.S. by about a third immediately and by about 90 percent when it is in full effect. The White House announced a number of other steps to improve control of pesticides, including consultations between the Agency for International Development and underdeveloped countries, where DDT plays a major role in the control of insect-borne diseases and the improvement of crop yields. In such countries DDT may still be the least of alternative evils. According to experts of the United Nations Food and Agriculture Organization, agricultural production would suffer badly without DDT, which is an effective and relatively cheap insecticide.

Kicking the Gong

Instruments left on the moon by the *Apollo 12* astronauts, Charles Conrad, Jr., and Alan L. Bean, have provided two pieces of unexpected information. The magnetometer has signaled that the moon's magnetic field at the landing site is about 30 gammas compared with an expected value of two to eight gammas. More surprising still, the seismometer showed reverberations lasting for 55 minutes when the ascent stage of the landing module crashed into the moon 40 miles from the instrument.

The expected value of two to eight gammas for the magnetic field of the moon was based on measurements made at a distance of 500 kilometers by *Explorer 35*. None of the craft that landed on the moon before *Apollo 12* had carried magnetometers. According to Palmer Dyal of NASA's Ames Research Center, the unexpectedly high readings from the *Apollo 12* magnetometer probably indicate the presence of a sizable body of magnetic material somewhere below the landing site. Dyal does not believe the *Explorer 35* values for the moon as a whole are in error.

The long-range goal of the magne-

tometer experiment is to estimate the temperature of the moon's interior. The magnetometer is designed to record changes in the moon's magnetic field induced by changes in the intensity of the solar wind, the stream of charged particles emitted by the sun. For example, the instrument recorded a rise of 60 gammas when the moon passed through the bow shock wave produced as the solar wind streams past the earth. The rise lasted for a few minutes. From such measurements Dyal and his associates will be able to calculate the electrical conductivity of the moon and from that the temperature of the interior.

"Watching the seismometer tracings when the *Apollo 12* stage hit the moon," says Maurice Ewing of the Lamont-Doherty Geophysical Laboratory, "was like watching a man strike a gong on the other side of the room and hearing it ring for almost an hour." On the earth a comparable experiment would produce tremors that quickly subside. The crash site of the *Apollo 12* stage was carefully chosen to transmit shock waves across the bay of a crater that seems to be filled with lava. The signals reached the seismometer about 20 seconds after the crash, having traveled at the expected rate of three to four kilometers per second. The seismic signals surprised everyone by increasing in intensity for six or seven minutes and then by continuing, with diminishing strength, for another three-quarters of an hour. "There is no guarantee," says Ewing, "that what we have seen is typical of the moon as a whole. But when you have an inexplicable record you tend to think of far-out explanations. You would be quite astonished how far-out some of them are."

Isolated Gene

The goal of isolating a single gene from the 3,000 to 5,000 genes that embody the complete genetic message in a bacterial cell has been accomplished at the Harvard Medical School. The isolated gene, designated *z*, is one of three genes in a sequence (known as an operon) that specifies the synthesis of three enzymes that enable the bacterium *Escherichia coli* to metabolize the sugar lactose. The sequence is called the β-galactosidase operon or the *lac* operon.

When an operon is translated into the protein molecules of enzymes, the translation of the last gene in the series is dependent on the translation of the preceding genes. The *z* gene is the first of three genes in the *lac* operon. Each gene is closely associated with two smaller genetic units, an operator and a promoter, that regulate the expression of the gene. The Harvard workers have determined that the helix of DNA constituting the *z* gene incorporates 3,700 pairs of bases, and that the operator and promoter region attached to it embodies only 410 base pairs. For purposes of comparison, all the genes of *E. coli* form a DNA molecule some three million base pairs long.

To separate the *lac* operon from all the others in the DNA of *E. coli,* the Harvard group employed the services of two "transducing" bacteriophages: bacterial viruses that multiply inside the *E. coli* cell and attach a portion of the cell's DNA to their own much smaller molecule of DNA as they replicate. Two phages, called $\lambda plac5$ and $\phi 80 plac1$, routinely incorporate the *lac* operon in their DNA. (The *p* indicates that they form clearly visible plaques, or clear areas, when they grow on a culture of *E. coli.*)

The DNA normally present in phages as well as in bacteria is a double-strand helix. One strand is the "sense" strand that is transcribed into messenger RNA and ultimately translated into proteins; the other, or "nonsense," strand is not transcribed. It had been discovered earlier that the two phages $\lambda plac5$ and $\phi 80 plac1$ insert the *lac* operon into their DNA molecules in opposite orientations. It also happens that because of differing base composition one strand of the DNA in each phage is distinctly heavier than the other, so that the two strands can be separated by centrifugation. When this is done, the heavy strand of one phage contains the sequence of "sensible" bases in the *lac* operon whereas the heavy strand of the other phage contains the complementary, or nonsense, sequence. To reconstitute a stretch of DNA containing both strands of the *lac* operon it is necessary only to bring the heavy strands of the two phages together; the complementary bases then spontaneously pair up. The remaining bases in the two strands, not being complementary, remain separated. The experiment was undertaken on the hypothesis that there would be no complementary stretches in the two heavy strands of the two phages except those provided by the sense and nonsense bases of the *lac* operon. The hypothesis was confirmed.

Electron micrographs of the reconstituted DNA molecule show a double-strand structure whose length (1.4 millimicrons) corresponds to that of the *z* gene of the *lac* operon together with its promoter and operator. At each end of the reconstituted gene the unattached strands form bushy tails. In other micrographs the tails have been chopped off by enzymes that attack single strands of DNA but not double strands, leaving the isolated gene standing alone.

The way is now clear to study in cell-free systems how individual genes are transcribed into messenger RNA and then translated into proteins. With the help of other transducing phages it should soon be possible to isolate a variety of other operons. The Harvard group that achieved the first isolation of a gene was headed by Jon Beckwith; his associates were Jim Shapiro, Larry Eron, Lorne MacHattie, Garret Ihler and Karin Ippen.

Abortion and the Courts

A Federal court's decision that any "qualified, licensed practitioner of medicine" can perform an abortion in the District of Columbia for reasons satisfactory to his patient and himself may soon bring the issue of legalized abortion before the U.S. Supreme Court. In issuing the decision U.S. District Judge Gerhard A. Gesell (whose father was the Yale pediatrician Arnold Gesell) declared that "a prompt appeal" of the case to the Supreme Court was "highly desirable." He suggested "that Congress should re-examine the [District of Columbia abortion] statute promptly in the light of current conditions."

Gesell's ruling dismissed a grand jury's indictment of Milan Vuitch, a physician in Washington, under a law that Congress wrote into the District of Columbia Code in 1901. The law forbids abortions "unless the same were done as necessary for the preservation of the mother's life or health and under the direction of a competent licensed practitioner of medicine." Gesell ruled that the second part of the law fell within the police power of Congress but that the first part of the law was too vague. "No body of medical knowledge," he said, "delineates what degree of mental or physical health or combination of the two is required to make an abortion conducted by a competent physician legal or illegal under the Code." A jury's opinion of a physician's interpretation "of the ambivalent and uncertain word 'health' should not determine whether he stands convicted of a felony," the judge said.

Gesell pointed out that the decisions of the Supreme Court have indicated increasingly that "a woman's liberty and right of privacy extend to family, marriage and sex matters and may well include the right to remove an unwanted child, at least in early stages of pregnancy. . . . Matters have certainly reached a point where a sound, informed interest

(The Great New Rover with V-8 Engine)

AMERICAN, EUROPEAN, OR UNIQUE?

The smoothness, reliability and power of a V-8 engine, automatic transmission, power steering, power brakes, electric windows—these are features that the Rover 35OOS has in common with many American sedans. The reason: they are right for American driving conditions.

89% of the cars Americans buy have V-8 engines, and with good reason. They are quiet; they are able to cover these tremendous distances of yours without undue straining; and they have the extra power desirable with automatic transmission, power steering, etc.—other features that have become almost indispensable to the American style of driving. Yet before now anyone wanting a V-8 engine combined with traditional European qualities (road-holding, handling, stopping power, safety, craftsmanship, elegance, economy) had to pay upwards of $10,000 for it.

The Rover 35OOS combines all the best qualities of both American and European cars for the first time anywhere, for a price of $5,398.* Moreover, our V-8 has averaged over 17 m.p.g. in three years of tests in this country—a pleasant surprise in a luxury sedan that is also capable of 117 m.p.h.

To learn about the hundreds of fine details that help make the 35OOS the unique car it is, please mail in the coupon below.

Rover Division, Dept. SA
British Leyland Motors Inc.
600 Willow Tree Road
Leonia, New Jersey 07605

BRITISH LEYLAND

Gentlemen: Please send me the four-color brochure on the Rover 35OOS, and tell me the location of a dealer near me.

Name_____

Address_____

City_____ State_____ Zip_____

**Suggested retail price at East and West Coast ports of entry; state and local taxes extra.*

of the state must affirmatively appear before the state infringes unduly on such rights."

Brain Gain

Forty-five percent of the postdoctoral students in U.S. universities and other institutions are from outside the U.S., according to a report published by the National Academy of Sciences. The report, titled *The Invisible University: Postdoctoral Education in the United States,* summarizes the results of a survey of such students, who play a major role in the day-to-day work of science in the U.S. Of the 10,470 students with doctorates answering the survey questionnaire 4,845 were citizens of other countries.

These students are concentrated in a few fields. In the physical sciences there are 1,936 postdoctoral students from abroad, and there are about the same number (2,018) in the basic and applied medical sciences. Some 400 are engaged in the biological sciences, and the rest are distributed among the social sciences, the arts and humanities and other fields.

More than half of the students come from the United Kingdom, India, Japan, Germany and Canada. Approximately a fourth come from Taiwan, Australia, Israel, Switzerland, Italy, Argentina, France and the Philippines. Sixty-eight other countries are represented.

The report indicates that the postdoctoral system does not contribute significantly to the "brain drain." More than 80 percent of the postdoctoral students from other countries who received their degree at home return there when their appointment expires. It is the students who begin their education in the U.S. at an earlier stage who are more likely to stay; for example, only 37 percent of the postdoctoral students who get their degree in the U.S. return home. It would also appear, the report states, that students from other countries are not depriving U.S. students of postdoctoral positions. A majority of U.S. Ph.D.'s go on to academic or industrial jobs without doing postdoctoral work.

Cryptic Computers

The prevention of the unauthorized use of information stored inside a computer or transmitted over data-communication lines has been a matter of increasing concern in recent years, particularly since the advent of large "time-shared" data-processing networks involving many different computers and terminal devices. Two potential solutions to the problem of data security—both cryptographic techniques—were put forward at the Fall Joint Computer Conference in Las Vegas by Ralph O. Skatrud, an engineer associated with the Systems Development Division of the International Business Machines Corporation.

One of the techniques described by Skatrud is called polyalphabetic substitution. In contrast to the ancient cryptographic technique of monoalphabetic substitution, in which only one letter is substituted for another to encipher a message, the polyalphabetic technique employs a number of continuously changing cipher alphabets for a single message. According to Skatrud, highly sophisticated computer-generated codes based on this technique would "defy being broken by even another computer."

The security of such a computerized cryptographic system is a function of the capacity of the computer memory. Skatrud's proposed polyalphabetic-substitution system would use five 256-character memories, providing a total of 2×10^{38} possible "bit" permutations. Using as few as 1,280 "addresses," a single permutation could be selected and combined 10^{12} different ways without a single repetition. These combinations would become the "keys" for encoding messages. In other words, the random contents of the successive memories would be selected by a stepped addressing control, summed and mixed with the data being transmitted. Such a system could encode all the data stored or transmitted by a computer at a rate of 2,000 bits per second for 583 years before it began to repeat itself. Deciphering would be a process identical with ciphering, and the two functions would be self-reversing, that is, the same key and identical hardware would be used to carry out both functions.

The second potentially applicable cryptographic technique described by Skatrud is called digital matrix transposition. According to this approach, data are read into a matrix by rows and are read out by columns, under the control of two different sets of random digits stored in the computer memory. The row-column mixing produces a "pseudo-random" stream of data that can be deciphered by simply reversing the enciphering process.

Skatrud contends that both of his proposed computer systems satisfy all the accepted criteria and principles for cryptographic systems. Neither requires manual intervention unless maintenance is required, and—since a one-time code would be used—each is in theory unbreakable. Moreover, he points out, high-density memories and the technology to support the logical control of such cryptographic systems exist today. He concludes that "with integrated circuits becoming available and the cost-per-circuit function decreasing, it becomes possible to consider undertaking designs that would offer relatively high degrees of privacy in computer systems at reasonable cost."

Man's Bag

What freed man from the literal hand-to-mouth existence typical of other primates? One anthropologist suggests it was a carrying bag. Although such perishable objects would not last, their existence in early Paleolithic times might be inferred. Speaking at a symposium sponsored by the Wenner-Gren Foundation for Anthropological Research, Richard Borshay Lee of Harvard University noted that many of the stone tools found at the campsites of early man in East Africa are made of stone available only at locations 10 miles or more from the camp. Lee points out that, unless one believes every two such tools represent a round trip of 20 miles or more, with the toolmaker holding a stone in each hand on the return leg, one must accept the existence of some kind of carrying device.

The principal advantage a man with a bag has over a bagless ape is that the man is no longer forced to devour on the spot everything edible that he encounters. After a day of foraging the gatherer can rendezvous with his fellows carrying many times the weight of nuts, berries, roots or insects that he has eaten during the day. Lee sees a number of immediate consequences. For one thing, an exchange economy tends to arise as berry-picker and grub-digger, say, find it beneficial to pool their gatherings. For another, a food surplus allows many kinds of constructive activity that are impossible for the constant collector. The toolmaker can journey 20 miles one day and spend the next day shaping a supply of implements and still not go hungry.

How did the carrying bag come to be invented? Lee conjectures that neither a collector nor a hunter made the first one. Instead, as hominid evolution progressed, the increasingly helpless infants lost the power to grasp while at the same time the mothers lost the torso hair that primate young normally cling to. The mothers must have found it disadvantageous not to have both hands free when there was work to be done. The first carrying bag, Lee suggests, was probably a sling for a child.

Coming soon: the bonded airplane.

As aircraft speeds and payloads increase, structural tolerances become more critical, materials more exotic and strength-to-weight ratios more crucial—all of which pose manufacturing requirements that were unheard of a few years ago. To solve these new problems, a high technology manufacturer in Washington State has made major advances in the science of bonding.

The Bonded Structures Group of Heath Tecna Corporation is now creating high-strength, light-weight structures of both fiberglass and metal —such as wing-to-fuselage fairings, metalbond honeycomb structures for helicopter landing skids and fiber-glass overhead stowage bins for superjet interiors.

On an even larger scale, Heath Tecna has recently completed prototype fuselage panels for Lockheed's new 1011 TriStar jetliner. These panels, which measure 13′ x 22′ over-all, are the largest ever designed for an aircraft and verify the feasibility of using adhesive bonded construction for an advanced technology jet. As a result, the entire fuselage of the L-1011 is a metal-bonded structure. With this bonding comes the advantage of higher strength-to-weight ratios, increased fatigue resistance and improved aerodynamic performance. Adhesive metal bonded panels also entail a minimum of secondary airframe attachments, such as rivets and fasteners.

For the prototype, 40 separate pieces of clad aluminum were used on each fuselage panel. To provide both corrosion resistance and surface bondability, a new, all-purpose primer was applied. The parts were then assembled with fail-safe titanium doublers and cured in the company's 15½′ x 44′ autoclave, one of the largest such units in the United States. Significantly, the unblinking scrutiny of ultrasonic inspections has revealed no flaw in the bonds.

Heath Tecna has also developed the world's first fully-automated spray clean line for the metal bond industry. The new facility represents a marked departure from conventional dip-tank immersion procedures and is a key step in achieving higher reliability and increased strength of adhesion in bonded assemblies. It has a production capability of some 2,000 square feet of cleaned, primed and cured material per hour and permits a broad variety of metals to be processed on the same line through easily programmed adjustments in chemical baths, solution application sequence, temperature levels and the rate of conveyor movement.

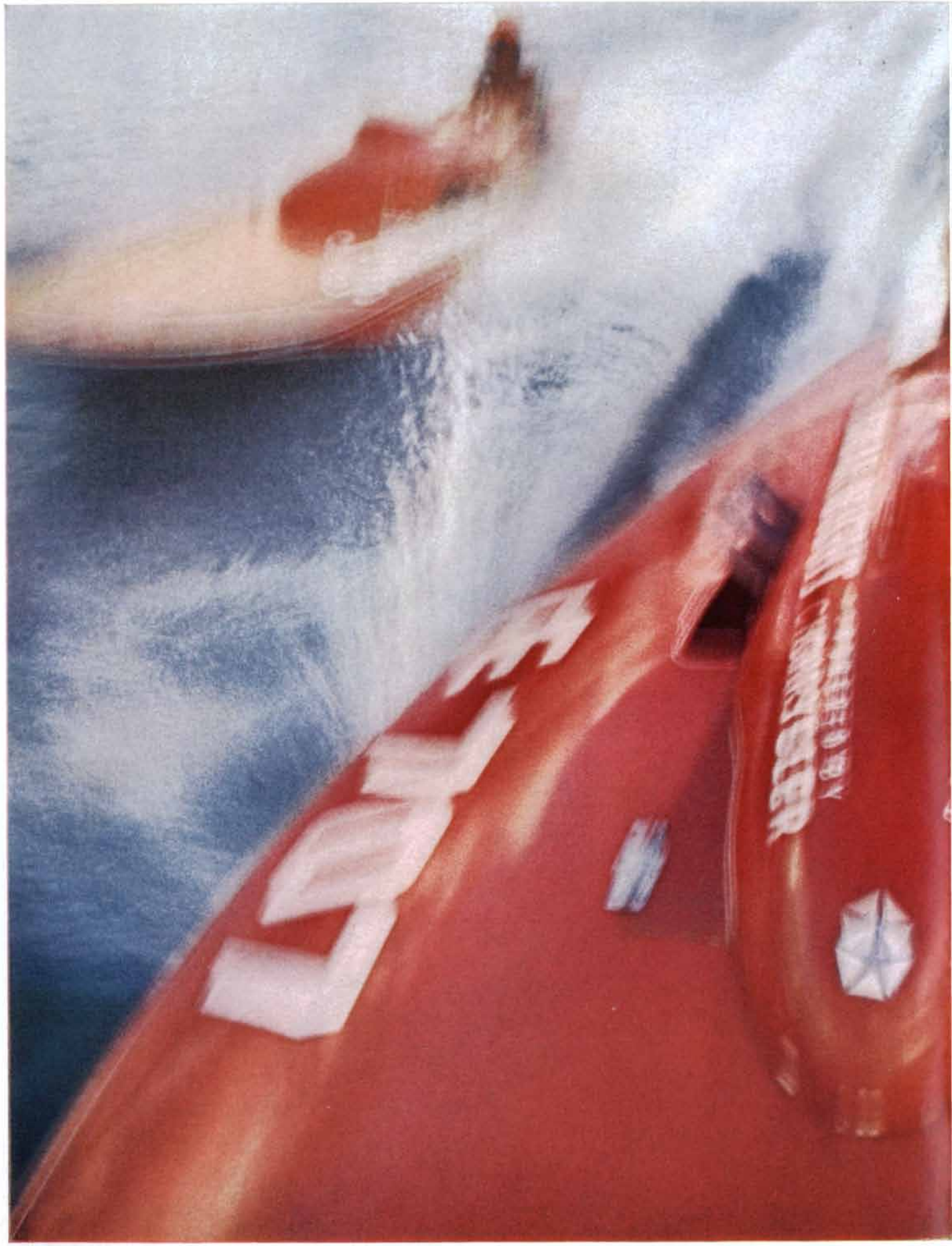
The company's goal—to develop sophisticated products and processes in new, carefully selected growth markets—is being well realized. In 1950, the company was a three-man machine shop. Today, Heath Tecna employs more than 2,500 people; it has grown to 16 divisions and subsidiaries in six states, with its corporate headquarters and over half its operations in Washington State. In addition to its aerospace activities, the company provides a wide range of products and services in avionics, air cargo and payload systems, building products, protective finishes, specialized scientific instruments and engineering services. Its fiscal 1969 sales reached $64.7 million—well over double that of the previous year.

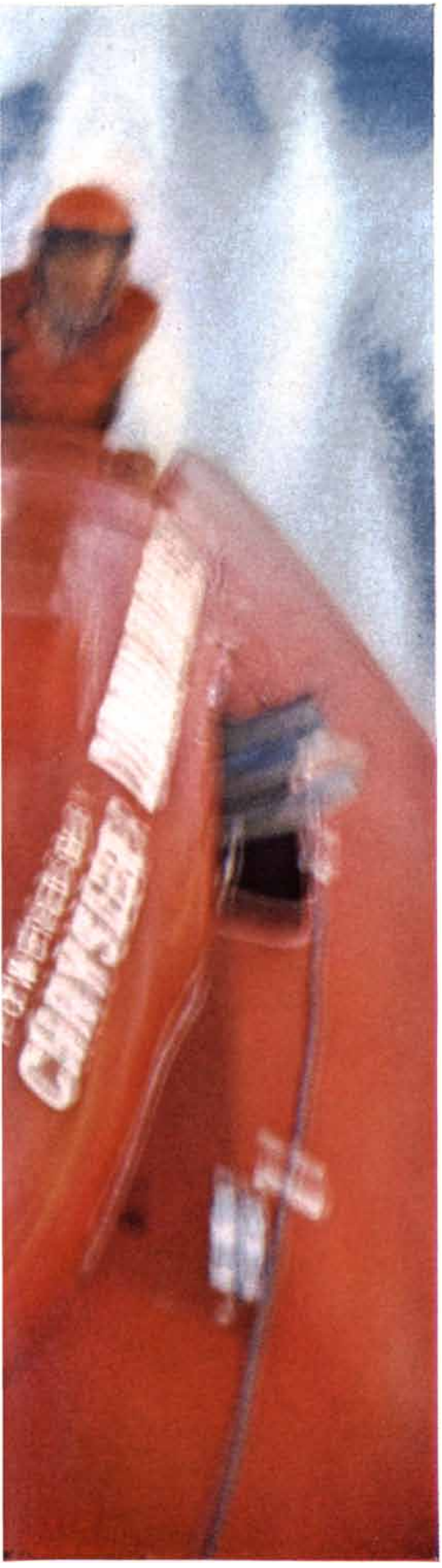
The State of Washington is a fertile field for the exciting new breakthrough industries of the future. In aerospace, oceanography, fisheries, agriculture, nuclear energy and many other areas, the smart money is betting on the State of Washington.

Daniel J. Evans
Governor

STATE OF WASHINGTON

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





The boat on the left is riding on water. The boat on the right is riding on Polyox.

When Union Carbide's Polyox resin is pumped out the bow of a boat, friction resistance between the water and boat is greatly reduced.

And the boat blurs ahead at record speed. With less than record effort.

It works so well, as a matter of fact, international yachting and rowing competition rules politely call Polyox only one thing. Patently illegal. Totally contrary to purity of sport and all that.

On the other hand, Polyox is the latest wrinkle in maritime technology. The newest way to get bursts of speed out of ships like ice breakers and rescue boats. Maybe the best way.

We're looking in a thousand different Polyox directions at once.

How about the "slippery water" theory for getting water into a burning house faster?

Or pushing concrete up a hose that's 12 floors high? Or pumping more water through an irrigation system?

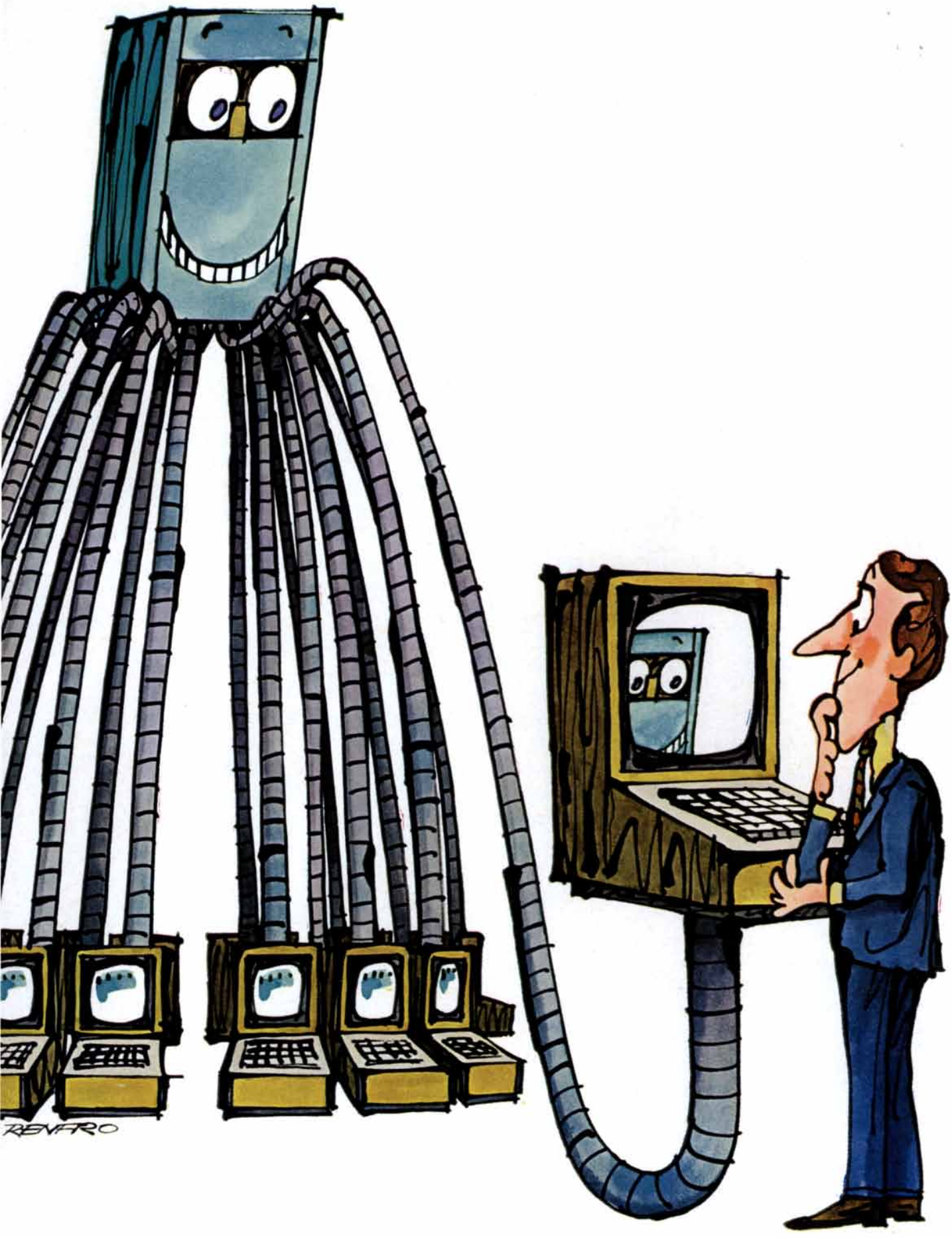
Or making a two-foot sewer pipe do the work of a three-foot pipe?

Or..?

Polyox resin is one discovery on the verge of becoming 10,000 discoveries.

UNION CARBIDE

THE DISCOVERY COMPANY



The Octopeeper

RCA's Video Terminal. Our TV experience puts you eye to eye with Octoputer. It's your best view of remote computing.

Remote computing is working with your computer from wherever you are to wherever it is.

It can be yards or miles away. And hundreds of people can share it.

For those people, user terminals are hooked up to the remote computer. There are all kinds of terminals, in all sizes and shapes.

But none of them sizes up to the terminal you see on the Octoputer's arms.

It's RCA's Video Terminal. The Octopeeper.

There's no better way to find facts, feed in facts, or solve problems. It's like a combination TV and typewriter. You see what you type. You see what the Octoputer says. Instantly. Clearly. In bright letters on the screen.

The Octoputer's peeper is the best Video Terminal on the market. It should be.

RCA pioneered television. We've put 44 years of research and experience into TV.

And 50 years into general communications and electronics.

The popularity of video terminals is growing faster than that of any other terminal, because they're the best links to remote computing.

Remote computing is the coming thing. That's why RCA is concentrating on it.

We got there first because it's based on communications.

The Octoputer puts us a whole generation ahead of our major competitor.

It can put you ahead of yours. And the Octopeeper is the best way to get to it. For more Octopeeper information, call RCA Computers at 609-424-2385.

RCA

Nothing comes close to our remote computers

The Shapes of Organic Molecules

The new Nobel prize in chemistry was given to men who showed that certain molecules can assume different shapes simply by rotations around single bonds. Such differences influence chemical reactivity

by Joseph B. Lambert

Chemists had quite remarkable insights about the shapes of molecules many years before the electronic theory of matter was fully developed by physicists. In 1865 Friedrich August Kekulé had the inspired idea that the six carbon atoms in the benzene molecule (C_6H_6) are joined in a ring. In 1890 Hermann Sachse proposed that the ring of six carbon atoms in cyclohexane, a molecule with six more hydrogen atoms than benzene, would be free of strain if the carbon atoms were located alternately above and below the plane of the ring instead of being located in the plane itself. Such a structure has the appearance of a reclining chair. Because the benzene ring has double bonds between alternate pairs of carbon atoms, the atoms are forced to remain in a plane. Sachse's chair hypothesis, and its implications for other organic molecules, was rejected for more than 30 years until physical experiments by Walter Hückel, Jacob Boeseken and Odd Hassel of Norway provided corroboration. Sachse's model was not universally accepted, however, until after 1950, when persuasive chemical evidence in its favor was supplied by Derek H. R. Barton of the Imperial College of Science and Technology. Last month Hassel and Barton received the Nobel prize in chemistry "for their work to develop and apply the concept of conformation in chemistry."

The concept of conformation, or conformational analysis, is concerned with the different three-dimensional forms that can be assumed by certain molecules whose atoms are free to rotate around one or more bonds. Such interconvertible forms are known as conformational isomers, or conformers, to distinguish them from other isomers in which two or more molecules of the same formula have different three-dimensional structures that are interconvertible only if bonds are broken and reformed. It was Barton more than anyone else who showed that different conformational isomers can exhibit distinctly different chemical reactivities. In the past 20 years conformational analysis has been invaluable in the synthesis of pharmacological agents, notably steroids and antibiotics of the tetracycline and penicillin families. In biochemistry conformational analysis is helping to clarify the mechanisms by which enzymes promote chemical reactions in the living cell.

Some Simple Hydrocarbons

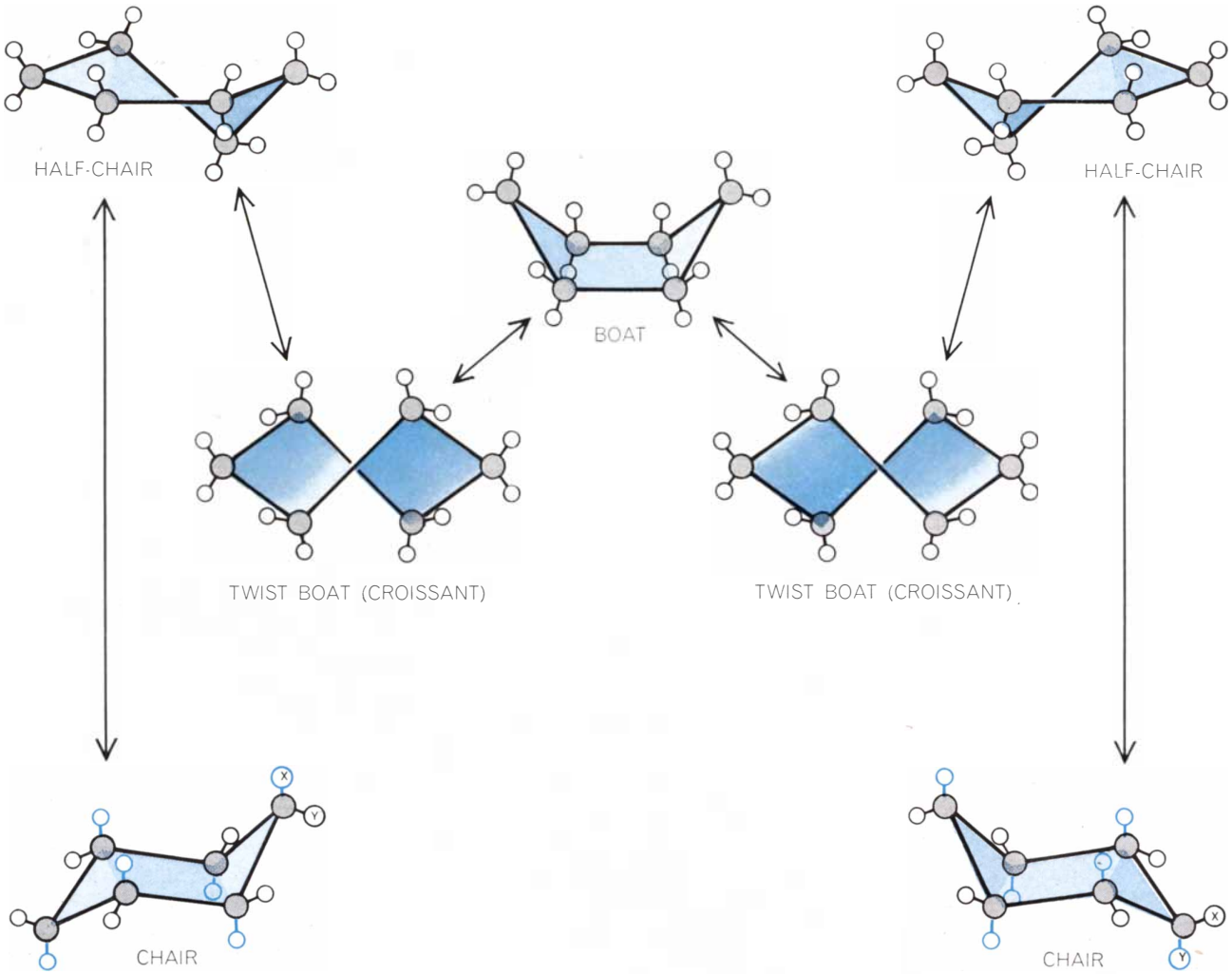
The principles of conformational analysis can be illustrated by describing the structures of several simple carbon-containing compounds. In methane (CH_4) each hydrogen atom is singly bonded to a central carbon atom and the four hydrogens form the corners of a tetrahedron. The angle formed by the C–H bonds between any two adjacent hydrogen atoms is 109.5 degrees [*see illustration on page 61*]. Since this tetrahedral shape is inflexible, methane has no conformational isomers. In ethylene (C_2H_4) the two carbon atoms are connected by a double bond, and two hydrogen atoms are bonded to each carbon in such a way that the structure is rigid and completely planar, or flat. Again no conformers are possible.

Now let us replace one hydrogen atom on each carbon atom of ethylene by a methyl group (CH_3), thus creating the hydrocarbon called 2-butene (CH_3–CH=CH–CH_3). Two different forms of 2-butene can exist: in one the methyl groups are both on the same side of the molecule (the *cis* form) and in the other the methyls are on opposite sides (the *trans* form). Rotation is not possible around the rigid double bond that connects the central carbon atoms. Interconversion of the *cis* and *trans* isomers of 2-butene requires breaking the double bond, rotating one of the methyl groups 180 degrees around the residual single bond and re-forming the double bond. Since conformers must be interconvertible without breaking bonds, *cis*- and *trans*-2-butene do not qualify. Isomers that require bond breakage for interconversion are termed geometrical isomers.

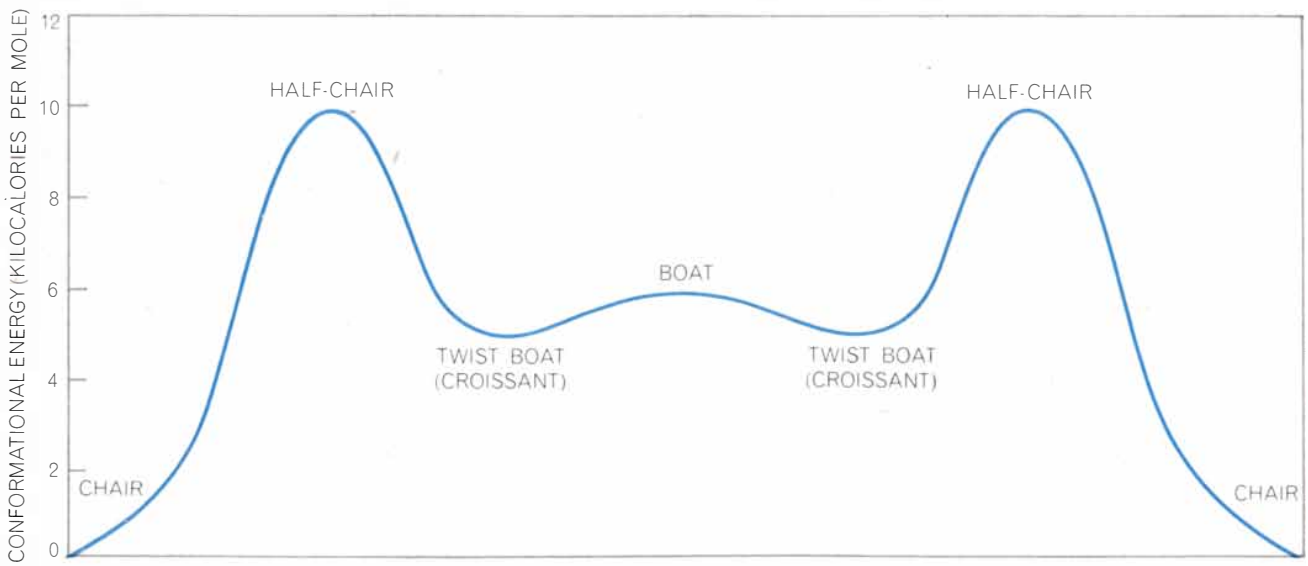
Ethane (C_2H_6) is the simplest hydrocarbon that exhibits conformational isomerism. The two carbon atoms are connected by a single bond and each carbon is bonded tetrahedrally to three hydrogen atoms. In other words, the molecule consists of two methyl groups linked by a carbon-carbon single bond, around which rotation is allowed and does occur. The methyl groups thus resemble propellers rotating in a well-understood and definable fashion. A view along the carbon-carbon bond, known as the Newman projection, clearly reveals the conformational isomers [*see illustration on page 61*]. At one instant the hydrogen atoms on the front carbon eclipse those on the back. At another instant each front hydrogen falls midway between two rear hydrogens. These "eclipsed" and "staggered" arrangements in ethane are conformational isomers. Nearly all the principles of conformational analysis can be illustrated by ethane and its derivatives.

Molecules that Rotate

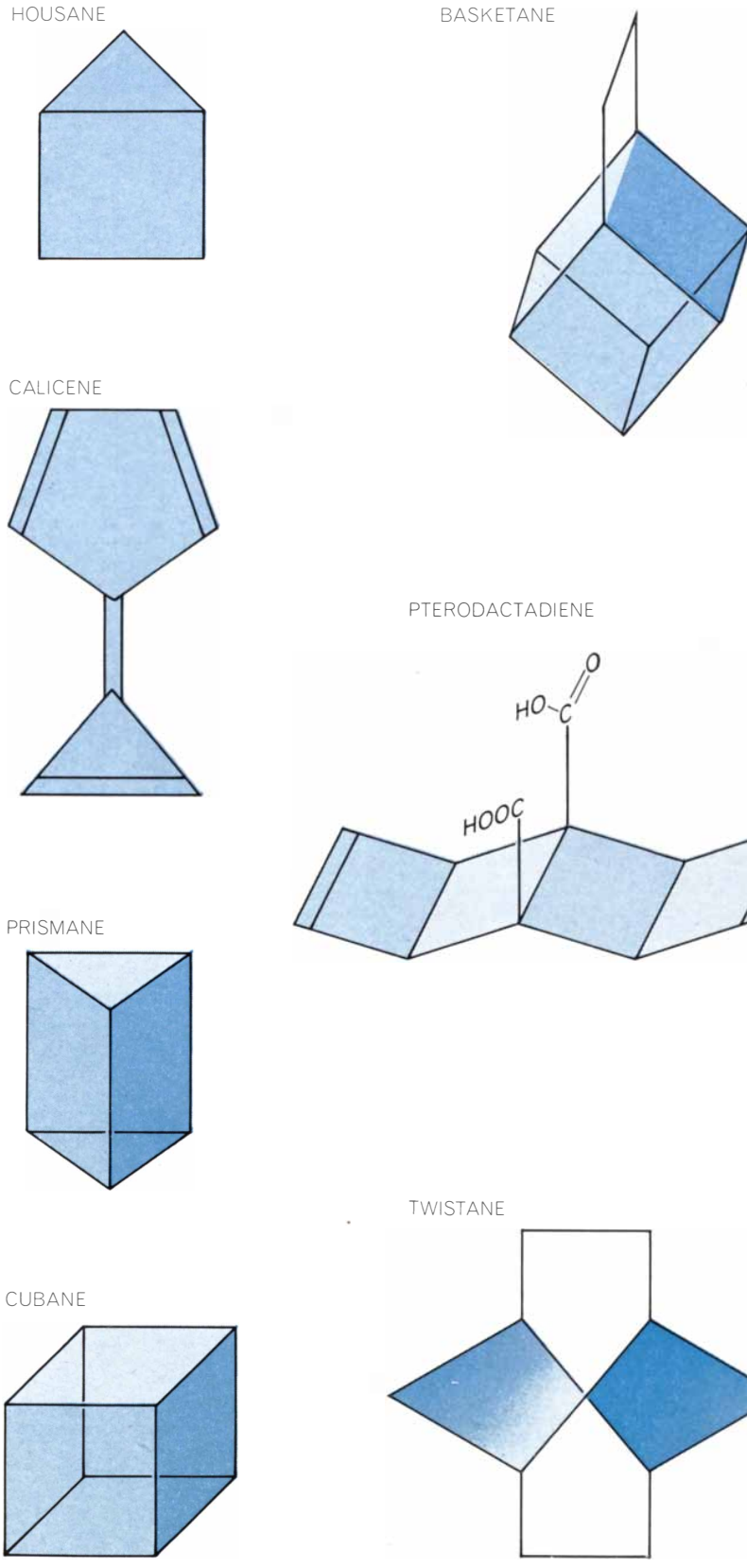
Until about 1935 it was thought that all rotational forms of ethane—eclipsed, staggered and intermediate—occurred with equal probability, implying that all possessed equal energy. From the work of Edward Teller, Kenneth S. Pitzer and others it became evident, however, that the staggered conformation has the least potential energy and therefore is the



SIX-MEMBER RING OF CYCLOHEXANE, C_6H_{12}, can exist in various shapes known as conformational isomers, or conformers. The most stable conformers are the chairs; the least stable are the half-chairs (*see energy diagram below*). The hydrogen atoms in the molecule can assume two distinguishable positions: "axial," when they are more or less perpendicular to the average plane of the ring; "equatorial," when they lie close to the plane. When the chair flips from one conformation to its mirror image, axial hydrogens become equatorial and vice versa. This reversal is shown for two atoms, *X* and *Y*. In the chairs axial atoms are shown in color.



INVERSION OF CYCLOHEXANE takes place through a sequence of ring distortions involving a spectrum of energy states. At room temperature the molecule flips back and forth between the two stable chair conformations. The boat conformers are quasi-stable.



DESCRIPTIVE AND HUMOROUS NAMES have been assigned to the structures of some recently synthesized organic compounds. The straight lines represent bonds between carbon atoms, which form the corners and intersections of the figures. Each carbon atom is assumed to have enough hydrogen atoms attached to it to satisfy any of its four valence bonds that are not linked to another carbon atom; thus housane would have eight hydrogens. Calicene looks like a chalice (*calix* in Latin). In pterodactadiene carboxyl groups form the "head" and the "tail" of a structure that resembles a prehistoric winged reptile, the pterodactyl.

most stable. As the hydrogen atoms move closer to the eclipsed conformation there is an increase in the repulsion between atoms and in other energy factors. The eclipsed form thus represents an unstable energy maximum [*see top illustration on page 62*]. Since a given hydrogen atom must pass three opposing hydrogen atoms in making a full 360-degree revolution, the energy barrier is said to be threefold. It follows that there are three distinct but energetically identical conformations, since any hydrogen atom can be staggered between three different pairs of opposing hydrogens. The increase in energy of the eclipsed forms is referred to as Pitzer strain.

A molecule with a similar but slightly more complex set of conformations is *n*-butane (CH_3–CH_2–CH_2–CH_3), which can be formed by adding two atoms of hydrogen to replace the double bond of either *cis*- or *trans*-2-butene. Rotation around the resulting carbon-carbon single bond (–CH_2–CH_2–) produces different conformational isomers [*see bottom illustration on page 62*]. The conformer of highest energy results when the two methyl groups eclipse each other. When the methyls are staggered 60 degrees apart, the energy drops to a certain minimum (not the lowest one), producing a stable conformer called the *gauche* isomer. When the methyl groups eclipse hydrogen atoms, the energy rises and the conformer is again unstable. The minimum of lowest energy and the most stable arrangement result when the methyl groups are 180 degrees apart, an arrangement called the *anti* isomer. Thus in a 360-degree circuit stable conformations are produced when the angles between one methyl group (imagined as being fixed at 0 degrees) and the second methyl group (imagined as being in rotation) are 60, 180 and 300 degrees. At room temperature about 80 percent of *n*-butane is in the 180-degree, or *anti*, conformation. The remaining 20 percent is divided between the two equivalent *gauche* conformers in which the methyls are 60 or 300 degrees apart.

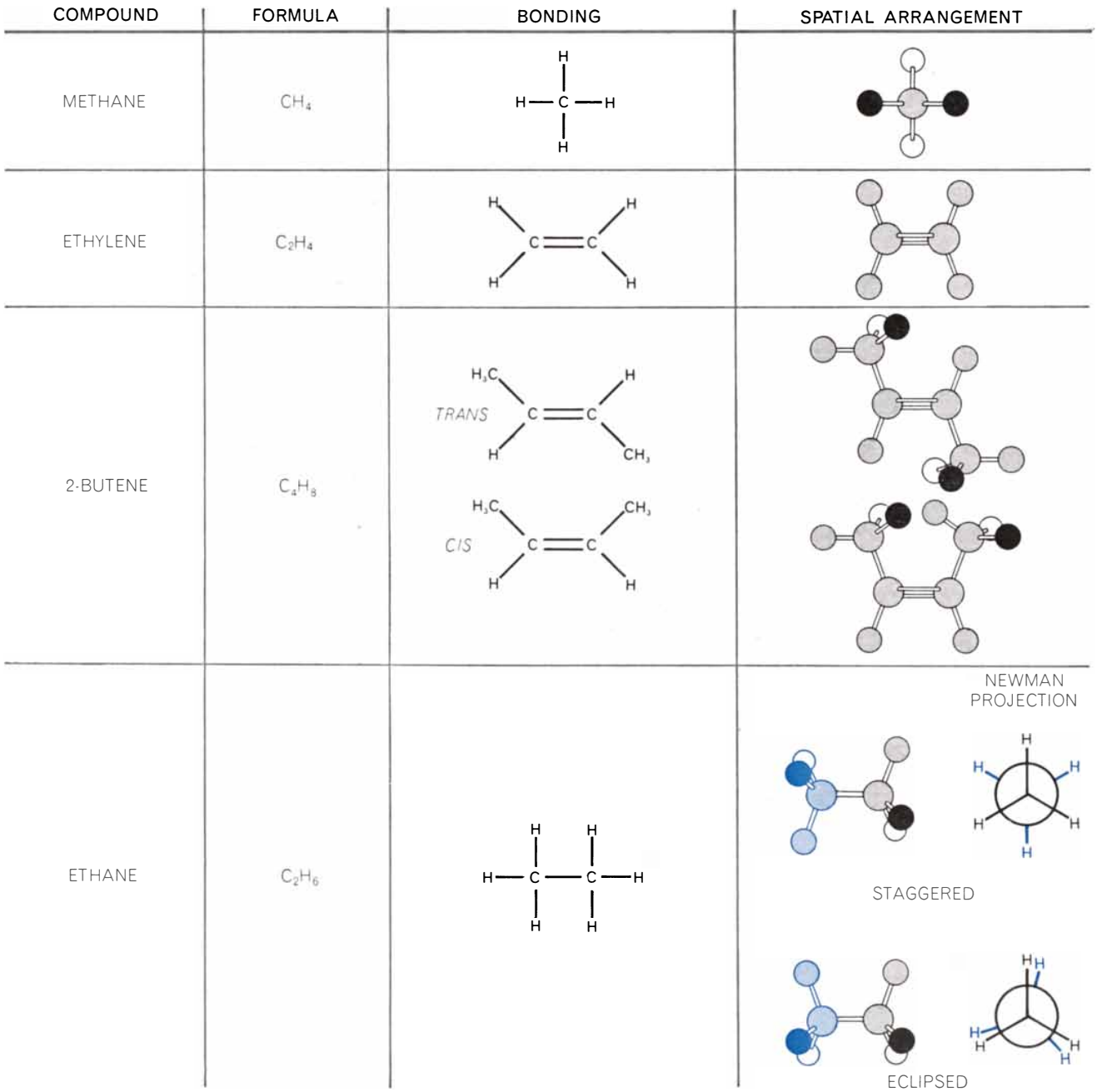
What no one fully appreciated before the work of Barton and others is that there is a powerful relation between conformational arrangement and chemical reactivity. For example, if one of the hydrogen atoms is removed from the second carbon in *n*-butane and replaced by bromine (Br), the resulting compound is 2-bromobutane (CH_3–$CHBr$–CH_2–CH_3), which yields the same variety of conformational isomers as *n*-butane. One way to prepare *cis*- and *trans*-2-butene is to remove hydrogen bromide (HBr) from the central carbon atoms of 2-bromobu-

tane. HBr is most easily removed when the hydrogen and bromine atoms are 180 degrees apart [*see illustration on page 63*]. When the methyl group rather than a hydrogen atom is *anti* to the bromine, the molecule is "sterile": HBr cannot be removed. When the methyl groups are *anti* to each other, removal of HBr yields *trans*-2-butene; when the methyls are 60 degrees apart (*gauche*), the reaction yields *cis*-2-butene. Thus each stable conformational isomer has its own distinctive reaction path: one leads to the *trans* product, one to the *cis* product and one to no reaction at all.

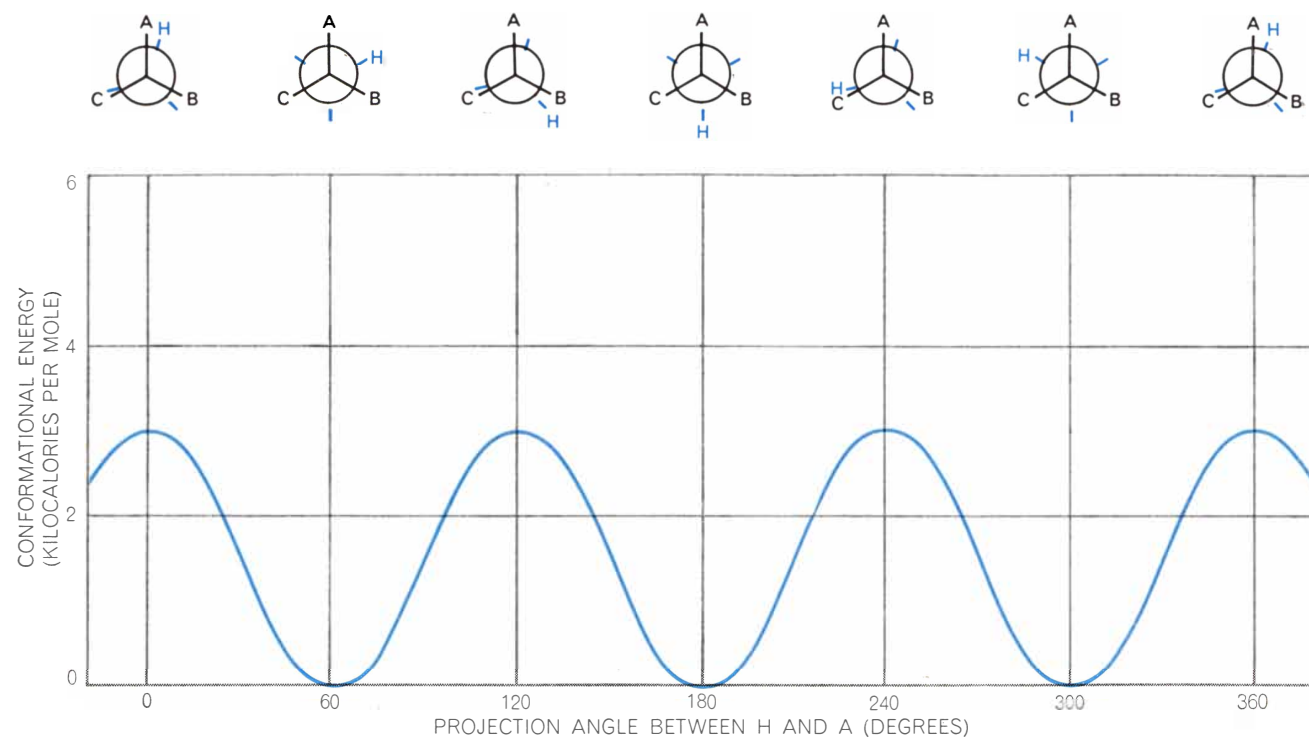
Carbon Atoms in Rings

The chemistry of carbon compounds, historically referred to as organic chemistry, owes its complexity to the remarkable stability of the carbon-carbon bond. Carbon chains, both straight and branched, can be constructed in a seemingly infinite variety of lengths and patterns. Regardless of length or pattern, however, the conformational properties of a particular bond will be determined by the principles described above.

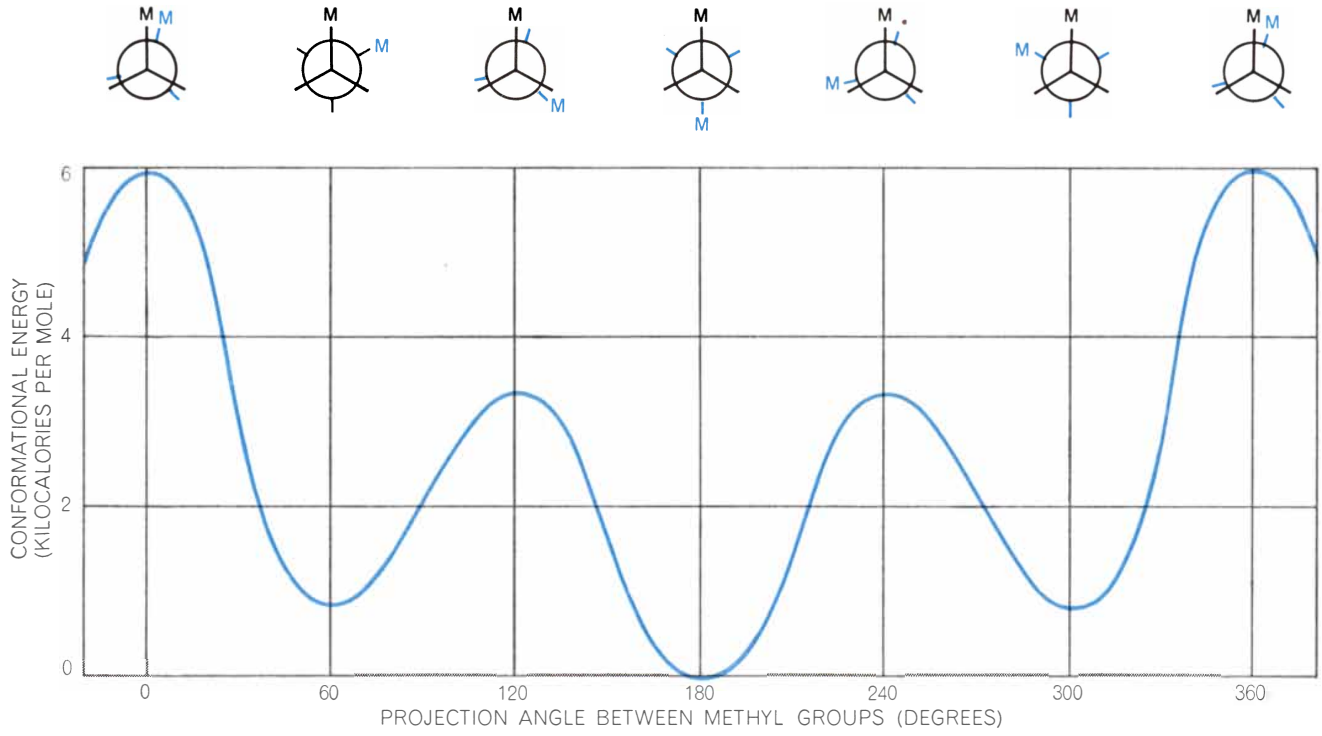
Let us now see what these principles



RIGID AND FLEXIBLE MOLECULES are represented by four simple hydrocarbon compounds. In methane the atoms form a rigid tetrahedron; the angle between any two hydrogen atoms, with carbon at the vertex, is 109.5 degrees. In more complex hydrocarbons, particularly ring structures, this angle often cannot be conserved, producing what is called Baeyer strain. Ethylene also has a rigid structure, but all its atoms lie in a plane. In 2-butene there are two rigid arrangements: the *cis* form, in which both methyl (CH_3) groups lie on the same side of the double bond, and the *trans* form, in which they lie on opposite sides. To interconvert these two forms the double bond must be broken and rejoined, hence they are defined as geometrical isomers. In contrast, ethane has a continuous set of conformational isomers, produced by simple bond rotation. At one extreme the hydrogen atoms are staggered 60 degrees; at the other extreme they are "eclipsed," or in line, as represented in the "Newman projections" at the lower right.



ENERGY OF ETHANE CONFORMERS traces out a simple sine curve when the front carbon atom and its three hydrogen atoms (*A, B, C*) are assumed to be stationary while the rear carbon atom and its hydrogens execute a 360-degree clockwise rotation. During this journey the molecule alternates between eclipsed states of high energy and staggered states of low energy. A given rear hydrogen (*H*) passes through three stable conformations at 60, 180 and 300 degrees that are spatially different but energetically equivalent.



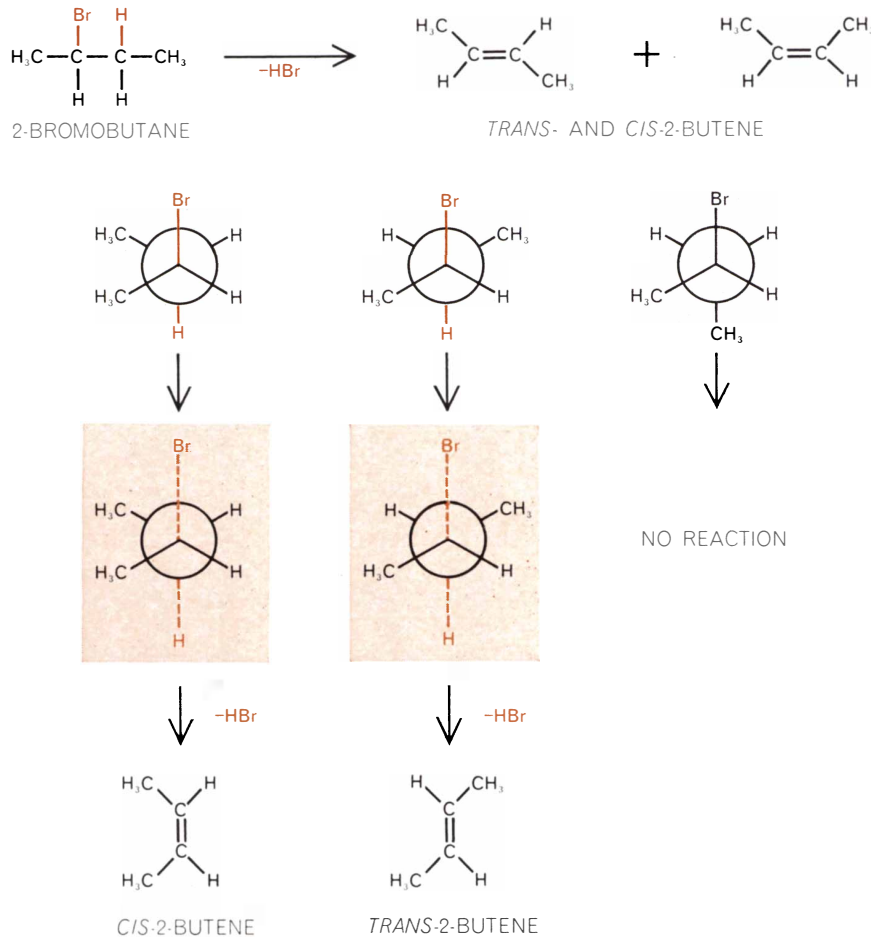
ENERGY OF *N*-BUTANE CONFORMERS traces out a curve similar to that for ethane. The molecule of *n*, or normal, butane (C_4H_{10}) can be thought of as a molecule of ethane in which one hydrogen atom on each carbon has been replaced by a methyl (CH_3) group. These groups are represented by the two *M*'s in the Newman projections. The stable conformation at 180 degrees is called the *anti* arrangement because the two methyls are antipodal. The slightly more energetic, and thus less stable, conformations at 60 and 300 degrees are termed *gauche*. In the *gauche* arrangements the methyl groups are closer together and consequently interfere with each other more than in the stable *anti* arrangement. Maximum steric interference occurs when the two methyl groups are fully eclipsed.

imply when a carbon chain is formed into a ring. The smallest and simplest ring is cyclopropane (C_3H_6), in which three carbon atoms form the corners of an equilateral triangle [*see top diagram in illustration on next page*]. The 60-degree angle between adjacent carbon atoms is far from the preferred angle of 109.5 degrees. For this reason the molecule, as Adolf von Baeyer was the first to perceive, is under considerable strain. Furthermore, when the hydrogen atoms are viewed down any carbon-carbon bond, they eclipse one another all around the ring. In spite of the strain in the cyclopropane ring, it is so rigid that no conformational isomers can exist.

The four-member analogue of this system, cyclobutane (C_4H_8), has a lesser amount of "Baeyer strain" between adjacent carbon atoms because they form 90-degree angles. Furthermore, the Pitzer, or eclipsing, strain can be relieved by deformations in the ring [*see middle diagram in illustration on next page*]. In the most stable arrangement opposite pairs of carbon atoms lie either above or below a plane containing the other pair. Between these stable extremes there is a continuum of unstable conformational isomers.

In the five-member system, cyclopentane (C_5H_{10}), the angle at each corner of the pentagon would be 108 degrees if the molecule were planar. Although almost no Baeyer strain would exist in the planar state, there would be strong eclipsing interactions among the subtended hydrogen atoms. If a single carbon atom, with its two hydrogens, is lifted out of the plane, only two pairs of hydrogen atoms remain eclipsed [*see bottom diagram in illustration on next page*]. This distortion travels around the ring like a wave, so that each carbon atom is out of the plane a fifth of the time, thereby equalizing the strain throughout the ring.

We come now to the important six-member system, cyclohexane (C_6H_{12}), which, as Sachse suspected long ago, is distinctly nonplanar. If the carbon atoms in cyclohexane were forced to lie in a plane, they would form a simple hexagon with bond angles of 120 degrees; the Baeyer strain would be considerable. There would also be strong eclipsing interactions among hydrogens on the ring. Sachse pointed out that strainless bond angles of 109.5 degrees would result if the carbon atoms were in alternate positions above and below the plane of the ring. Moreover, the hydrogen atoms would be staggered and thus would not eclipse one another [*see top illustration on page 59*]. Such a chair conformation should be free of both Baeyer (angle) strain and Pitzer (eclipsing) strain.



ACTIVE AND INERT CONFORMERS are illustrated by 2-bromobutane, a molecule of *n*-butane in which a bromine atom replaces a hydrogen atom on one of the interior carbon atoms. When 2-bromobutane reacts with a base such as potassium hydroxide, a molecule of hydrogen bromide (HBr) is removed, forming *cis*- and *trans*-2-butene. It turns out that for the reaction to take place the departing bromine and hydrogen must be opposite each other. One of three stable conformers, the one at the far right in the Newman projections, does not meet this requirement, so that it is unreactive. When the two methyls are *gauche* (*diagram at left*), the reaction yields *cis*-2-butene. When the methyls are *anti* (*middle*), the product is *trans*-2-butene. The structures in the colored panels represent transition states in which the bonds to the bromine atom and the opposite hydrogen have weakened, prior to breaking.

Why did Sachse's plausible model meet with so much resistance from chemists? In the presumed planar form all the hydrogens in cyclohexane are chemically and physically indistinguishable. In Sachse's chair arrangement, however, there should be two different types of hydrogens. Half of the 12 hydrogen atoms should extend directly up and down from the average plane of the chair; the other half should lie more or less in the plane. The former hydrogens are termed axial, the latter equatorial. Each carbon atom should therefore be bonded to one axial hydrogen atom and one equatorial hydrogen atom. If another atom, such as chlorine or bromine, replaced a hydrogen atom, two isomers should be possible: one with the replacement-atom axial, the other with it equatorial. Chemists were unable to find the two isomers.

The reason is now understood. Sachse himself described a second conformation of cyclohexane, the "boat conformation," that is free of angle strain but not of eclipsing strain. It is obtained conceptually by forcing the carbon atom that forms either the head or the foot of the chair to flip to the other side of the plane of the molecule. The chair can be re-created by performing the same operation on the carbon atom directly opposite to the first. When the original chair is inverted in this manner, all the hydrogen atoms that were axial in the first conformation become equatorial, and all the equatorial hydrogen atoms become axial. At ordinary temperatures

cyclohexane chairs invert so rapidly that one cannot replace a hydrogen atom with, say, chlorine and hope to isolate two different isomers. Nonetheless, a few years ago, by working at very low temperatures, Frederick R. Jensen and his co-workers at the University of California at Berkeley succeeded in separating isomers of monochlorocyclohexane in which the chlorine atoms were either axial or equatorial.

Making Isomers Visible

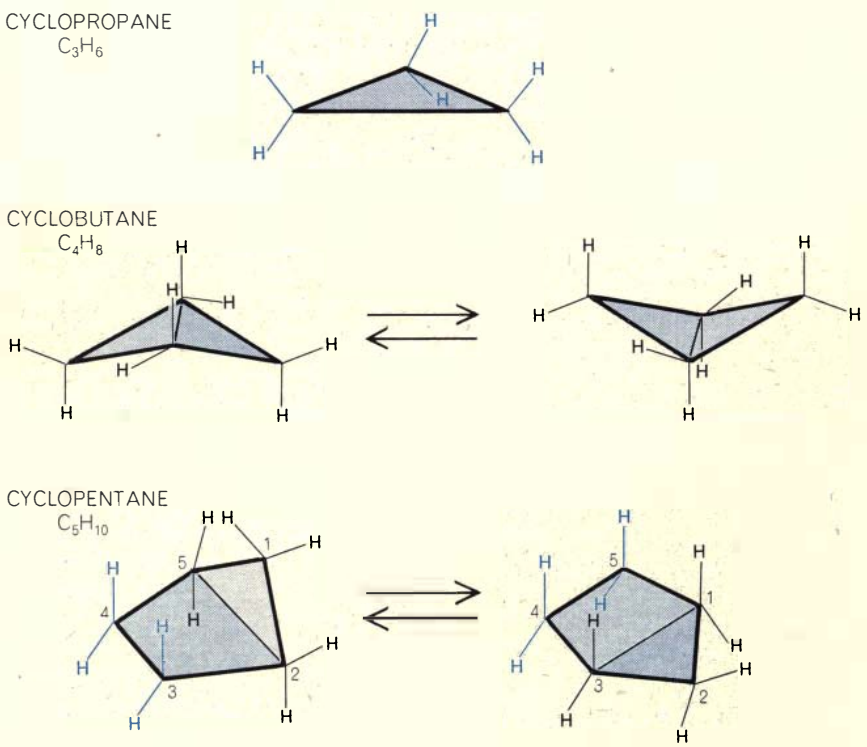
A striking confirmation of the existence and interconversion of the axial and equatorial positions in cyclohexane has been provided by nuclear magnetic resonance (NMR) spectroscopy. During the past decade NMR has emerged as the organic chemist's most valuable tool for conformational analysis. Theoretically each chemically distinct hydrogen atom resonates at a different natural frequency. The frequency of the signal varies with the structural environment of the hydrogen atom; the strength of the signal varies with the total number of hydrogen atoms of a given chemical type in the molecule. As the spectrum is usually recorded, peaks correspond to resonances. Thus methane produces an NMR spectrum with only one peak because the four hydrogen atoms are indistinguishable. Ethane and ethylene also produce spectra with one peak, but the spectrum of *cis*-2-butene has two peaks: one large peak for the six hydrogen atoms that belong to methyl groups and a peak one-third as large for the two hydrogens attached to the carbon atoms joined by a double bond.

One would expect the NMR spectrum of cyclohexane to exhibit two peaks of equal size, one for the six axial hydrogens and one for the six equatorial hydrogens. At room temperature, however, the spectrum shows only one large peak. This observation implies that the molecular chair is inverting so rapidly that the spectrometer can record only the average signal from the two kinds of hydrogen atom. As the temperature is lowered, however, the single peak broadens and finally splits into two distinct peaks, each half the height of the original peak [*see illustration on opposite page*]. The two peaks correspond to the axial and equatorial hydrogen atoms in a ring that no longer appears to be inverting. When the NMR technique is used to look for the conformational isomers of cyclopentane and cyclobutane, one finds that the warping motions are so rapid that both compounds give only one sharp peak even at extremely low temperatures.

Although NMR spectroscopy clearly shows that at room temperature and above cyclohexane exists in a rapidly flipping chair conformation, neither NMR nor any other technique has demonstrated the presence of the boat conformation. Evidence for its being an intermediate during ring inversion is mainly presumptive. Because of eclipsing strain the boat conformers have more energy and therefore are less stable than the chair [*see bottom illustration on page 59*]. Some strain can be released if the eclipsed hydrogens are twisted away from one another. A slightly more stable form of cyclohexane known as the twist boat (or, in French terminology, the *croissant*) is thereby produced. The molecule twistane, for example, was synthesized specifically because it incorporates the structure of the twist boat, held in position by carbon-carbon bridges [*see illustration on page 60*]. This flexing motion that relieves eclipsing strain can be carried around the ring so that each carbon atom in turn serves as the bow or the stern of a boat. Thus when discussing cyclohexane conformers, it is more appropriate to speak of the flexible boat family—even of the conformational fleet—than of a single boat-shaped conformer, since so many nearly equivalent forms are interconverting.

When one or more hydrogen atoms of cyclohexane are replaced by a bulky substituent such as a methyl group, one can see more clearly how the occupation of an axial or equatorial position determines the preferred conformation of the molecule. If the methyl group is in the axial position, its hydrogen atoms are so close to nearby axial hydrogens that the hydrogens are unnaturally crowded [*see illustration on page 66*]. In the equatorial position the methyl group has plenty of room. As a result the axial isomer of methylcyclohexane is less stable than the equatorial isomer. At room temperature only about 5 percent of methylcyclohexane is present as the axial isomer. As one can imagine, the size of the substituent determines how much of the compound will be in the axial form or the equatorial one.

Let us now consider what happens when cyclohexane is modified so that



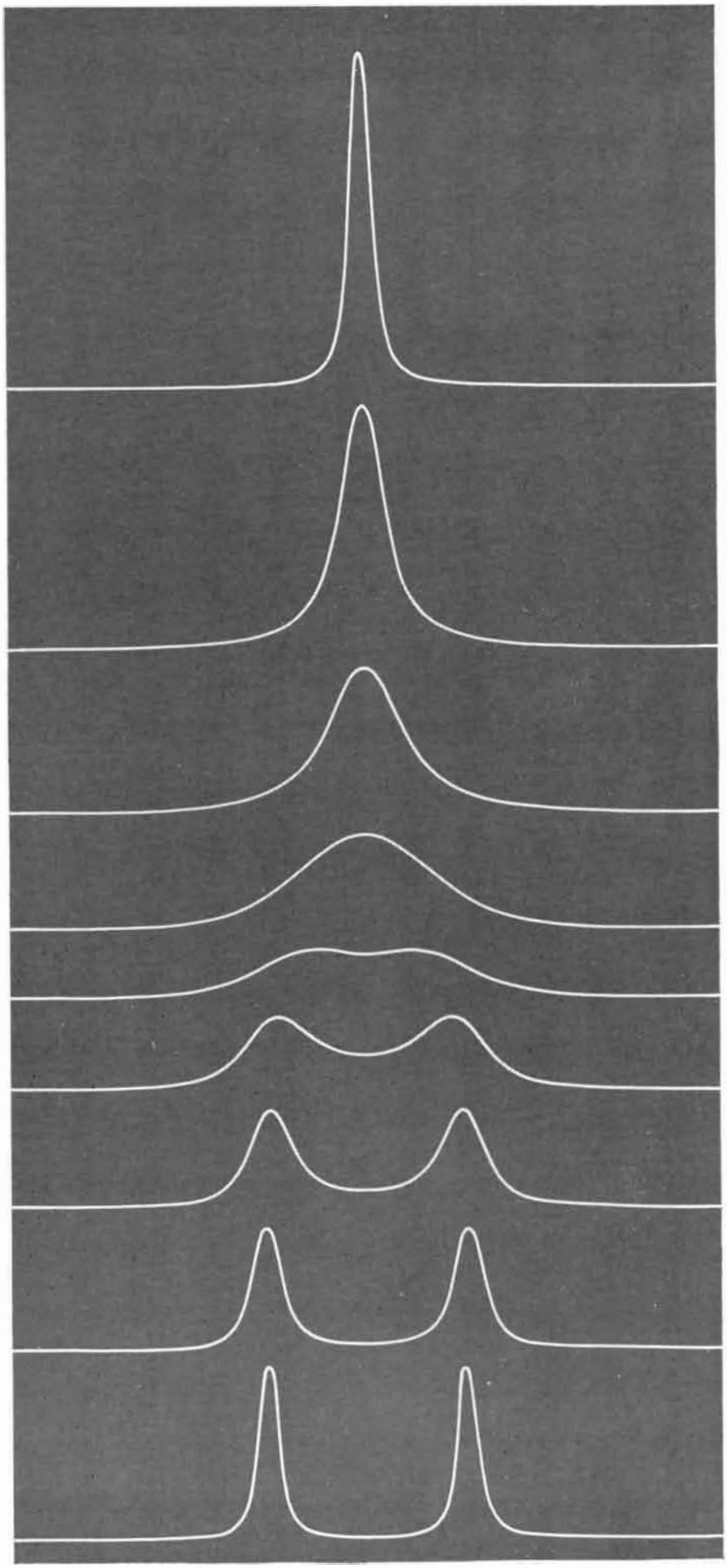
CYCLIC COMPOUNDS form a general class in which conformational isomerism is important. Cyclopropane, held rigid hy geometrical constraints, is an exception. Its carbon-carbon bonds are under high Baeyer strain and the hydrogen atoms eclipse one another all around the ring. Eclipsed hydrogens are shown in color. In cyclobutane Baeyer strain is relieved by bending of the ring, which also serves to stagger all the hydrogen atoms. The "creases" in bent rings are shown by thin black lines; they are not bonds. The cyclopentane ring could be planar if Baeyer strain were the only consideration since the angles of a regular pentagon are 108 degrees, which is close to the preferred value of 109.5 degrees. But to relieve the eclipsing strain of hydrogen atoms one corner of the ring is pushed out of the plane so that only four hydrogens eclipse one another. If carbon atom No. 1 points upward at one instant, carbon atom No. 2 points downward the next and so on around the ring.

two hydrogen atoms on adjacent carbon atoms are replaced by two methyl groups; such a compound is 1,2-dimethylcyclohexane. Three distinct arrangements are possible: both methyls can be axial (*ax-ax*), both can be equatorial (*eq-eq*) or one can be in each position (*ax-eq*) [*see illustration on next page*]. Inasmuch as ring inversion exchanges the axial and equatorial positions, the *ax-ax* and *eq-eq* isomers must be interconvertible; similarly, the *ax-eq* isomer must interconvert with an equivalent *eq-ax* isomer.

The *eq-eq* and *ax-ax* isomers are commonly referred to as *trans* isomers because in each case one methyl group points down from the plane of the ring and the other points up. The *ax-eq* and *eq-ax* isomers are *cis* because both methyls point to the same side of the plane. The *ax-ax* form of the *trans* isomer must be almost nonexistent because two methyls in the axial position would be extremely crowded. The *cis* and *trans* forms cannot be converted into each other without breaking and re-forming a carbon-carbon bond; therefore they must be geometrical isomers.

The Multiplicity of Rings

Instead of adding two methyl groups to a cyclohexane ring one can add a complete second ring so that the two rings share a common side. The compound decalin, which is used as a paint and lacquer solvent, is one of the most important examples of a molecule with two rings "fused" in this fashion. From the point of view of each ring the other appears to be a 1,2-disubstituent [*see illustration on page 68*]. If the rings are fused in a *cis* fashion, one bond from each ring is axial and one is equatorial. Of two conceivable *trans* arrangements, *eq-eq* and *ax-ax*, only the former is structurally possible. Because axial-axial bonds point 180 degrees away from each other it is physically impossible to bridge them with only four carbon atoms (the four that complete the second ring). The rings of *cis*-decalin can invert simul-



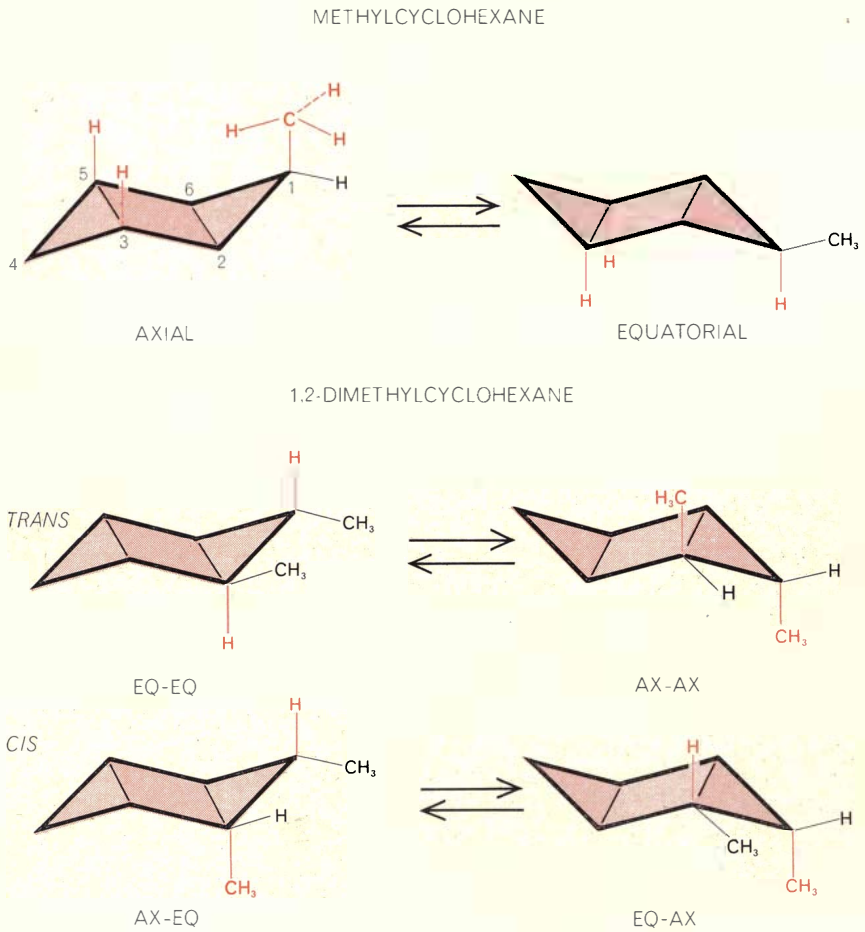
EVIDENCE FOR CHAIR conformation in cyclohexane is supplied by nuclear magnetic resonance (NMR) spectroscopy, which supplies a separate signal for each chemically distinguishable hydrogen atom. The series of curves shows how the inversion rate of the cyclohexane ring slows down as the temperature of the molecule is lowered. Below about −60 degrees Celsius (*bottom curve*) the distinct axial and equatorial hydrogen atoms produce two very sharp peaks.

taneously to give an identical conformer in which the axial-equatorial roles of the substituent positions are reversed.

In principle it is possible to keep fusing ring on ring indefinitely. Anthracene, a well-known coal-tar derivative, consists of a sequence of three rings in a row. Because the rings in anthracene possess alternating double and single bonds, as in the benzene ring, the three rings are forced to remain in a plane. If, however, all the double bonds are hydrogenated, producing what is called a saturated molecule, the resulting three-ring product is perhydroanthracene, a molecule that has five principal conformational isomers. The most stable is the one in which all the fusion bonds are equatorial so that the structure is *trans-trans* [*see illustration on page 68*].

If the third ring is offset from the axis of the first two rings, in which case the points of fusion are adjacent to the carbons that join the first and second ring, the skeleton of perhydrophenanthrene is produced. Again the all-equatorial, or *trans-trans,* arrangement of bonds is the most stable. If a cyclopentane ring is added to the offset ring of the perhydrophenanthrene skeleton, one obtains perhydrocyclopentanophenanthrene, the skeleton of a family of important biological substances: the steroids. The four rings are labeled *A, B, C* and *D,* with *A* representing the six-member ring most distant from the five-member ring, which is *D.* Although many geometries of ring fusion are possible in steroids, the linkage is invariably *trans* between the *B* and *C* rings and usually *trans* between the *C* and *D* rings. The steroids are such an important class of compounds that an enormous amount of study has been devoted to them in the past 50 years. They include such natural products as cholesterol, the sex hormones, cortisone and the related adrenocortical hormones, and recently an entire family of synthetic birth-control substances.

Although rings of more than six members are common in organic chemistry, not much is known about their conformational characteristics. It is known, however, that the saturated seven-member rings resemble cyclopentane and the boat family of cyclohexane in their flexibility. The properties of larger rings will undoubtedly be closely examined during the next few years.



INTERCONVERTING ISOMERS are produced when one or more methyl groups are substituted for hydrogen atoms in cyclohexane. In methylcyclohexane an axial methyl group on carbon No. 1 is crowded by axial hydrogens on carbon No. 3 and No. 5. Thus the conformer with the methyl in the equatorial position is favored. When there are two methyl groups on adjacent carbon atoms (1,2-dimethylcyclohexane), three arrangements are possible. The *trans* geometrical isomer consists of two conformational isomers, one with both methyls equatorial (*eq-eq*) and one with both axial (*ax-ax*). Only one arrangement is possible for the *cis* isomer: *ax-eq*. Ring inversion yields an identical substitution pattern (*eq-ax*).

Some Modified Chairs

The cyclohexane chair is frequently modified when one of the carbon atoms in the ring is replaced by the atom of another element or when various substituents are added to the ring. In general one can expect the altered molecule to assume a spatial arrangement that will minimize steric interactions, that is, to adopt the "most comfortable" shape. A series of modified cyclohexane structures is illustrated on page 70.

When one of the carbon atoms is replaced by oxygen, the resulting structure, tetrahydropyran, is the basis for a large class of sugars. In the most common hexose sugar, *β-D*-glucose, four of the carbon atoms in the ring carry a hydroxyl (OH) group in place of one hydrogen and the fifth carbon carries a hydroxymethyl (CH_2OH) group. The chair is very little distorted, and all the substituents are equatorial. The abundance of *β-D*-glucose is undoubtedly due to its conformational stability. The shapes of sugar molecules were among the earliest subjects of conformational analysis; in fact, Norman Haworth first defined "conformation" as it is used today in his 1929 book on sugars.

Another "heteroatom" that creates little distortion in the cyclohexane ring is nitrogen. When a CH_2 unit is replaced by NH, the resulting structure is the piperidine ring, found in most alkaloids, a large class of polycyclic compounds that includes morphine, lysergic acid, strychnine and codeine. The piperidine chair inverts so rapidly that the H of the NH group flips continuously from equatorial to axial. At room temperature the axial and equatorial conformers are present in almost equal amounts.

When a sulfur atom rather than an oxygen or nitrogen atom is inserted in the cyclohexane ring, producing thiane, the chair is significantly distorted because the carbon-sulfur bond is appre-

Impact Energy Absorption by Polymeric Foams—an Analytic Approach

Polymer foams are important energy absorbing materials largely because control of the load-compression response can be effected through variations in cell-geometry, density and matrix polymer. Analytical techniques—supplanting trial-and-error procedures—now make it possible to delineate precise relationships between these critical foam parameters and energy absorption characteristics. The unifying approach developed in this way permits convenient comparison of widely different polymer systems and structures.

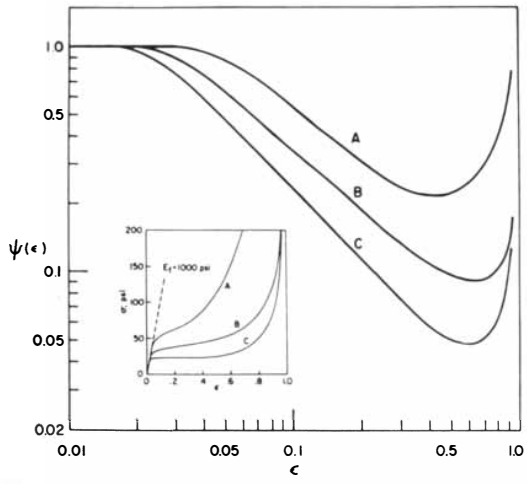


Fig. 1—Experimentally evaluated $\psi(\ )$ functions for three low density ($\varphi \simeq 0.03$) rigid foams; the original compressive stress-strain data are displayed as an insert, where the compressive stress is reduced by a constant factor so that the initial slope is 1000 psi for each curve.

Using classical laws of motion, the energy absorption characteristics are calculated from experimental compressive stress-strain data, σ-ϵ, and expressed in terms of three dimensionless quantities: K, the energy absorbing efficiency; I, the impact-energy per unit volume divided by E_f, the apparent foam modulus; and I/K, the maximum decelerating force per unit area divided by E_f.

For this calculation, the compressive stress is expressed as $\sigma = \epsilon E_f \psi(\epsilon)$, where $\psi(\epsilon)$ is an experimentally evaluated dimensionless function of compressive strain, and E_f the initial slope of the σ-ϵ curve. The parameters $\psi(\epsilon)$ and E_f serve to "fingerprint" a given foam, each reflecting different foam characteristics: $\psi(\epsilon)$ measures matrix buckling and is sensitive primarily to cell-geometry and matrix brittleness, while E_f which determines the stiffness of the material depends on the modulus of the matrix polymer and its volume fraction.

Typical $\psi(\epsilon)$ curves of three common rigid polymer foams with varying compression responses are shown in Fig. 1; the original σ-ϵ data are presented as an insert; calculated relationships between the dimensionless quantities are shown in Fig. 2.

For optimum energy absorption, the plateau in the plot of I/K vs I must be wide and flat; the height of the plateau must represent a less-than-damaging force level; and, the plateau must occur at the most probable impact velocity. The shapes of the energy absorption curves depend solely on $\psi(\epsilon)$, whereas their location along the impact-energy (I) axis varies only with E_f and the bulk dimensions of the sample.

This treatment—relating the energy absorption characteristics to foam parameters—reveals in fact that optimum absorption properties are obtained with brittle foams possessing a large cell-size, narrow cell-size distribution, and minimal number of reinforcing membranes between cells.

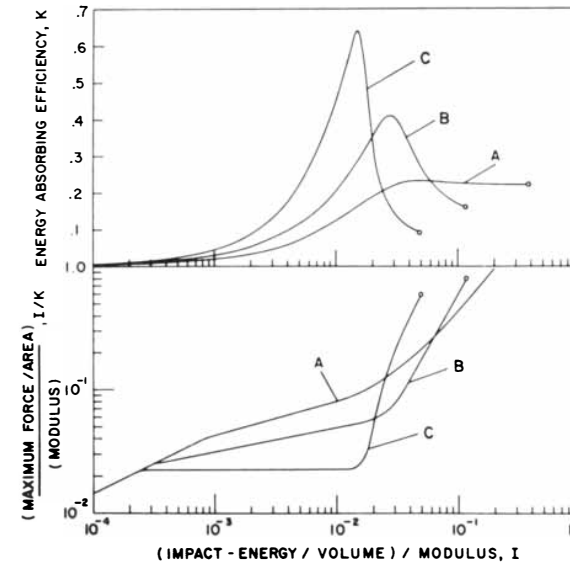


Fig. 2—Characteristic energy absorption curves calculated from the experimental data in Fig. 1; circles on these curves represent the stage at which the foam is completely compressed.

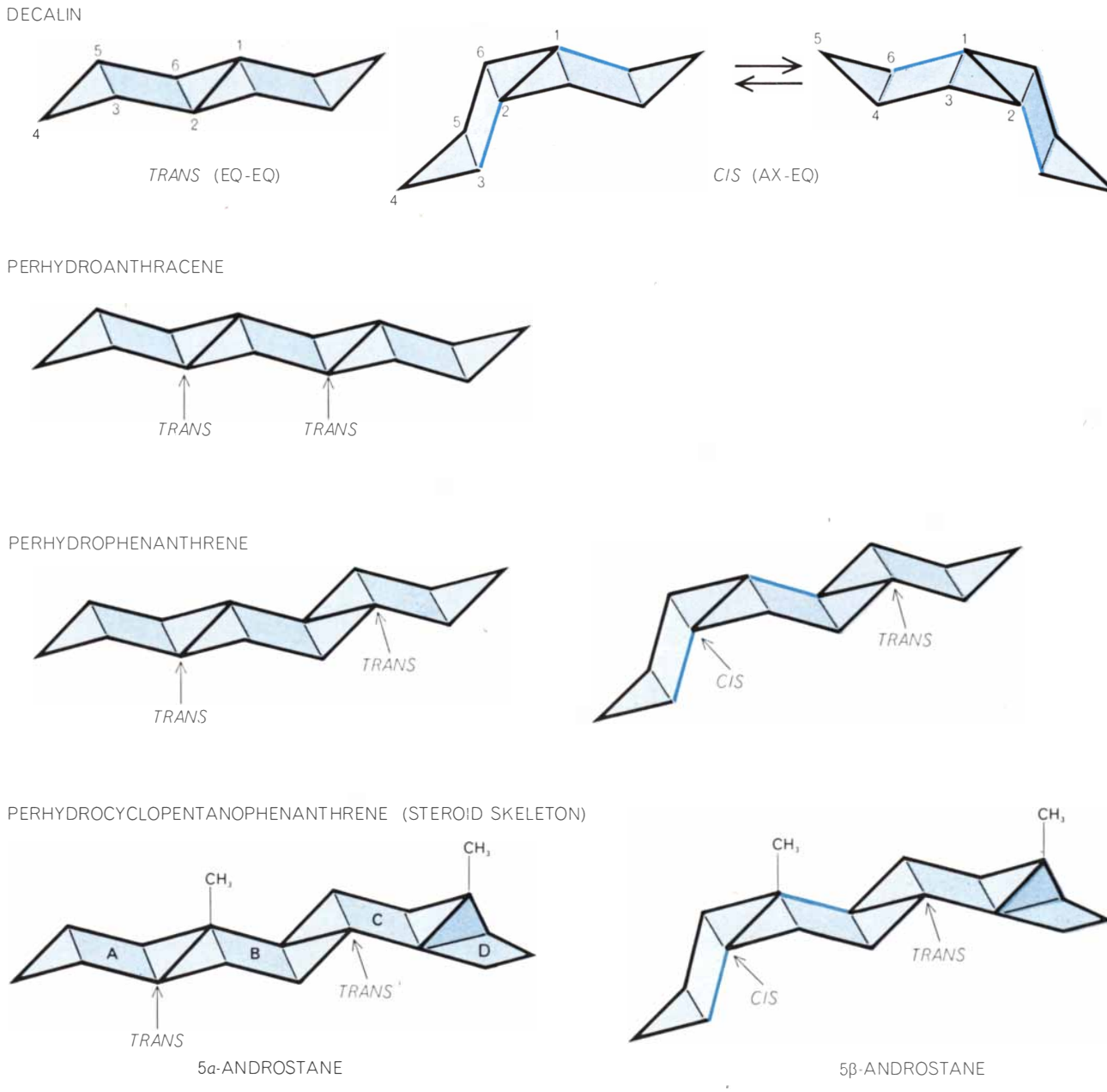
This research represents only one aspect of Ford Motor Company's continuing study of the fundamental properties of matter. It's a small part of our never-ending search for better materials and better devices to help us build the best products possible today.

ciably longer than the carbon-carbon or carbon-nitrogen bond. Moreover, the normal C-S-C angle is close to 90 degrees, rather than 109.5 degrees. As a result the thiane ring is puckered, so that the molecule resembles a beach chair that has been raised from a reclining position to a more upright one.

The reverse distortion, a flattening, takes place when one of the carbon atoms in the cyclohexane ring is doubly bonded to an oxygen atom, forming cyclohexanone. If another oxygen atom is added to the carbon atom at the opposite side of the ring, producing 1,4-cyclohexanedione, one might expect still further flattening to occur. Instead the molecule flips into a twist-boat structure, probably to relieve eclipsing strain that would be present if the molecule were extremely flattened. The half-chair conformation, which corresponds to the state of highest energy in the inversion of cyclohexane, can be achieved as a preferred molecular conformation by removing two hydrogen atoms from adjacent carbon atoms in cyclohexane and joining the carbons by a double bond; the resulting molecule is cyclohexene.

The Conformation of Proteins

Although steroids, alkaloids and sugars are not small molecules, the proteins that, in the form of enzymes, catalyze the most important processes in the living cell are many times larger. Proteins are long chains of the 20-odd different amino acid molecules. The conformation of protein chains depends on complex interactions among the amino acids and on their specific sequence. In many cases the chain first develops a helical structure, and the helix as a whole folds into a conformation that probably minimizes the steric and electrostatic interactions among all the various groups. The final conformation is so important to the molecule's biological function that any alteration in shape may reduce its activity or destroy it altogether. The complete



FUSION OF CYCLOHEXANE RINGS produces complex structures in which the geometry of ring fusion can be either *trans* (*eq-eq*) or *cis* (*ax-eq*). An *ax-ax trans* conformer cannot be built with six-member rings. Axial bonds are shown in color. Perhydroanthracene has four conformers, including one boat, besides the one shown. Perhydrophenanthrene also has four other conformers.

THAT'S OUR BAG.

The Post Office is an $8-billion-a-year business. And we're in it. Working with specialists from the Department, we're designing a prototype post office from the ground up. How come they asked us? Because we've done some unusual things in computer analytical techniques and dynamic modeling. The postal people aren't looking for the tried and true, and we don't intend to give it to them. So it's fresh ideas, bright ideas, that count. The kind that carry the mail speedily through snow, and rain, and sleet, and hail, and gloom...

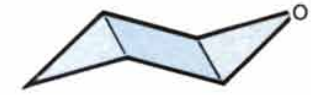
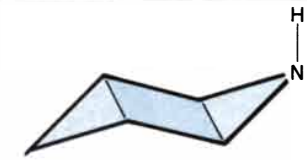
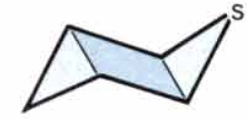
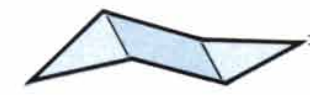
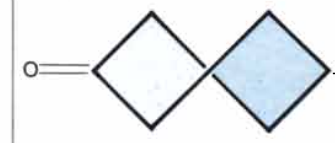
Martin Marietta Aerospace Group. Headquarters: Friendship International Airport, Maryland.

MARTIN MARIETTA

three-dimensional structures of about a dozen proteins have now been worked out by the X-ray-diffraction analysis of proteins in crystalline form. One of the proteins whose structure is known—the enzyme lysozyme—destroys the cell wall of bacteria by cleaving long polysaccharide chains, which consist of many sugar units tied together. For the enzyme to operate on the sugar linkages, one of its tetrahydropyran rings must first flip from its normal chair conformation to a much flattened structure [see "The Three-dimensional Structure of an Enzyme Molecule," by David C. Phillips; SCIENTIFIC AMERICAN, November, 1966].

Flavor chemists of the Monsanto Company have recently proposed a conformational dependence between a particular protein and substances that taste sweet. When the protein combines with "sweet" molecules, its conformation changes; conceivably the change is relayed to the brain as a signal of sweetness. The intensity of the signal may be related to the amount of change.

Presumably DNA, the double-strand helical molecule that embodies the genetic message in living cells, has a structure susceptible to conformational change. One of the greatest mysteries in genetic chemistry is how the DNA helix unwinds so that each strand can act as a template for the construction of a complementary strand of DNA (or for the construction of a strand of messenger RNA, the molecule that directs the synthesis of protein molecules). Rotation around carbon-carbon, carbon-nitrogen and carbon-oxygen bonds must be involved in this elaborate and precise process. A present goal of conformational analysis is a bond-by-bond description of the rotational processes that accompany conformational changes in biochemical systems such as proteins and nucleic acids. Much of the current work of this type is based on X-ray-diffraction studies of crystalline solids. One of the most pressing needs today is for new methods for obtaining structural information about molecules in liquids, the state of matter in which most chemical and biochemical reactions take place.

	DISTORTION	COMPOUND	SHAPE
1	NONE	TETRAHYDROPYRAN	
2	NONE	PIPERIDINE	
3	PUCKERING	THIANE	
4	FLATTENING	CYCLOHEXANONE	
5	TWIST BOAT	1.4-CYCLOHEXANEDIONE	
6	HALF-CHAIR	CYCLOHEXENE	

DISTORTED CHAIRS are often produced when the basic structure of cyclohexane is modified by substituent atoms. The chair may be puckered (3) or flattened (4). Addition of two external oxygen atoms produces a twist boat (5). Removal of two hydrogens creates a double bond, producing a half-chair (6). There is good evidence for all these conformations.

Give them this day their daily bread.

Think of the last time that *you* were hungry. Really hungry. Was it because dinner was late? Or because you missed a lunch?

Can you imagine what it is to go through life never knowing what it is like *not* to be hungry? Subsisting day after day on a few greens around noon... and some pinto beans in the evening? Nothing more. Nothing different. And not even enough of that.

It sounds incredible. And it is incredible. Because it's taking place right now... in the midst of the good life so many of us are now living in America.

But walk down the back roads of most any Mississippi Delta town and you'll see tenant farmers, field hands, seasonal workers ... and their children ... with stomachs bloated, eyes dulled, feet swollen, arms and legs matchstick thin.

The irony is that they aren't starving at a rate dramatic enough to arouse the indignation of the nation and the world. Otherwise something would have already been done.

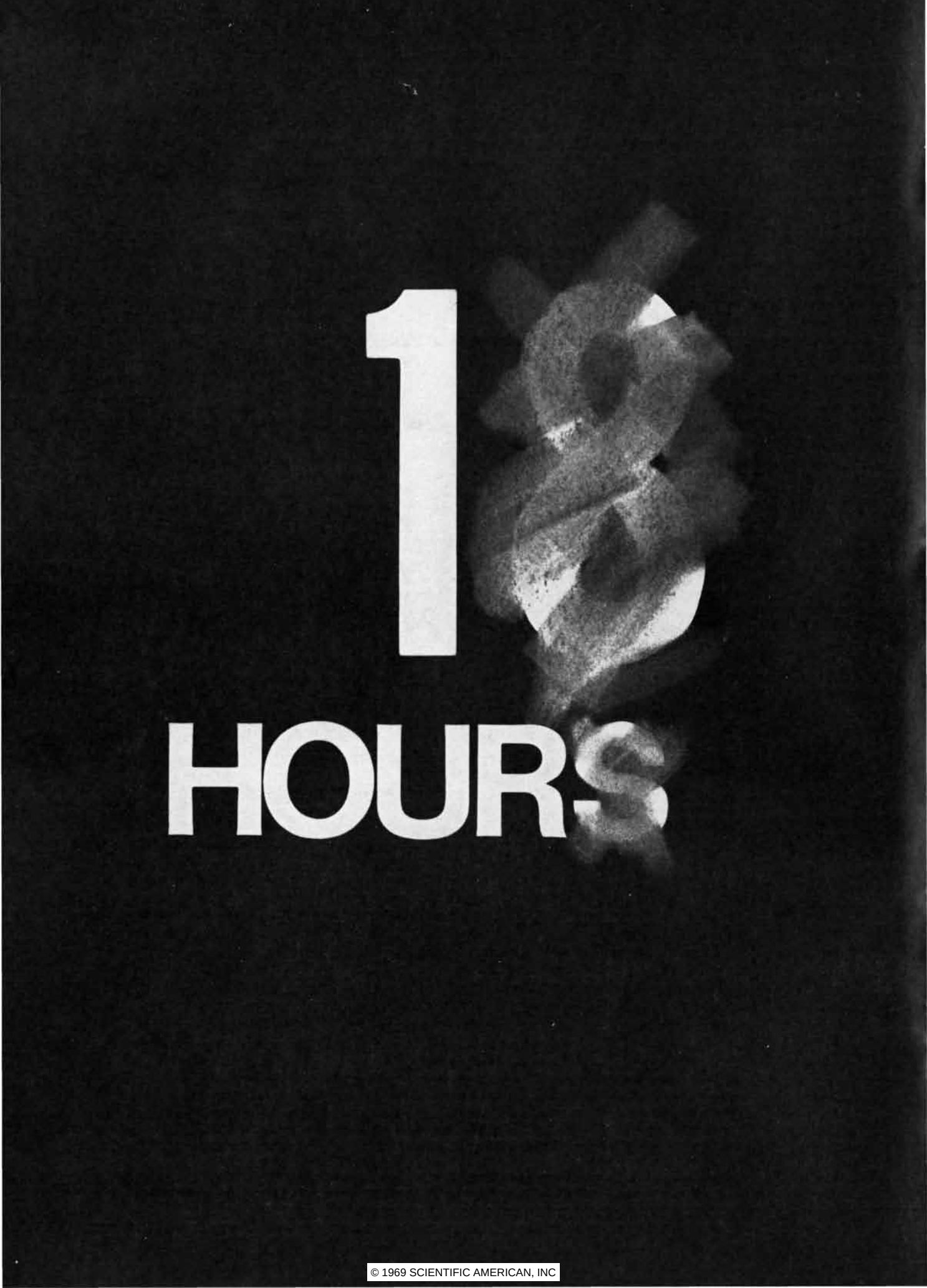
One of the programs that is aiding many of these families is the federally sponsored Food Stamp Plan. Under this plan a needy family can convert a 50¢ food stamp into as much as $12.00 worth of food. The problem is getting that 50¢, because many families have *no* income at all.

The NAACP Special Contribution Fund has begun a nationwide drive to help thousands survive. If you can do with one less "dinner out" this month, the money can mean a month's supply of meat, milk, and bread for a family of five. Just $10.00 buys up to $240.00 in food stamps.

If you would like to contribute to this fund, please send your tax-deductible check, for as little or as much as you can, to the NAACP Mississippi Emergency Relief Fund.

Thank you. And may *your* next meal be a little more enjoyable.

NAACP MISSISSIPPI EMERGENCY RELIEF, DEPT. SS1, BOX 121, RADIO CITY STA., NEW YORK, N.Y. 10019
(A project of the NAACP Special Contribution Fund—tax-deductible arm of the National Association for the Advancement of Colored People.)



General Electric computers erase 17 hours from average job turnaround time at Hughes Aircraft Co.

Information Systems

Serving Customer Needs-Worldwide

From 18 hours average job turnaround to 1.3 hours in four short years — in spite of a 20 percent annual increase in total jobs!

Remarkable progress? You bet it is. And it's getting better all the time.

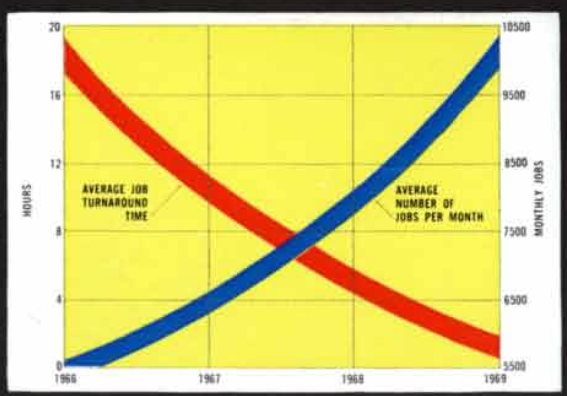
When Hughes needed to upgrade their earlier scientific computer they looked for a large system that could, from one central data base, concurrently handle time-sharing, remote batch, and local processing. Only General Electric had such a system.

Now Hughes is putting the GE-635 system to work taking great advantage of its 3-Dimensional capabilities.

Local processing. The central facility handles 40 percent of the workload direct.

Remote batch processing. Six GE-115 computers in outlying locations tie into the central GE-635 via high-speed Telpak lines. Hughes' GE-115's handle over 5,000 jobs a month.

Time-sharing. Over 1,000 scientists and engineers work from 60 strategically placed deskside Teletypewriters and portable terminals, some with remote plotting capability. Information comes back instantly from either their multiprocessing GE-635 or their smaller GE-265.



Multiprocessing. Hughes' GE-635 system was the first of it's kind to run multiple programs utilizing dual GE-635 processors. They are getting 20 percent more work out and saving half a million dollars in the process.

Multiprogramming. Hughes consistently runs 6 or more programs concurrently. A queue of 55 jobs is immediately accessible for processing.

The secret: GECOS III, the operating system everyone's talking about. Hughes was the field test site for GECOS III. Now the results are paying off. No software compares to GECOS III for matching a computer to any workload . . . for processing so much productive work through one system . . . for maximum utilization of one central data base of information.

Follow the lead of a growing number of 3-Dimensional GE-600 system believers. For more information write: Section 290-52, General Electric Co., 1 River Road, Schenectady, N. Y. 12305.

Some of the most progressive people in the world choose GE computers.

GENERAL ELECTRIC

Polaroid has a new way to ease the class struggle.

For under $70.

It's the new Polaroid ED-10 Land Instrument Camera. It puts instant photomicroscopy into any lab, at a price that puts it in a class by itself.

It fits any microscope, can be attached in moments, and is easy to operate.

You don't even have to know photography to use it.

It's molded of rugged high-impact material. To withstand rough classroom handling.

It gives you 3¼" x 4¼" full-color pictures in a minute, black-and-white in just seconds.

And you get the same picture quality as with the most expensive instrument cameras (because they all use the microscope's own optical system).

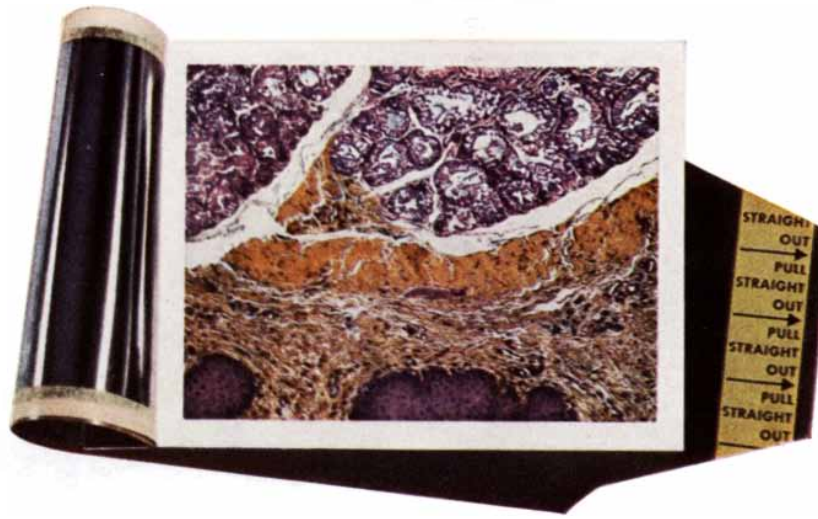
It puts a valuable and exciting teaching aid within reach of even a modest school budget. And the teacher saves classroom time, gains and holds attention better and makes demonstrations and comparisons easier.

The student gets what he sees without laborious sketching. He sees tangible, memory-reinforcing results. And his involvement advances the learning process. (He'll be developing more than a picture: he'll be developing an interest.)

For more information, write to: Polaroid Corporation, Industrial Marketing, Dept. 57-169, Cambridge, Mass. 02139. Or check with your scientific supply house or microscope dealer.

For under $70, it might pay you to look into what's new in the classroom. Polaroid®

The Polaroid Land Instrument Camera for schools.



FOUR JAWBONES of *Gigantopithecus* are seen as casts. They are from an old female (*top left*), a juvenile male (*top right*) and a very old male (*bottom left*), all discovered in China between 1956 and 1958, and from a young adult female (*bottom right*), found in India in 1968. The jaws from China are half a million to one million years old; the one from India is at least five million years old.

GIGANTOPITHECUS

This extinct ape was the largest primate that ever lived. First discovered as a fossil tooth in China, it is now represented by four massive jawbones, one of which was recently found in India

by Elwyn L. Simons and Peter C. Ettel

In 1935 the Dutch paleontologist G. H. R. von Koenigswald found a huge but manlike fossil tooth among the "dragon bones" for sale in a Hong Kong pharmacy. The discovery presented a problem to students of evolution: Where did the extinct primate from whose jaw the tooth had come fit on the human family tree? Von Koenigswald at first judged the animal, which he named *Gigantopithecus,* to be an oversized and relatively recent ape. Other scholars favored the view that it was quite old, that it was probably an ancestor of Java man and Peking man and that it was thus a forebear of *Homo sapiens.* Fossils discovered in China during the 1950's and in India in 1968 now provide evidence that not only resolves this dispute but also tells us what the animal was like and how it lived. The 1968 find in particular shows that *Gigantopithecus* had a much longer history than was formerly supposed. By far the largest of the primates, it was successfully adapted to a life in the savannas and forest fringes of Asia at least five million years ago and perhaps as long ago as nine million years.

In searching through the Chinese pharmacy's collection of dragon bones von Koenigswald was following an established stratagem of fossil-hunters in the Far East. Traditional Chinese medicine sets much store by the curative powers of dragon bones, which in actuality are fossil bones and teeth of various kinds. They are pounded into powder and taken internally, and Chinese pharmacists throughout the Orient pay well for any fossils offered them. Von Koenigswald was familiar with the custom; as a student he had studied a large collection of fossil teeth in the Munich museum, acquired by a traveler from pharmacies all over China in the 1900's. When he joined the Netherlands Geological Survey in the East Indies in 1931, he began to pick over dragon-bone collections whenever he found a Chinese pharmacy, looking for the teeth of fossil primates in particular.

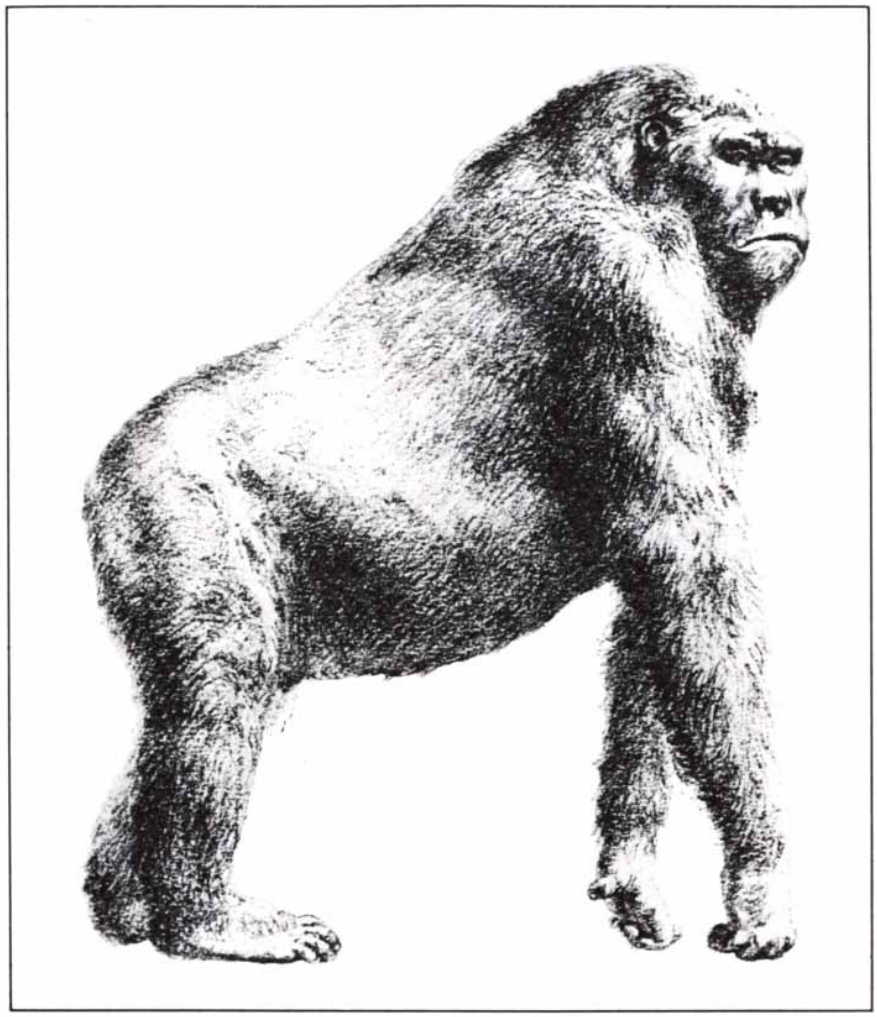
The tooth von Koenigswald bought in 1935 was a yellowish right lower third molar that clearly belonged to a primate. The crown measured nearly an inch from front to back, suggesting that its owner, if proportionately as big, had been larger than the largest-known gorilla. Von Koenigswald published a description of the fossil tooth the same year, establishing a new primate genus. To the generic name *Gigantopithecus* he added the species name *blacki* in honor of Davidson Black, an anatomist at Peking Union Medical College who had been instrumental in the discovery of Peking man.

Continuing his dragon-bone purchases elsewhere, von Koenigswald had by 1939 acquired a total of four *Gigantopithecus* molars. All of them were yellow or had bits of a yellowish matrix still attached to them. Exactly where they had come from was not known, but they shared their distinctive color with a number of other dragon bones—fossils of animals known collectively as the "yellow earth" fauna of southern China. Among the fauna's members were elephants now extinct, such as *Stegodon* and *Mastodon,* and a number of animals belonging to modern genera: orangutan, bear, porcupine, rhinoceros and giant panda. The age of the animals was not certain but the fact that the group included extinct elephants suggested that the yellow-earth fauna had flourished during the Pleistocene epoch.

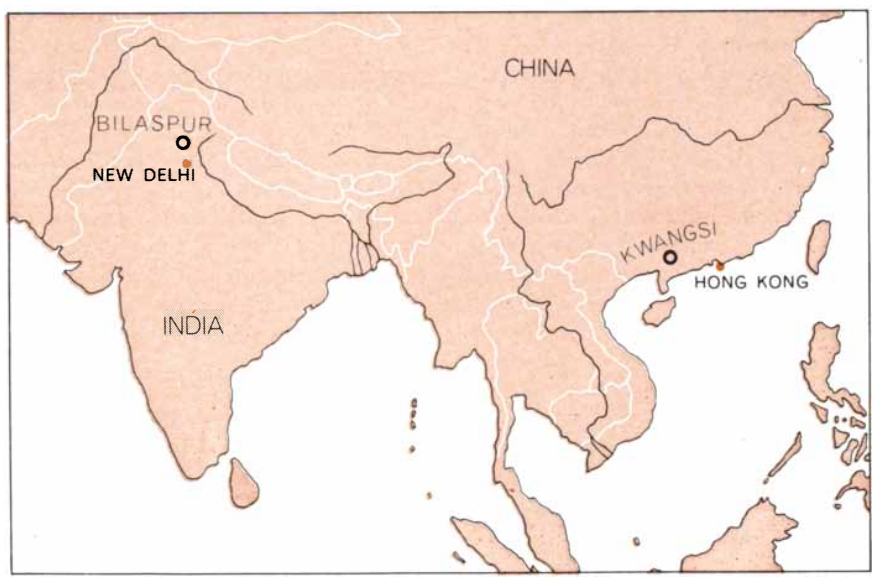
When the East Indies were occupied by Japan during World War II, von Koenigswald was interned as an enemy alien. At about the same time a student of fossil man working in the U.S., the late Franz Weidenreich, opened the controversy over *Gigantopithecus.* When the description of the first tooth was published, Weidenreich studied the report and decided that, far from representing a new primate genus, the tooth probably came from an oversized orangutan. As time passed, however, he became increasingly impressed by the tooth's similarity to human teeth. In 1944, while von Koenigswald was still interned in the East Indies, Weidenreich published a paper dealing with the four molars then known and declared that they were the remains of one of man's ancestors.

Weidenreich's argument was as follows. The teeth were demonstrably larger and probably older than the teeth in two very ancient primate lower jaws that had been found in Java and that had surprised scholars by the largeness of their teeth. (At first the two jawbones were given the name *Meganthropus.* They are now thought to resemble the jawbone of the fossil African primate *Australopithecus habilis* and of Java man.) The *Gigantopithecus* teeth, Weidenreich continued, were also larger and probably older than those of Java man (a hominid then called *Pithecanthropus erectus* and now known, along with Peking man, as *Homo erectus*). He concluded that the evolutionary line leading to modern man must have run from *Gigantopithecus* by way of *Meganthropus* to *Pithecanthropus* and then to *Homo sapiens.* In other words, he was proposing that modern man had evolved from earlier and larger forms by a process of diminution.

When von Koenigswald was released from internment after the war, he disagreed with his friend Weidenreich's hy-



RECONSTRUCTION of an adult male *Gigantopithecus* is conjectural because no remains have been found except partial lower jaws and single teeth. It is based on the assumption that the giant ape's body was in proportion to its massive jaw and that, except for its size and much higher face, *Gigantopithecus* was otherwise like a gorilla. If this is true, it would have stood about nine feet tall when upright and may have weighed as much as 600 pounds.



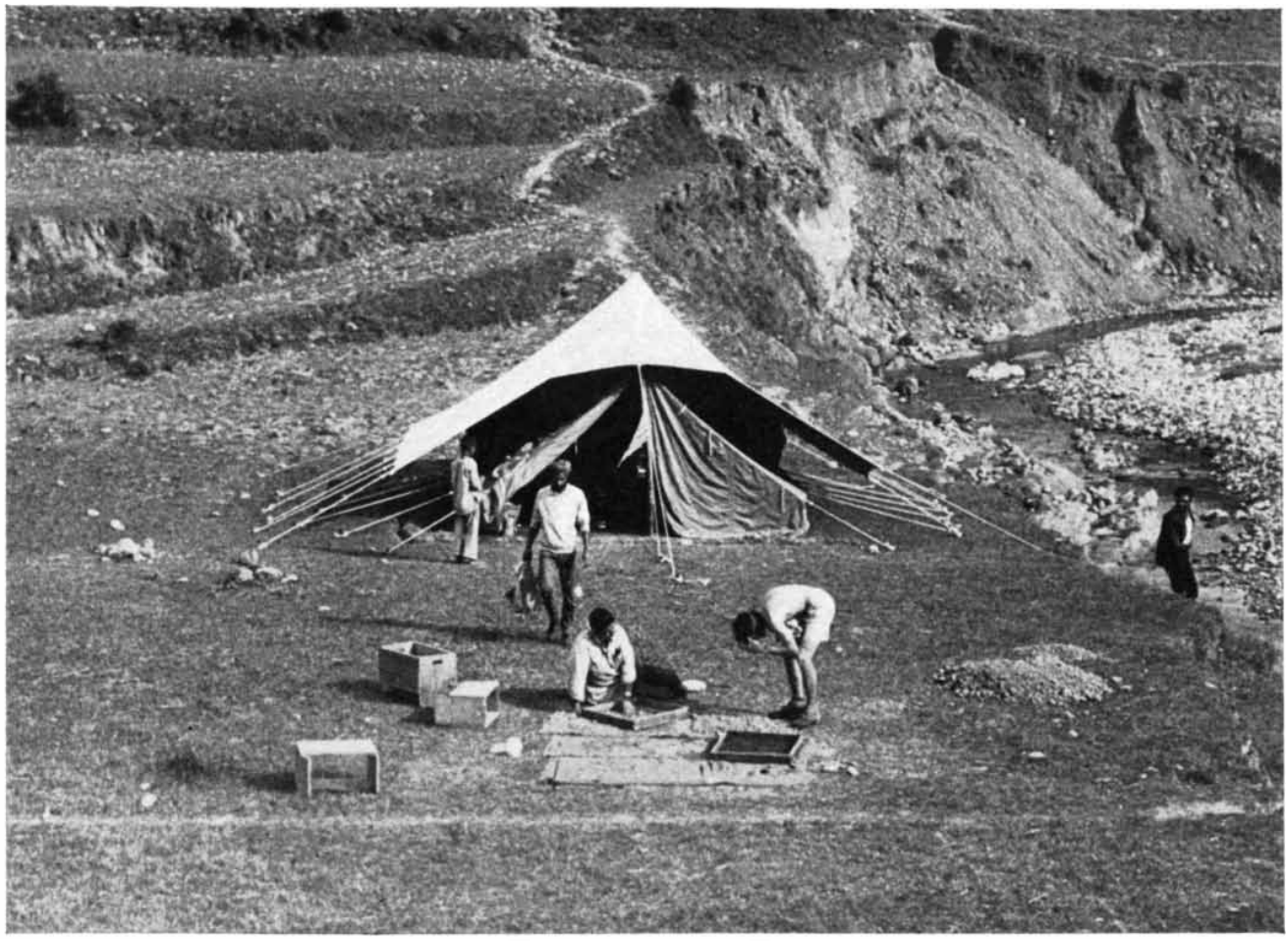
FOSSIL DISCOVERIES were made in cave deposits in two districts of Kwangsi province in southwest China (*right*) and in the Siwalik Hills, north of New Delhi in India (*left*).

pothesis and began to look for teeth again. By 1954 his total of *Gigantopithecus* teeth approached 20. Since the specimens were all single teeth, it was impossible to judge if any had come from the same individual, and it was difficult to assess the significance of their variations in size. Von Koenigswald was nonetheless able to reach some conclusions. The teeth evidently came from fossil deposits in one or both of two provinces in southern China, Kwangtung and Kwangsi. The nature of the other yellow-earth fauna suggested that all were of early Middle Pleistocene age, which would make *Gigantopithecus* a contemporary of *Homo erectus*. Finally, reversing his earlier opinion, von Koenigswald decided that the giant ape had some affinities with what he loosely termed "the human group."

Meanwhile the Chinese paleontologist Pei Wen-chung and other members of the Academia Sinica, China's central scientific body, arranged with the government pharmaceutical directorate in Peking to screen all incoming collections of dragon bones in order to identify any new or unusual fossils. In a single year (1955) Pei found 47 *Gigantopithecus* teeth among the dragon bones that had been shipped north from Kwangtung and Kwangsi. In the spring of 1956 an Academia Sinica field party was able to narrow its search for the source of the fossils to the district of Tahsin in southern Kwangsi. There, in a cave on the face of a limestone cliff, the searchers found a fossil deposit from which they unearthed three more giant ape teeth. Then a farmer in the nearby Kwangsi district of Liucheng, learning of the Peking party's interests, came forward with a large lower jaw that he had found while digging lime phosphate for fertilizer from a fossil deposit in a second cave. The farmer's sons, searching the fields where they had scattered the fertilizer, were even able to retrieve some teeth that had fallen out of the jawbone.

Pei published a report on the mandible in the winter of 1956–1957. The Academia Sinica field party simultaneously began excavations at the phosphate cave. By the end of 1958 the diggers not only had unearthed the remains of many other animals but also had added two more mandibles and more than 1,000 isolated teeth to the inventory of *Gigantopithecus* fossils. Curiously, no other skeletal parts were found; this richest of all known *Gigantopithecus* sites yielded only teeth and jawbones.

Of the three jawbones (which were



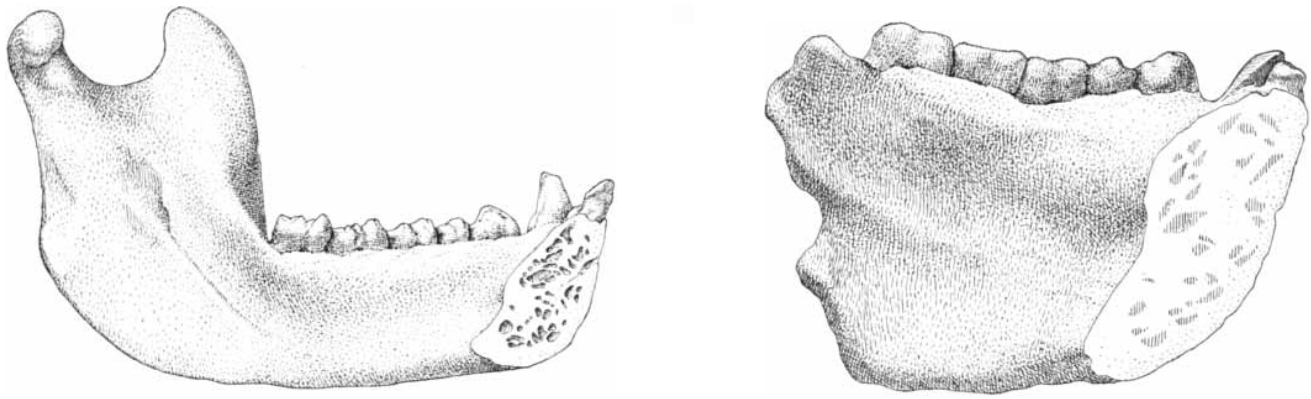
FIELD TEAM of the expedition to northern India, where the fourth mandible of *Gigantopithecus* was found, camped beside the stream that runs near the hill village of Haritalyangar. The fossil-hunters used the stream to dissolve the siltstone surrounding their finds.

assigned Roman numerals indicating the order of their discovery) Mandible III is enormous, Mandible I is relatively small and Mandible II cannot be fully compared with the other two because it represents a juvenile ape. To the discoverers the difference in size between Mandible III and Mandible I seemed explainable in either of two ways. It could be due to sexual dimorphism (the larger mandible representing a male), or the two jaws could have belonged to different species of the same genus. In any case, the discoveries were a major breakthrough. At last scholars, instead of attempting to analyze stray teeth, could study how *Gigantopithecus* teeth were interrelated in the animal's jaw.

The inventory of *Gigantopithecus* mandibles was further increased in 1968, when a fourth jawbone turned up in Bilaspur, a former princely state some 200 miles north of New Delhi in the Siwalik Hills of India. A local villager, Sunkar Ram, had discovered the jawbone while digging terraces on his farm several years earlier and had put it away for safekeeping. The fossil came from an exposure of sedimentary rocks that form part of a geological formation named Dhok Pathan; the sediments were laid down between five million and nine million years ago, in Middle Pliocene times. In 1968, when a joint Yale University–Panjab University expedition to the fossil-rich Siwalik area visited Bilaspur, Ram heard of our interest in old bones and brought his remarkable find to Grant Meyer, who was in charge of a field team digging at Haritalyangar. The descriptions that follow are based on the four known mandibles.

All the higher primates, man included, have 32 teeth: 16 in each jaw, arrayed in two symmetrical sets of eight. Each set contains two incisors, one canine, two premolars and three molars. In man the premolars and molars, or cheek teeth, are used for grinding. The canines and incisors, or front teeth, do the work of shearing. In *Gigantopithecus* the incisor teeth are small and peglike; their functional role is uncertain. The next teeth, the canines, are large, but unlike any living ape's teeth they have been worn flat with age, evidently from grinding food against the corresponding canine teeth in the upper jaw. The giant ape's cheek teeth are similarly flattened.

To us the differences between the three Kwangsi jaws suggest that the distinction between Mandible I and Mandible III is indeed due to sexual dimorphism and not to a difference in species. We believe Mandible I belonged to an old female and Mandible III to a very old male. The canine teeth of Mandible II have not been preserved. The roots of the canine teeth form at the same time that the teeth erupt. If death occurs before full eruption, as seems to have happened in this case, the crowns may fall out of the jaw. The canine sockets in Mandible II are quite large, however, and it seems safe to assume that the jawbone represents a juvenile male. The fourth specimen, the Bilaspur mandible, has small canines and evidently belonged to an adult female. The condition of the third molars indicates that the female died when still young: the crowns



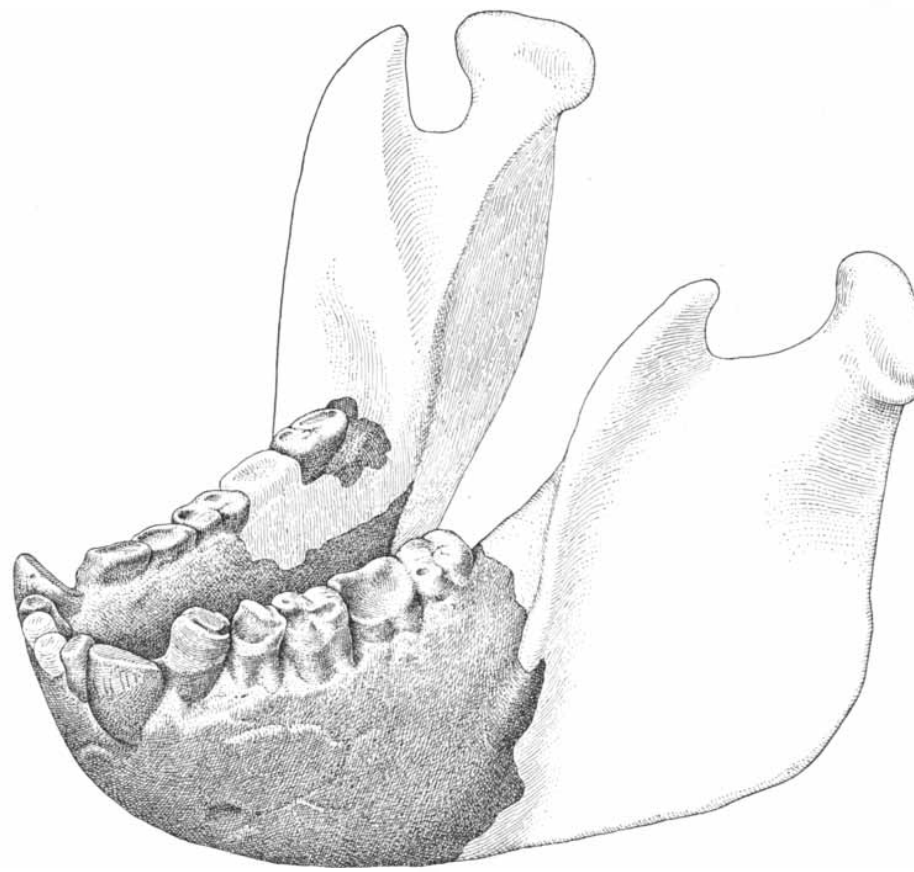
MASSIVE JAW of the old male *Gigantopithecus* from China (*right*) is compared with the jaw of a male lowland gorilla (*left*). The gorilla has a tooth row that is only 20 percent shorter than the tooth row of *Gigantopithecus*, but its jaw is less than half as deep.

have been ground almost flat but the enamel of the cusps has not yet worn down to the underlying dentine.

The molar cusps of living apes such as the gorilla and the chimpanzee consist of large cores of dentine thinly covered with enamel. In contrast, the cusps of the Bilaspur female's molars must have been composed almost entirely of enamel. Thick enamel is an adaptation for resisting wear caused by powerful chewing and abrasive foodstuffs. The heavy wear shown by all the specimens' molar and premolar teeth is further support for the conclusion that powerful grinding was the giant apes' principal method of mastication.

The shape of the mandibles and the shape and small size of the incisor teeth suggest that the animals' feeding habits involved little preparatory nipping or shredding. (Shredding in particular plays an important role in the feeding of living apes.) The mandibles show great depth, and the front edges of their ascending portions are set far forward. (This is particularly notable in the Bilaspur mandible.) These are features that increase grinding power. The thick cross section at the central symphysis where the two halves of the jaw meet, together with the robustness of the jaw under the molars, indicates an ability to resist heavy racking and shearing stresses as well as stresses created by up-and-down champing. Finally, the back of the jaw is turned slightly outward, a feature that presumably increased the mechanical advantage of certain chewing muscles.

All these adaptations are evidence that *Gigantopithecus* was a strong chewer. This is scarcely a surprise. If its overall proportions were in keeping with the size of its jaw, the giant ape must have weighed as much as 600 pounds and, when it stood upright, have been almost nine feet tall. Any herbivore as large as that would have had to be an efficient eater in order to have adequately nourished itself. In this connection it is interesting to note that a contemporary of *Gigantopithecus*, the giant panda *Ailuropoda*, is a herbivore that evolved from carnivorous ancestors. In the process of changing from one diet to another the lineage of the giant panda underwent transformations in dental anatomy that in the end gave the animal's jaws and teeth a number of resemblances to those of *Gigantopithecus*. In contrast to its bear cousins, the giant panda has a short, deep face, a closely packed row of teeth and large, flat premolars with accessory grinding cusps. Similar adaptations are visible in the giant ape's mandibles: accessory or enlarged grinding cusps are present not only on its molar teeth but



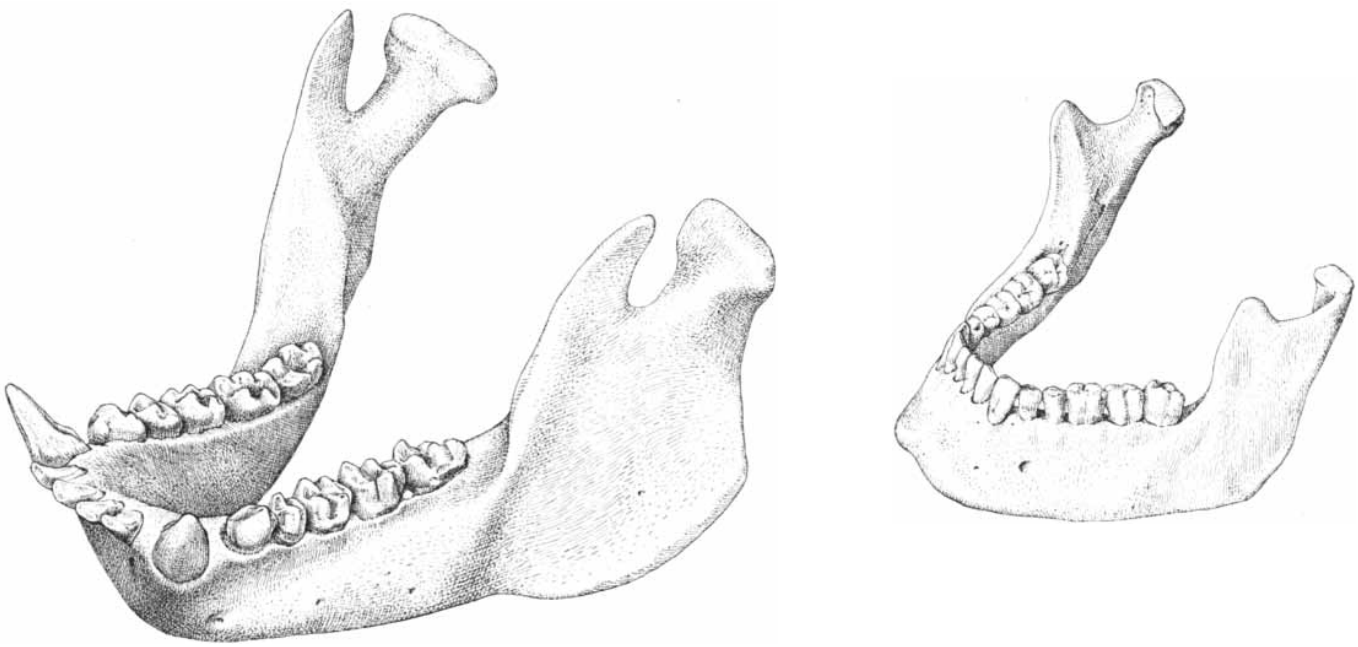
LARGE DIMENSIONS of the biggest *Gigantopithecus* jaw (*left*) are apparent in this comparison with the jaws of a male mountain gorilla (*center*) and modern man (*right*). The

also to some extent on the premolars. We can speculate that *Gigantopithecus* may even have adopted the seated feeding posture used by the giant panda. Sitting, it could have sorted out food items with its hands, passing the selected objects back to its powerful grinding teeth.

Clifford J. Jolly of New York University has recently enumerated a series of dental characteristics that he considers to be not only functionally interrelated but also the evolutionary product of a mode of feeding he terms "graminivorous." The term means feeding by the ingestion of large numbers of comparatively small, tough morsels—grass seeds, stems, rhizomes and the like—while at the same time chewing powerfully and almost continuously with the cheek teeth. Jolly goes on to suggest that the first cycle of evolution that separated the lineage of man from ancestral apes was precipitated by the adoption of just such a feeding habit. In Jolly's view the line of primate evolution that leads to man (the hominid line) came into existence when a stock of forest-dwelling apes (the pongid line) abandoned the characteristic pongid diet of fruits and leaves in favor of graminivorous feeding and left the deep woods to live in a more open savanna-woodland habitat.

Jolly's proposal was developed from present-day observations. Among all the ground-dwelling nonhuman primates, one—the Ethiopian highland baboon *Theropithecus gelada*—is the most fully adapted to a terrestrial life and is also the most completely herbivorous. Called geladas, these baboons have interrelated dental characteristics Jolly associates with graminivorous feeding; he has named these characteristics the *T* complex (for *Theropithecus*). Among the dental features that distinguish geladas from, for example, their more omnivorous cousins the baboons of the genus *Papio* are the following. First, the gelada's molar teeth are very high-crowned when fully erupted but are rapidly worn down, exposing a scalloped surface of dentine and enamel. Their surfaces then resemble the teeth surfaces of primitive herbivores, for example the first horses that adapted to feeding on grass. Second, the molar teeth of the gelada provide significantly more grinding surface per pound of body weight than *Papio*'s do. Third, as the gelada grows older its teeth are packed together in its jaws. This phenomenon, termed mesial drift, is associated with strenuous grinding mastication and appears comparable to the close packing of the giant panda's teeth. Fourth, compared with *Papio* the gelada's lower jaw is shorter, deeper and much thicker under the molars. Fifth, the ascending part of the gelada mandible is more vertically arranged than it is in *Papio*, and its front edge is set farther forward on the jaw. Sixth, the gelada's incisors are small compared with its other teeth and are implanted vertically rather than jutting forward. Finally, compared with *Papio* the gelada's canines are somewhat reduced, particularly in females. This reduction is seen in its most extreme form in one of the modern gelada's extinct relatives from East Africa [*see illustration on next page*].

Jolly notes that various *T*-complex elements can be seen in most fossils of the early hominid genus *Australopithecus*. They are especially well developed in the specimens of *Australopithecus robustus* from South Africa, in one of L. S. B. Leakey's Kenya specimens (*Australopithecus boisei*, formerly named *Zinjanthropus boisei*) and in a very robust *Australopithecus* mandible some



ascending portions of the giant ape's jaw, missing from all four fossils, are restored in this illustration. The wear visible on the giant ape's canine teeth, in contrast to the pointed canines of the gorilla, is a product of the extinct animal's grinding mode of mastication.

two million years old that was recently unearthed in the Omo valley of Ethiopia.

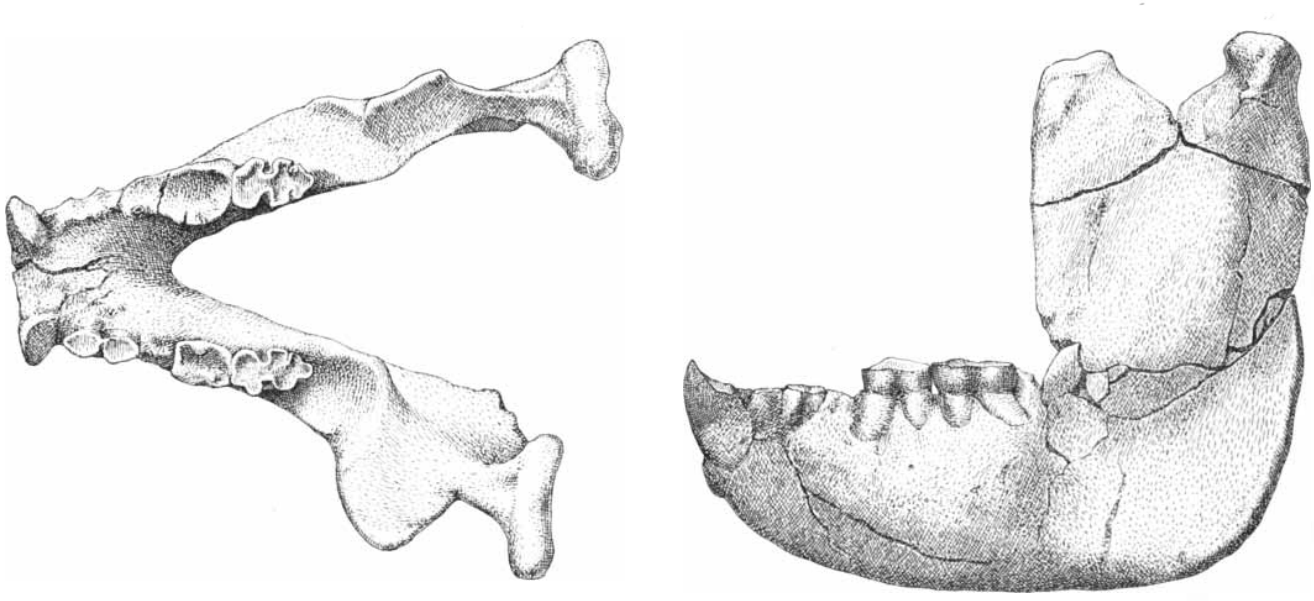
The complex of dental features that distinguishes geladas from other baboons is therefore much like the complex that distinguishes the hominids (including man) from the pongids (gorillas, chimpanzees, orangutans and gibbons). Unlike pongids, hominids have small incisors that are implanted vertically, molar teeth that are relatively broad, premolars with comparatively flat surfaces, a deep and heavy buttressed mandible with an ascending part that is vertically aligned, a closely packed tooth row and canines that are reduced in size. The strength of these resemblances leads Jolly to contend that the characteristic hominid dentition arose because the earliest hominids were graminivorous rather than because, as has been suggested, early hominids learned to fabricate weapons, thereby rendering large canines unnecessary and establishing conditions under which smaller canines could evolve.

The existence of several *T*-complex features in the dentition of *Gigantopithecus* sheds some light on the giant ape's probable environment. *Gigantopithecus* appears also to have been a graminivorous feeder. Moreover, the identity of Jolly's hypothetical pioneer hominid may not be totally beyond conjecture. Recently we and our Yale colleague David R. Pilbeam have been studying the primitive fossil hominid *Ramapithecus* [see "The Early Relatives of Man," by Elwyn L. Simons; SCIENTIFIC AMERICAN, July, 1964]. The jaws and teeth of *Ramapithecus* also show several *T*-complex features. *Ramapithecus,* however, flourished in Africa and India in late Miocene or early Pliocene times, between 10 million and 14 million years ago. This is at least eight million years earlier than the oldest generally accepted hominid tools. It does not seem reasonable to assume that the reduction in the size of the canine teeth in *Ramapithecus* is the result of some capacity for using tools at an even earlier date. Can *Ramapithecus* instead have been the protohominid envisioned in Jolly's hypothesis—a graminivorous primate species just beginning the first cycle of hominid evolution?

The differences between the *T*-complex manifestations seen in *Gigantopithecus* and those seen in the hominid line are instructive. In early hominids the process involves what could be called the "molarization" of the premolar teeth. These teeth have become flat-crowned, increasing the total available grinding area. In the giant ape not only the premolars but also the canines appear to have been used for grinding: they have been worn down until their surface lies in the same plane as the crowns of the cheek teeth. Even the incisors may have served as grinders: these small, peglike teeth are generally worn flat. The implication is that there was strong selective pressure for an increase in total grinding area acting on the *Gigantopithecus* lineage. A combination of a graminivorous feeding habit and large body size might plausibly have constituted or at least contributed to this evolutionary pressure.

Among the hominids the canine teeth have evolved in a different way. In late Pliocene times, between two million and four million years ago, the hominid line developed an essentially modern dentition. It consisted of a continuous shearing blade at the front, composed of incisors and canines combined; grinding was left to the cheek teeth. Seen from above, the tooth row forms a parabola. *Gigantopithecus* retained a tooth row that formed a *V.* A final difference between the hominids and *Gigantopithecus* lies in the morphology of the mandibles. Both the giant ape and the hominids have deep, robust jaws, but *Gigantopithecus* shows these characteristics in an extreme form.

The kinds of fossil animals found with *Gigantopithecus* guide us in reconstructing its probable way of life. The richest of the associated faunas is the one from the Kwangsi caves. It includes 19 mammals in addition to the giant ape. One of them is a fellow primate, the orangutan, and one is a rodent, the porcupine. Six are carnivores: the Indian dhole (a dog), a bear, a cat, the spotted hyena, the hog-nosed badger and the masked palm civet. One is a herbivore evolved from a carnivore: the giant pan-



FOSSIL BABOON'S JAW found in East Africa is from a genus of monkeys ancestral to today's ground-dwelling gelada baboons of the Ethiopian highlands. Its canine teeth show signs of reduction in size, unlike the canine teeth of baboons that are more omnivorous. The geladas do not eat fruits and leaves, as forest-dwelling apes and monkeys do, but instead feed on grass stems, roots and the like. This "graminivorous" diet has been accompanied by changes in the shape of their jaws and teeth that resemble many of the alterations from standard ape dentition that are visible both in *Gigantopithecus* and in early hominids that apparently fed in the same way.

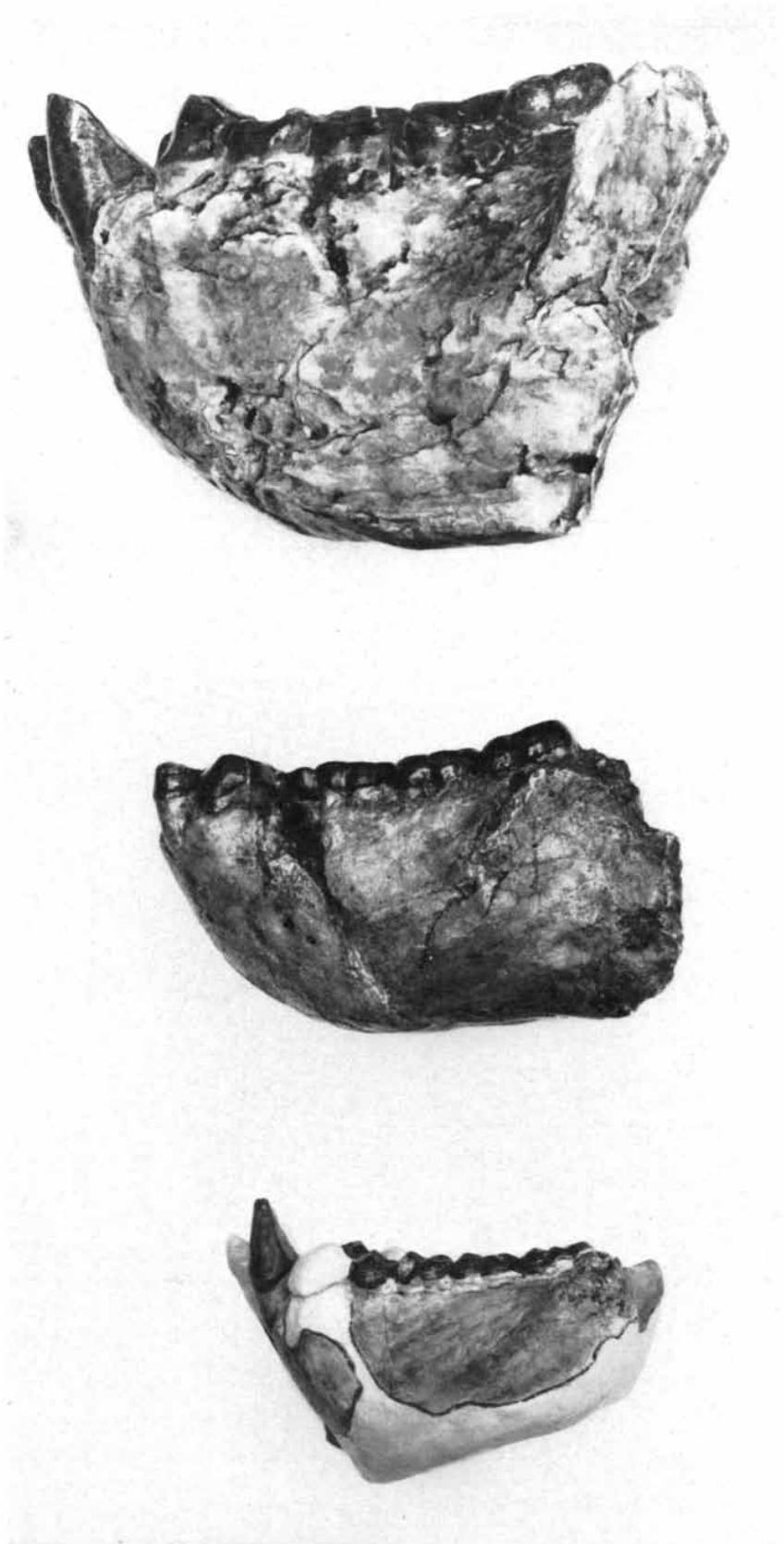
da. Two are extinct elephants: *Mastodon* and *Stegodon*. Four are even-toed ungulates: a pig, a goat, a deer and a member of the cattle family. Four are odd-toed ungulates: a rhinoceros, a tapir, a horse and a chalicothere (an extinct claw-footed mammal).

The carnivores are clearly the predominant faction of the fauna. When we add that most of the larger animals, particularly the odd-toed ungulates, are known chiefly from the isolated milk teeth of young animals, the Kwangsi deposits begin to look like the kind of bone pile that is accumulated by predators. The presence of the bones of the Indian dhole particularly strengthens this impression. Today these dogs hunt in packs, attacking deer, wild pigs, wild sheep, ibexes, antelopes and water buffaloes. They have even been known to bring down bears, leopards and tigers. Dholes also commonly make their lair in caves or holes in the ground.

In this connection, a reconstruction of *Gigantopithecus* proposed some years ago shows it as a huge manlike carnivore carrying its prey up the face of the Kwangsi cliffs to be devoured in the shelter of a cave. This proposal can be dismissed on geological grounds as well as biological ones. What are now cliffside caves were sinkholes in a limestone plateau when the giant apes flourished. The weight of the evidence leads to a less romantic conclusion: *Gigantopithecus* appears to have been the prey and not the predator.

There are other possibilities. Many of the Kwangsi fossils show abrasions which indicate that porcupines once gnawed the bones for their calcium content. For example, a number of the isolated *Gigantopithecus* teeth have had their roots chewed away. Perhaps the Kwangsi bone piles are only the leftover contents of porcupine burrows. If this is the case, it would help to explain why no remains of the giant ape other than teeth and mandibles have been found. It is also possible that no collecting agent was involved; the bones may simply have been washed into limestone fissures by the natural processes of erosion. The information available from China at present is insufficient to allow a choice among these alternatives.

In ecological terms the Kwangsi fauna can be divided into two groups. One group—including the orangutan, the civet, the badger, the cat, the tapir and the dog—is suited to a woodland or forest environment. The other—including the elephant, the horse, the rhinoceros, the hyena, the giant panda, the goat and



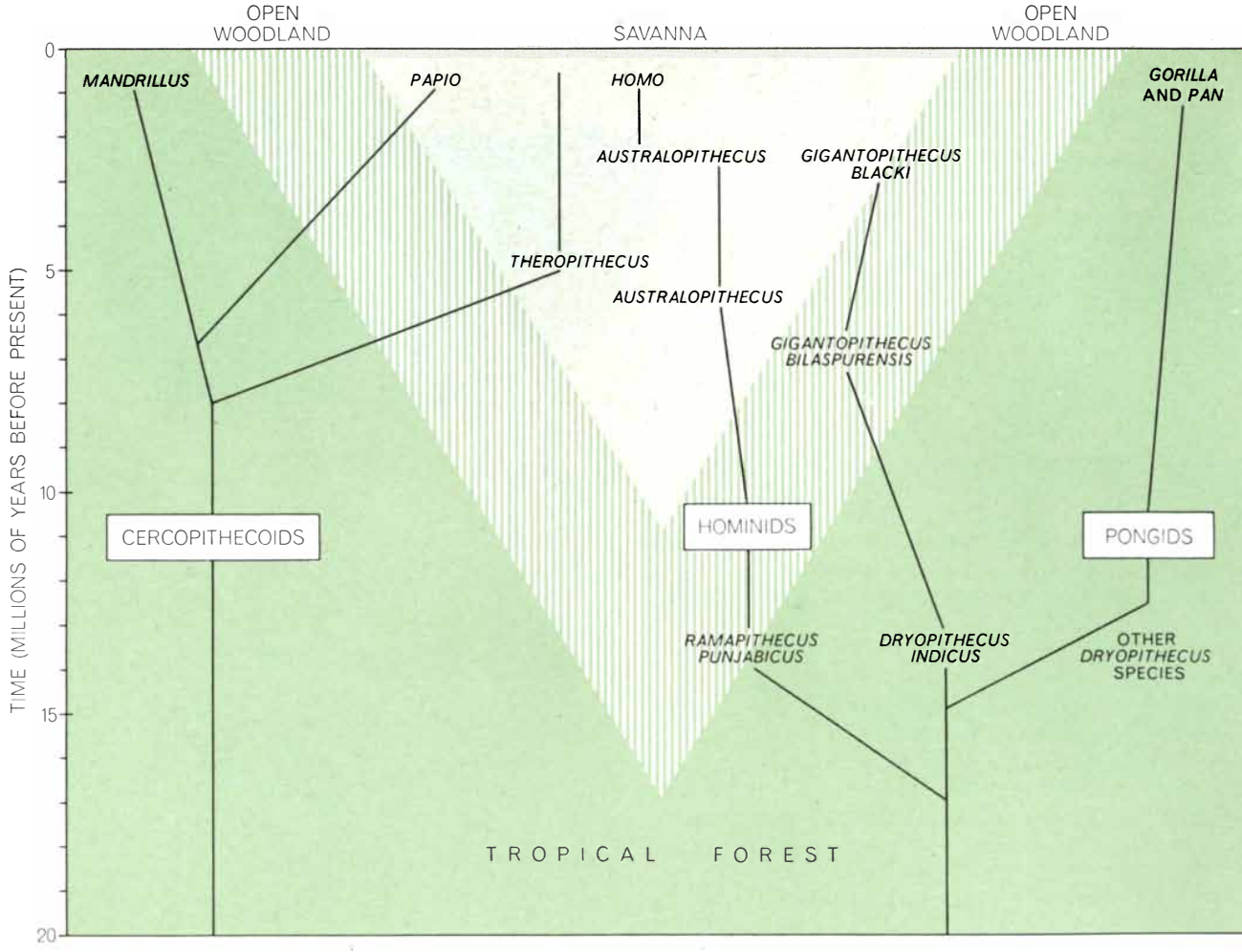
JAWS OF THREE PRIMATES that flourished millions of years apart are, from top to bottom, that of *Gigantopithecus blacki*, from the Middle Pleistocene, of *Gigantopithecus bilaspurensis*, from the Middle Pliocene, and of *Dryopithecus indicus*, from the early Pliocene or late Miocene. *Dryopithecus indicus* had a jaw almost as large as a lowland gorilla's. It is likely that the *Gigantopithecus* group arose from stock close to *Dryopithecus indicus*.

cattle—is better adapted to mixed or open habitats, such as savanna-woodland, open woodland or grassland. The duality of the fauna allows us to say with some assurance that the countryside of the period was a mixture of forest, open areas and areas transitional between the two. This certainly appears to be an appropriate habitat for a graminivorous giant ape.

Just when *Gigantopithecus* and the rest of the yellow-earth fauna inhabited Kwangsi is more difficult to assess. No absolute dates are available, and a judgment must be based on correlations between the animals there and similar animal groups of known age found elsewhere. The existence of the bones of modern elephants at some sites, the fact that the species of *Stegodon* elephant present is more advanced than the *Stegodon* typical of early Pleistocene deposits and the preponderance of species that are still extant over species that are extinct—all suggest that an appropriate age for the Kwangsi assemblage is the Middle Pleistocene, between half a million and a million years ago.

The habitat of the Indian specimen of *Gigantopithecus* (named *Gigantopithecus bilaspurensis*), which flourished at least four million and possibly more than eight million years earlier, seems to have been somewhat like the habitat in Kwangsi. The fauna found in the early Dhok Pathan sediments, which includes relatives of the elephant and some precursors of the modern horse (*Hipparion* in particular), suggests that the environment consisted largely of dry grasslands. Thus both the Indian and the Chinese faunas lend support to the hypothesis that the giant apes had adapted to an open environment quite unlike the forest habitat of their fruit-and-leaf-eating pongid ancestors.

How are we to fit *Gigantopithecus* into its rightful place on the primate family tree? The Chinese species, *G. blacki*, is so much like the older Indian species that it is probably a direct descendant, although the discovery of remains other than jaws would help to clarify the relationship. A more difficult question is: From what earlier primate lineage did this graminivorous Pliocene ape spring? Beginning in late Miocene times and continuing throughout the Pliocene a habitat of open woodlands and grasslands became increasingly available along the foothills of the Himalayas. The same zone was the northern boundary of the territory occupied by the forest-dwelling apes of the period, a range that extended southward and



PRIMATE FAMILY TREE that spans some 15 million years has been annotated to suggest the changes in habitat and mode of feeding that have affected the shape of some primate teeth and jaws. The reason the teeth of *Gigantopithecus* resemble human teeth so closely is that both evolutionary lineages left the tropical forest, where monkeys (*left*) and apes (*right*) still live, in favor of more open environments and a graminivorous diet. By the time the hominid lineage produced *Australopithecus* and the pongid lineage produced the first *Gigantopithecus*, the teeth of both had become alike because they were serving much the same functional purpose.

westward to include Africa. In fact, India and Africa seem to have shared much the same kind of fauna in late Miocene times; for example, fossil forms from the Himalayan foothills include ancestral aardvarks and giraffes.

Dryopithecus indicus, a large fossil ape, was among the animals present in the northern border area in late Miocene or early Pliocene times. The fossil remains of *Dryopithecus indicus,* which had a jaw almost as large as an African lowland gorilla's, have been found both in West Pakistan and in northern India. It is even possible that *Dryopithecus indicus* represents a northern extension of the same primate stock that in the southwest was ancestral to the gorillas of Africa. Could the Indian *Dryopithecus* species, then, have been ancestral to *Gigantopithecus?*

In most ways *Dryopithecus indicus* was a rather conventional ape. Its canine teeth were large, and the upper and lower canines overlapped. Moreover, they were separated from the adjacent incisors by a gap. *Dryopithecus* clearly had not yet begun to exhibit the tooth-crowding and canine-to-canine wear that characterize *Gigantopithecus.* Nonetheless, there are some resemblances between the two animals. The size of the early Pliocene ape's jaw is large, and its cheek teeth are broad and relatively flat-crowned. In the absence of a more likely candidate, it seems reasonable to assume that *Gigantopithecus* evolved from *Dryopithecus indicus* or from some very similar large, conventional forest ape.

Gigantopithecus thus represents a side branch in pongid evolution, a line of enormous apes that became increasingly adapted to a specialized mode of feeding. The lineage of man quite independently adapted to this same mode of feeding during the first 10 million years of its history, but to a lesser extent and in somewhat different ways. Seen in this light, it is not surprising that, at the time when the only remains of *Gigantopithecus* available for study were a few isolated teeth, the remarkable likeness of these teeth to the teeth of man led scholars to suggest a close relationship between the two lines. In the end, however, it is the differences rather than the likenesses that have become significant. For man the special combination of characteristics possessed by his ancestors set the stage for a second cycle of human evolution. For *Gigantopithecus* a parallel set of adaptations, differing principally in detail and proportion, led to extinction.

How to make a do

When a machine ties up your people on a job, they can't do anything else for you.

Like some other job that's a little more profitable.

Here's how to make a machine that will free them up:

Start with a Xerox duplicator... either a 2400 or a 3600-I.

Both have **(1)** copy counters and both shut themselves off automatically.

Add **(2)** an Automatic Document Feeder. You can put in up to 125 originals of different weights and sizes. Then dial the number of copies you

XEROX CORPORATION, ROCHESTER, NEW YORK 14603. OVERSEAS AND THROUGH RANK XEROX LTD., FUJI-XEROX CO., LTD., TOKYO.

-it-itself machine.

want, press a button and go away.

Next add **(3)** an Automatic Sorter so that multi-page reports come out collated, ready to staple.

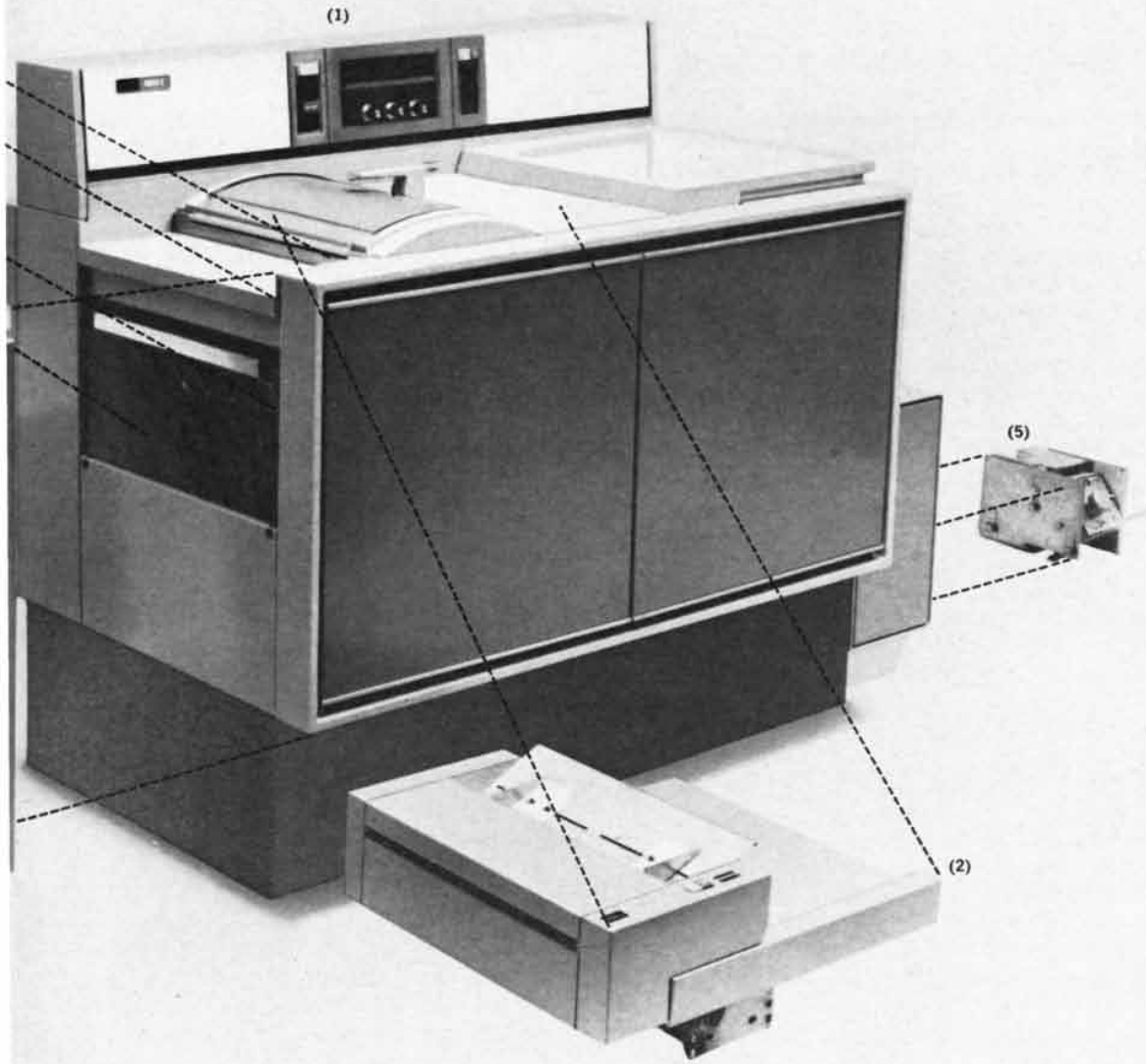
Now put on **(4)** a Slitter-Perforator. It can cut special-size jobs to order and deliver perforated jobs. Automatically.

Then with **(5)** the Variable Weight Paper Feeder to let you use paper all the way up to 110-pound card stock, your machine is all set to go.

A machine that can turn out your copies, all by itself.

While the people who aren't working it work on something else.

XEROX



The Recognition of DNA in Bacteria

Some bacteria have enzyme systems that scan invading DNA molecules injected by viruses and break them unless they are chemically marked at specific recognition sites

by Salvador E. Luria

The genetic code closely resembles a universal language. As far as anyone knows every word in this language (that is, every triplet of nucleotides) means the same thing for all forms of life: it specifies a particular amino acid. By the same token, organization of a sequence of the words into a sentence, written in the form of a molecule of deoxyribonucleic acid (DNA), carries a similarly unvarying meaning: it specifies the construction of a particular protein. Hence the genetic script, like the script of a book printed in a universal language, is read in the same way by all organisms.

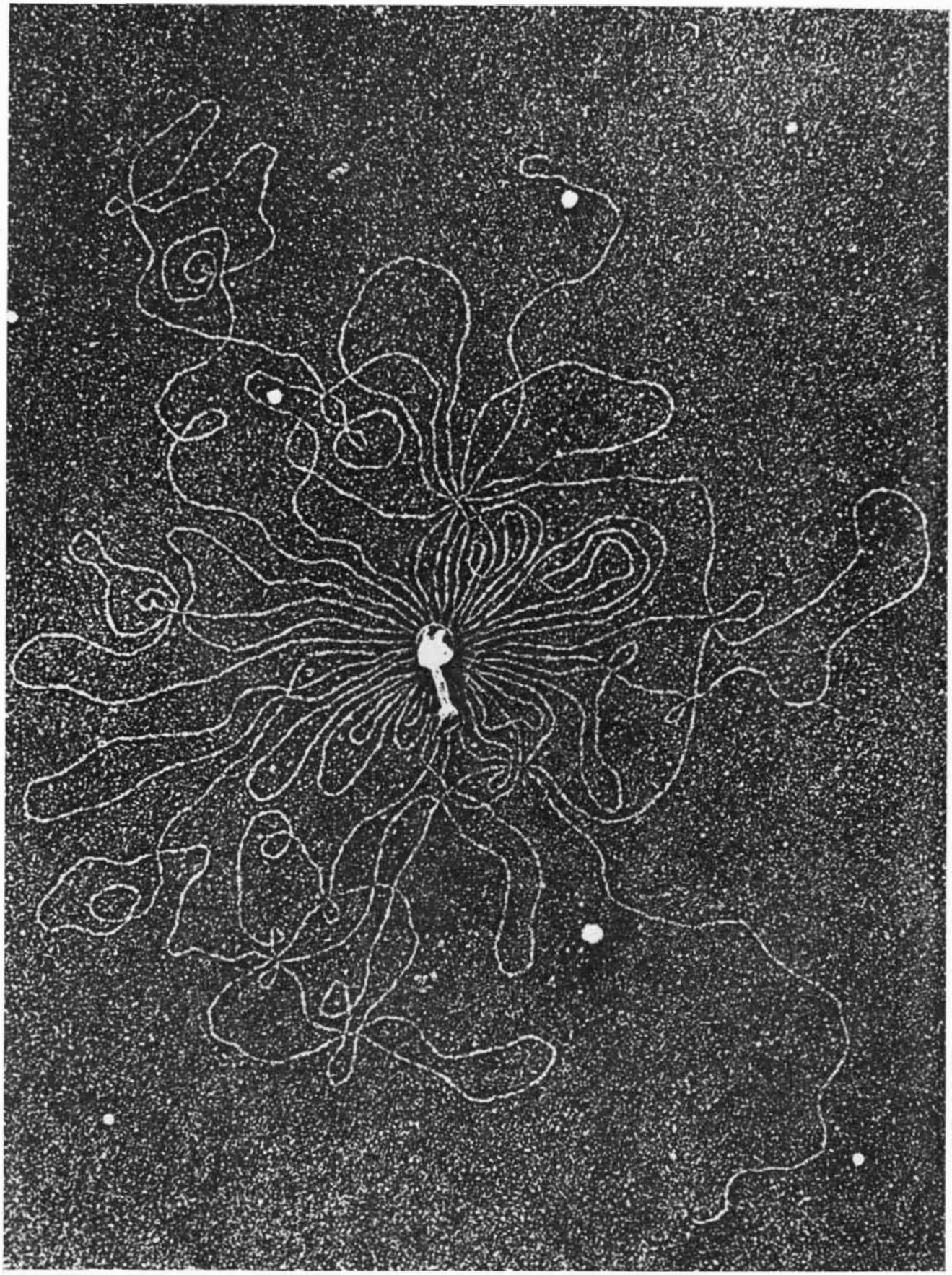
There are situations, however, where the organism examines the DNA script not as a linguist would but as a bibliophile would. A bibliophile may find in the structure of a book's script little signs or marks that identify the printer. It turns out that DNA often has just such identifying marks, and that these decisively affect the behavior of the organisms that recognize them. This unexpected finding has begun a fascinating chapter in the study of molecular biology and evolution.

The story begins with a curious discovery Mary L. Human and I made nearly 20 years ago in experiments with the bacteriophage, or bacterial virus, known as T2 [see "The T2 Mystery," by Salvador E. Luria; SCIENTIFIC AMERICAN, April, 1955]. Ordinarily T2 readily invades and multiplies in the bacterium *Escherichia coli,* but we found that when the virus was grown in a certain *E. coli* strain (called *B*/4), almost all the daughter phages that came out were altered in such a way that they could no longer multiply in the usual *E. coli* hosts of T2. It developed in further experiments that the altered T2 could multiply perfectly well in dysentery bacilli, and this breeding had the effect of transforming the phage back to full ability to multiply in *E. coli* bacteria.

Since the change T2 had undergone was completely reversible, it was obviously not a genetic mutation; an alteration of a gene or genes would be expected to persist in the progeny that inherited it. What, then, could account for the modification of T2's character? The phenomenon we had observed was not a freak; this was soon shown in other experiments with phages conducted by Giuseppe Bertani in my laboratory at the University of Illinois and independently by Jean J. Weigle at the California Institute of Technology. They found, for example, that when a certain phage called lambda (λ) was grown in the cells of an *E. coli* strain called *C,* only one in 10,000 of the daughter λ phages coming out of *C* could reproduce in a different *E. coli* strain called *K.* The descendants of the few phage particles that did manage to grow in *K* were then able to multiply in *K* cells as well as in *C* cells. A single cycle of growth in *C* cells, however, would restore these phages to the original form: capable of growing in *C* cells but not in *K.* Similarly, it was found that certain other strains of *E. coli* bacteria could restrict the growth of specific phages or modify their form [*see illustrations on pages 90 and 91*]. A given phage could be modified to a series of different forms by shifting it from one host strain to another; each time the daughter phages became adapted to the new host, and the descendants could be returned to the original form by shifting them back to the original host.

The enigma of the changeable phages did not begin to clear up until 1961, when a Swiss investigator, Werner Arber of the University of Geneva, discovered a clue to the reason for the different reception of phages by different strains of a bacterium. Arber and his colleague Daisy Roulland-Dussoix found that when phage lambda injects its genetic material into an "alien" bacterium (one that will restrict the phage's multiplication), the cell breaks up most of the phage's DNA molecules into small fragments. This happens, for example, when phages grown in *E. coli* of strain *K* invade bacterial cells of strain *B.* The broken DNA of course cannot reproduce new phage. A few of the DNA molecules injected into the *B* bacterium manage, however, to remain intact, and they multiply, producing about 100 daughter phages. These now have the ability to multiply in *B* cells. It turns out that two of them (that is, about 2 percent of modified phages) can also still multiply in *K* bacteria as well. Arber performed a pretty experiment that revealed why this is so [*see top illustration on page 92*].

He used tracer isotopes—heavy nitrogen (^{15}N) and heavy hydrogen (^{2}H, or deuterium)—to label the DNA of phages bred in *K* cells. This was done by growing the bacteria and phages in a medium containing the heavy isotopes. The "heavy" phages were then employed to infect *B* bacteria growing in a medium of ordinary (light) nitrogen and hydrogen. When the new crop of daughter phages emerged from the lysed bacteria, Arber separated the phages by weight by means of a centrifuge that layered the particles (in a cesium salt solution) according to their relative buoyancy, based on their density. Most of the daughter phages proved to be "light," indicating that they were composed of material newly synthesized in the infected bacteria. A few particles, however, contained DNA that was half-heavy; that is, their weight indicated that half of the DNA was made up of new material and the other half of material from the heavy parent phages that had infected the bac-



MOLECULE OF BACTERIOPHAGE DNA is shown here as a long, tangled thread after being released from the head of the T2 phage particle. The magnification is 100,000 diameters. The T2 bacteriophage is one of several "T even" phages that infect cells of *Escherichia coli*. When the phage DNA molecule is modified in a certain way, it can be "recognized" as an invader by the cell and destroyed. This electron micrograph was made by Albrecht K. Kleinschmidt of the New York University School of Medicine.

PROBABILITY OF SUCCESSFUL INFECTION IN

	E. COLI B/4	*E. COLI* B/4	*S. DYSENTERIAE* SH
T2 • B	1	1	1
T2 • SH	1	1	1
T2 • B/4 = T*2	10^{-5}	10^{-5}	1
T2 • B/4 • SH	1	1	1

PROBABILITY OF SUCCESSFUL INFECTION IN

	E. COLI K	*E. COLI* B	*E. COLI* C
λ • K	1	10^{-4}	1
λ • B	4×10^{-4}	1	1
λ • C	4×10^{-4}	10^{-4}	1

MODIFICATION OF PHAGES can be demonstrated by growing phages in one strain of bacteria and observing how successfully the progeny grow when another strain serves as the host. In these tables the original host strain of T2 or lambda (λ) phages is indicated, in the first column, by a suffix such as *B* or *B/4*, which represents *E. coli* strains *B* or *B/4* respectively. The other columns indicate the probability of successful growth when the phage is obliged to grow again in the same strain or in another one. Fifteen years ago the author and Mary L. Human discovered that when phage T4 was grown in *E. coli B/4*, yielding T2 · *B/4* (originally called T*2), the phage was so altered that it would scarcely multiply in its usual hosts. It would grow freely, however, in dysentery bacilli (*Shigella dysenteriae Sh*). Daughter phages from this cycle, designated T2 · *B/4* · *Sh*, were completely normal.

teria. Since the phage DNA is a typical double-strand molecule, it could be deduced that in these phages one strand of their DNA was light and the other strand was heavy—contributed intact from the parent phage. Arber found that the phage particles containing this hybrid DNA retained the ability to multiply in *K* cells as well as in *B* cells. There was also a small fraction of fully heavy daughter phages (both DNA strands being heavy), and these too proved able to grow in both *K* and *B*.

The result of Arber's experiment made clear that the lambda phage's DNA strands carried some kind of marking that identified specific phages for the bacteria. In a phage generated in *K* cells the DNA somehow acquired a *K* marking, and a phage grown in *B* cells had its DNA marked *B*. When phage DNA that lacked the right marking was injected into a bacterium, the DNA was almost sure to be broken down. The experimental results also said something more: they said that the specific marking on the DNA molecule was attached by a stable, covalent chemical bond, since the mark was retained during the chemical events attending the construction of the daughter phage. Arber confirmed the stability of the bond by using highly purified phage DNA (instead of the intact phage) to infect bacteria; the DNA retained its specific marking even after going through the chemical purification treatment.

Arber's findings raised a number of interesting questions. What was the nature of the DNA markings? How did a bacterium recognize the absence of the right markings in phage DNA? What mechanism in the bacterium was responsible for destroying DNA with the "wrong" markings? A number of laboratories have looked into these questions and have worked out much of the answer. Actually two sets of answers have come out, one for phages of the lambda type (with *K*, *B* or *C* markings) and one for the T2 and other "T even" phages. Let us look first at the lambda markings.

It was known even before Arber's discoveries that every kind of DNA can occasionally have a seemingly spurious methyl group (CH_3) attached to some of the nucleotides. For example, the methyl group can be tacked on at a certain position in adenine; the base is then called methylaminopurine, or MAP, instead of simply A. Similarly, the base cytosine (C) can be methylated, so that it becomes methylcytosine (MC). In each case the methyl group is added (with the help of a special enzyme) only after the DNA molecule has been built [*see bottom illustration on page 92*]. And it plays no observable part in the molecule's functioning: MAP behaves just like A, and MC just like C. In short, the methyl group does not alter the genetic spelling.

Could one now suppose the addition does change the style of the script? Is the methyl group perhaps a kind of serif tacked onto the letters? Arber tried the experiment of cutting down the amount of methylation of the phage DNA. He did this by growing *K* bacteria in a medium in which they were deprived of the amino acid methionine, the precursor of the substance that donates methyl groups to DNA. It turned out that phages grown in these bacteria generally did not acquire the *K* marking. Apparently they did not have the serifs (methyl groups) that would identify them as *K*.

Arber found further that the methyl groups serve as markers not just anywhere on the DNA molecule but only at certain strategic spots. This was clearly shown in experiments with a very tiny phage known as fd. Attached to each DNA molecule of this phage are a few MAP groups. Arber and his colleague Urs Kühnlein found that when the fd phage was grown in *K* bacteria, it had two fewer MAP groups than when it was grown in *B* bacteria. The *K*-marked phages failed to grow in *B* cells; these cells broke down the phage DNA.

This suggests that the fd phage's DNA has two sensitive sites, located on adenine bases. If the two sites are methylated (that is, marked MAP), the phage can grow equally well in both *K* and *B* bacteria. If, however, these sites are unmethylated, the *B* bacterium recognizes the phage as being the "wrong" kind and breaks down its DNA. Presumably the recognition is effected by a special enzyme that can split the DNA molecule. The *B* bacterium also has a methylating enzyme that can convert the two critical A bases to MAP (that is, attach a serif) and thus make the phage DNA acceptable so that it multiplies in *B* cells [*see top illustration on page 98*].

This interpretation has now been confirmed by various experiments. Some of the specific enzymes that break the vulnerable DNA sites and some of those that can methylate them have been isolated and identified. For example, Arber's group in Geneva and Matthew S. Meselson and Robert T.-Y. Yuan at

Harvard University have identified the enzymes that break the DNA molecules marked *K* and those that break the DNA molecules marked *B*. As expected from Arber's vulnerable-site hypothesis, it turns out that in each case the enzyme makes just a few breaks in the DNA molecule. Similarly, Arber and his colleagues have isolated a marking enzyme: from bacteria of the *B* strain they extracted the enzyme that can transfer methyl groups from a suitable methyl-donor substance (S-adenosyl methionine) to the *K*-marked (unmethylated) DNA of fd phages.

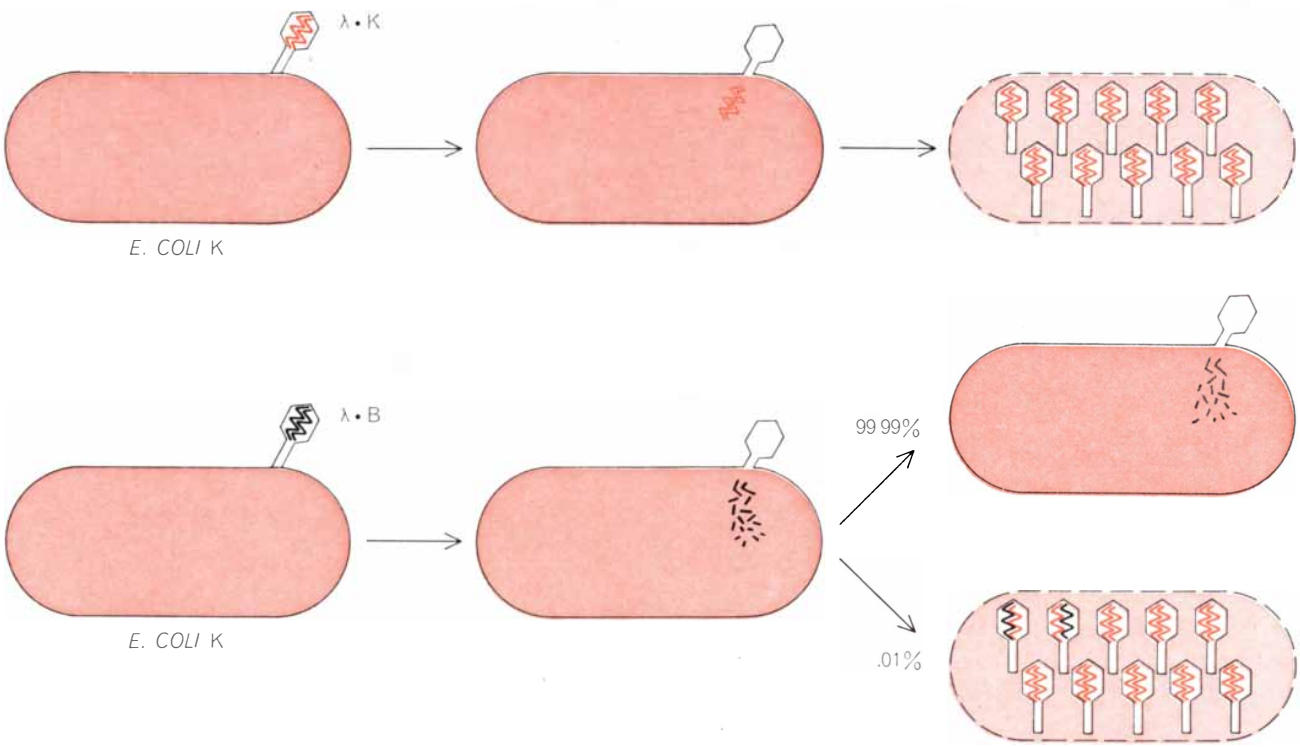
Thus we see that the bacteria possess a well-defined system for marking and recognizing phages. Shifting from our printing metaphor, we might say that each strain of *E. coli* bacteria stamps its own trademark on the DNA of the phages it produces, just as a factory brands its commercial product.

Work in several laboratories has elicited further details of the bacteria's branding and recognition system. It has been learned that the system in *E. coli* involves three closely linked genes. One directs the synthesis of the DNA-breaking enzyme, another controls the synthesis of the methylating enzyme, and the third gene generates a mechanism that is responsible for the recognition of the critical DNA sites that are to be either broken or methylated. It seems likely that this mechanism, or component, is a protein chain that associates itself with both the breaking and the methylating enzymes, and that can recognize the specific sequence of nucleotides that represents the critical DNA sites [*see bottom illustration on page 98*].

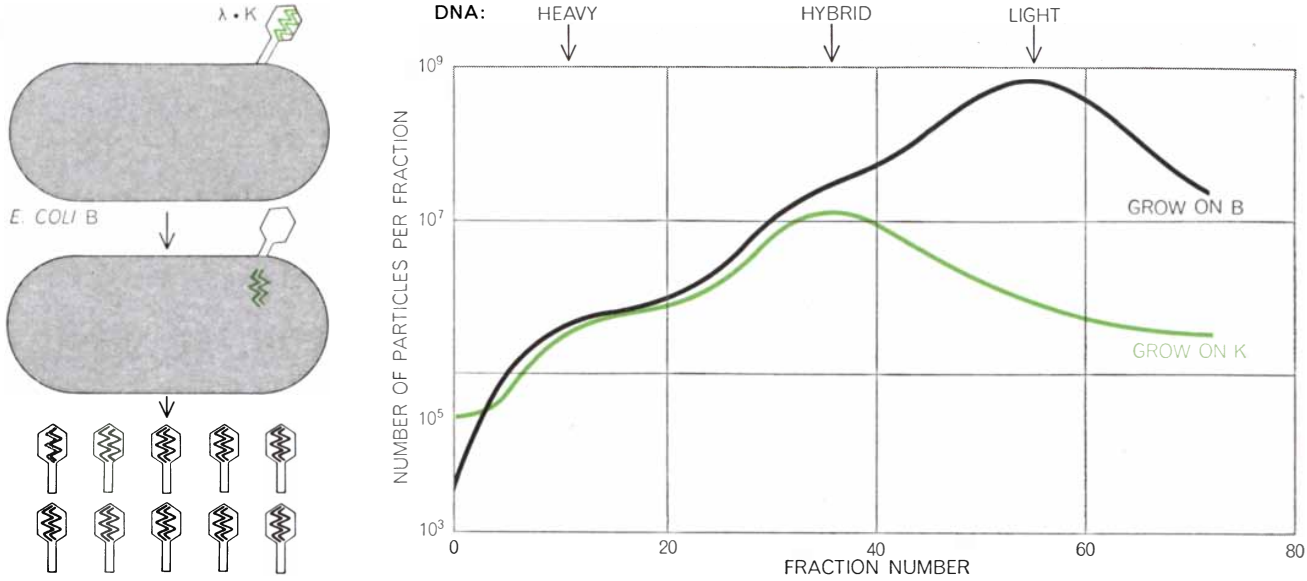
The marking and restricting system is widespread among the *E. coli* and related strains of bacteria; it is possessed not only by the *K* and *B* strains but also by others (except for the *C* strain and certain others that have lost the recognition system, perhaps through mutation). Also Arber and his co-workers found that DNA incompatibility is not confined to the case of invasion by a phage. It also applies to exchanges of DNA among the bacteria themselves. When a female *E. coli* cell mates with a male cell carrying the wrong DNA brand (for example, if the female is *B* and the male *K*, or vice versa), the female on receiving the male's DNA will break it down, just as if it belonged to a phage.

The answer to the T2 mystery turned out to be a different story. The investigation of this problem, carried out in our laboratory at the Massachusetts Institute of Technology by my colleagues Toshio Fukasawa, Costa P. Georgopoulos, Stanley Hattman and Helen R. Revel, demonstrated that the DNA in the T2 phage is not branded in the same way as that in the lambda and fd phages.

The DNA of T2 (and of its even-numbered relatives T4 and T6) carries an oddity: the base cytosine always has a hydroxymethyl group (CH_2OH) attached to it, so that the nucleotide contains hydroxymethylcytosine (HMC) instead of cytosine as its base. The discovery of the HMC base by Gerard R. Wyatt of Yale University and Seymour S. Cohen of the University of Pennsylvania played a major role in phage biochemistry. In most of the HMC nucleotides of these phages one or more sugar molecules (glucose) normally are attached to the hydroxymethyl group [*see illustration on page 100*]. What our laboratory team discovered was that when an *E. coli* bacterium of the *B*/4 strain



GROWTH RESTRICTION is demonstrated by cells of *E. coli* strain *K*. No restriction occurs when *K* cells are infected by phage $\lambda \cdot K$ (*top*). The deoxyribonucleic acid (DNA) of the phage (*colored zigzag shape*) enters the cell and exploits the cell's chemical machinery to produce about 100 new phage particles, which are released when the cell lyses, or dissolves. Restriction occurs (*bottom*) when *K* cells are infected by $\lambda \cdot B$ particles: lambda phages previously grown on *E. coli* strain *B*. The DNA of the phage (*black zigzag*) enters the cell but is broken down. In about one cell in 10,000, however, the phage DNA manages to multiply and give rise to phage progeny. About 2 percent of the progeny can grow in both *B* and *K* cells because their DNA is a hybrid molecule consisting of one strand of DNA (*black*) from the original $\lambda \cdot B$ and one strand (*color*) newly made inside the *K* cell. The remaining progeny are now modified so that they will grow normally in *K* cells but with a probability of only 10^{-4} in *B* cells.

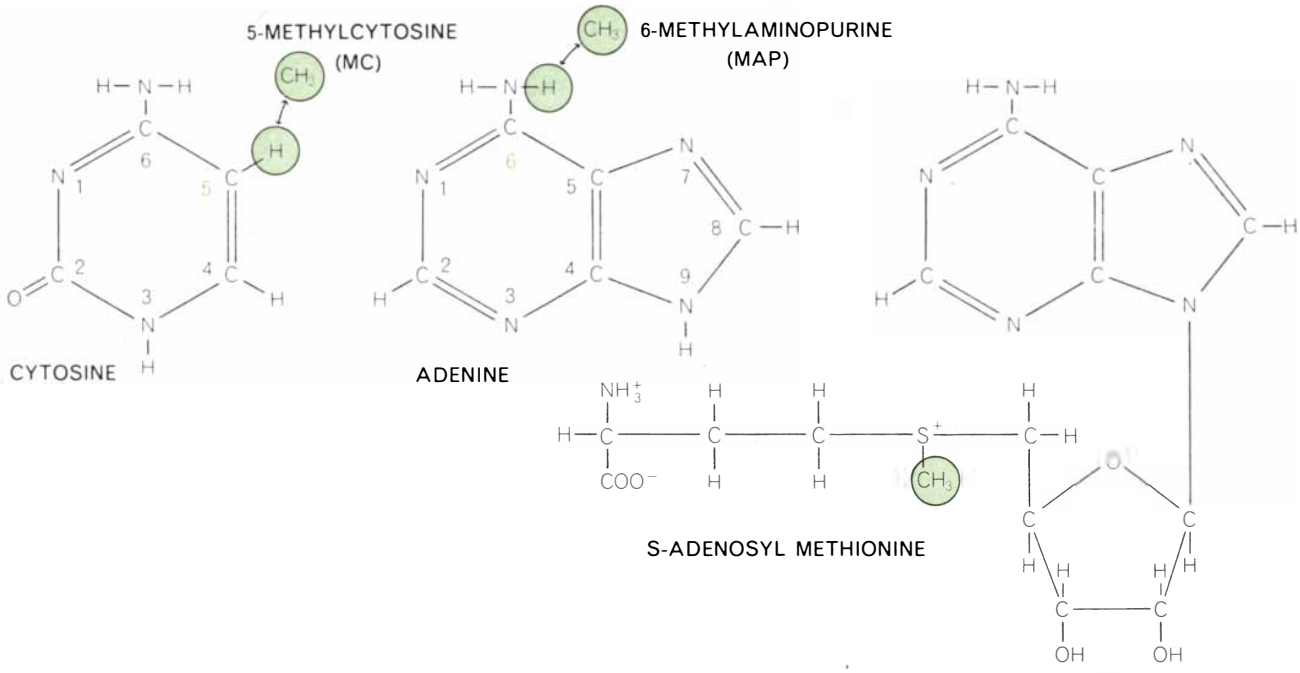


LABELING OF DNA demonstrates that phage particles possessing the ability to grow on both *B* and *K* strains of *E. coli* are predominantly those with hybrid DNA molecules. The experiment was conducted at the University of Geneva by Werner Arber and Daisy Roulland-Dussoix. They infected cells of strain *B* made up of atoms of ordinary weight with phage λ · *K* that had been grown on *E. coli K* cells incorporating heavy hydrogen (deuterium) and heavy nitrogen (^{15}N). Thus the DNA molecules in particles of λ · *K* were labeled with heavy atoms. The progeny produced in the light *B* cells were spun in a centrifuge containing a gradient of cesium chloride. The phage particles become distributed in the centrifuge tube according to their weight: heaviest particles at the bottom, lightest at the top. The phage particles in different fractions are then tested for their ability to grow on *B* and *K* cells, with the result plotted at the right. The particles containing hybrid DNA, about 2 percent of the total, grow in both kinds of cell. A small fraction of phage inherits two heavy strands of DNA from its λ · *K* parent and can also grow in both *B* and *K*. For this experiment Arber used a special strain of *E. coli B* that can impress the *B* modification on the phage DNA but lacks the *B* restriction function.

modifies, or brands, a T2 phage, the way it does so is to fail to attach the glucose to the HMC at the sensitive sites in the DNA molecule. In short, it changes the DNA from "sweet" to "sour"!

The soured phage can no longer multiply in *E. coli* cells; the cells detect the absence of glucose at certain critical sites and break down the DNA. Desugared T2 can, however, grow in the cells of dysentery bacilli, and these cells mark the phage DNA by attaching glucose at the necessary sites, thus restoring the phage's ability to grow in *E. coli*.

The special strains of *E. coli* that transform the phage from sweet to sour lack a substance (uridine diphosphoglucose, or UDPG) that is needed to donate glucose to the phage's DNA. This is one way for a T2 phage to acquire the sour branding. The brand can also be put on



"MARKED" BASES found in phage DNA that has been modified are 5-methylcytosine (MC) and 6-methylaminopurine (MAP). They are formed from the standard bases cytosine and adenine by the addition of a methyl group (CH_3), supplied by S-adenosyl methionine. Adenine (A) and cytosine (C) supply two of the four "letters" that spell out the genetic message in DNA molecules.

Part of you is riding with him.

If you're the kind of person who gets a kick out of watching Americans compete in international athletic competition, we have a worthy cause for you.

If you're the kind of person who feels proud when an American athlete brings home a medal, we have a worthy cause for you.

The United States Ski Team.

They represent Uncle Sam all over the world. But Uncle Sam doesn't foot the bill. Everytime they win, America wins. And everytime they lose, America loses. But Uncle Sam doesn't foot the bill. That's why The United States Ski Team has got to come to you.

Please help equip the team that represents you. Help train the team that represents you. Help the boys and girls win, who win for you. Please send a contribution to: The United States Ski Team, 1726 Champa St., Denver, Colo.

Help equip the U.S. Ski Team
Help train the U.S. Ski Team
Help the U.S. Ski Team

Ask about a membership in the United States Ski Association.

just published—two important texts for college chemistry

Third Edition

General Chemistry

LINUS PAULING, Stanford University

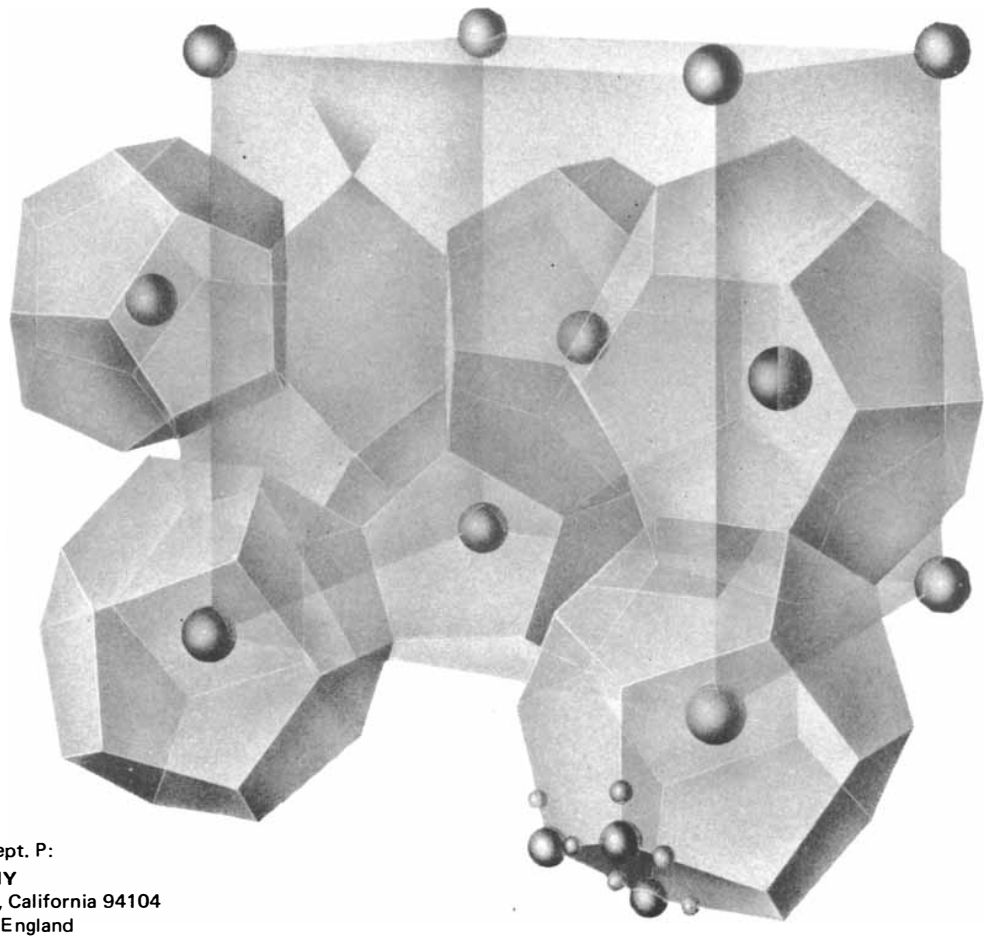
Extensively revised and updated, here is the third edition of the textbook that—when first published—revolutionized the teaching of chemistry by presenting it as a subject to be understood in terms of unifying principles instead of as a body of unrelated facts.

General Chemistry provides a sound and logical development of the theories of greatest importance in modern chemistry—atomic and molecular structure, quantum mechanics, statistical mechanics, and thermodynamics—along with enough descriptive chemistry to introduce the student to the multitude of chemical substances and their properties. The book is designed for use by first-year college and university students who plan to major in chemistry or in closely related fields, and by other students who have a special interest in chemistry and some knowledge of physics and mathematics.

In preparing this edition, the author has extended even further the correlation of the facts of descriptive chemistry with theoretical principles central in earlier editions. The principles of quantum mechanics are discussed on the basis of the de Broglie wave length of the electron. The quantized energy levels of a particle in a box are derived by means of a simple assumption about the relation of the de Broglie waves to the walls of the box. No attempt is made to solve the Schrödinger wave equation for other systems, but the wave functions of hydrogen-like electrons are presented and discussed in some detail, and the quantum states for other systems are also discussed.

Statistical mechanics is introduced before thermodynamics, and the discussion of thermodynamics is based on it. This arrangement reflects the author's belief that beginning students can better understand statistical mechanics than chemical thermodynamics.

The amount of descriptive chemistry has been decreased somewhat, and the presentation of the subject, especially in relation to the nonmetals, has been revised in such a way as to permit greater correlation with the electronic structure of atoms, especially electronegativity. In this edition use is made almost entirely of the International System of units. Many of the illustrations are new.



From your bookseller, or from Dept. P:
W. H. FREEMAN AND COMPANY
660 Market Street, San Francisco, California 94104
Warner House, Folkestone, Kent, England

Chemical Systems

Energetics, Dynamics, Structure

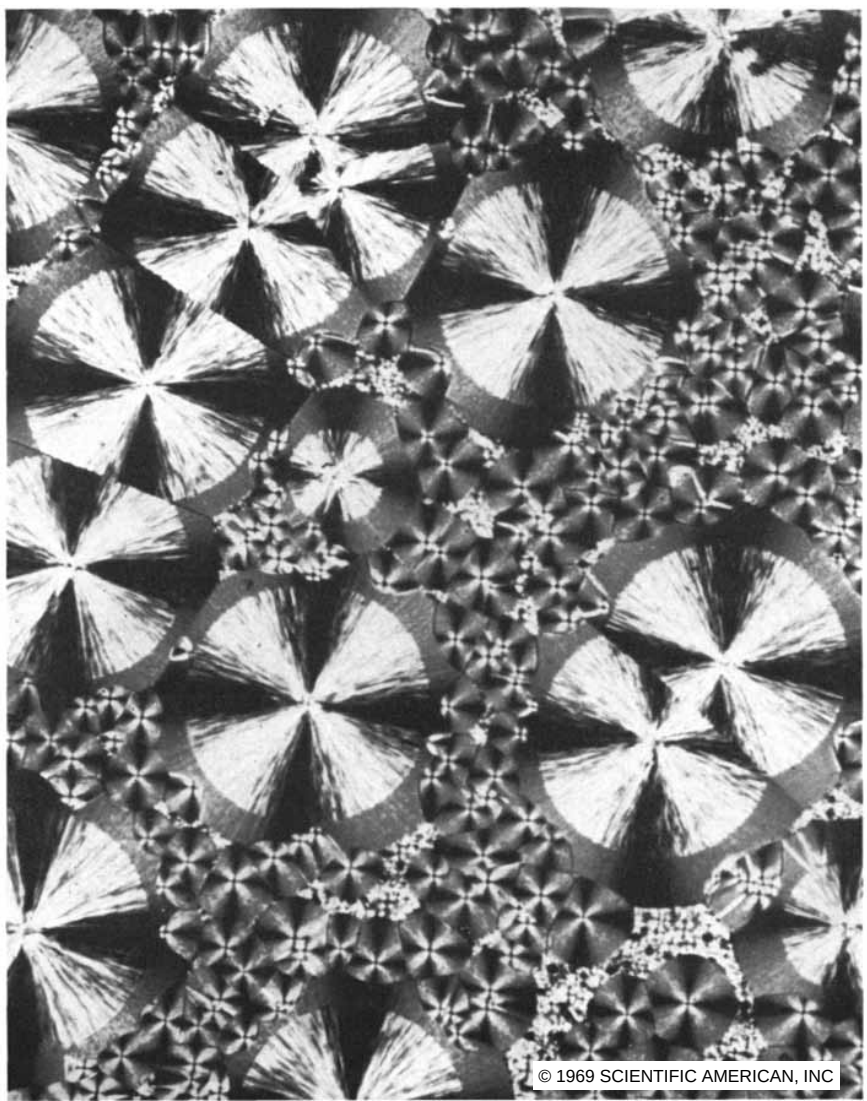
J. ARTHUR CAMPBELL,
Harvey Mudd College
With chapters by Tad A. Beckman,
Stephen V. Filseth, Kenneth M. Harmon,
Mitsuru Kubota, Philip C. Myhre,
William G. Sly, and Roy A. Whiteker,
all of Harvey Mudd College, and
by Neal W. Cornell, Pomona College

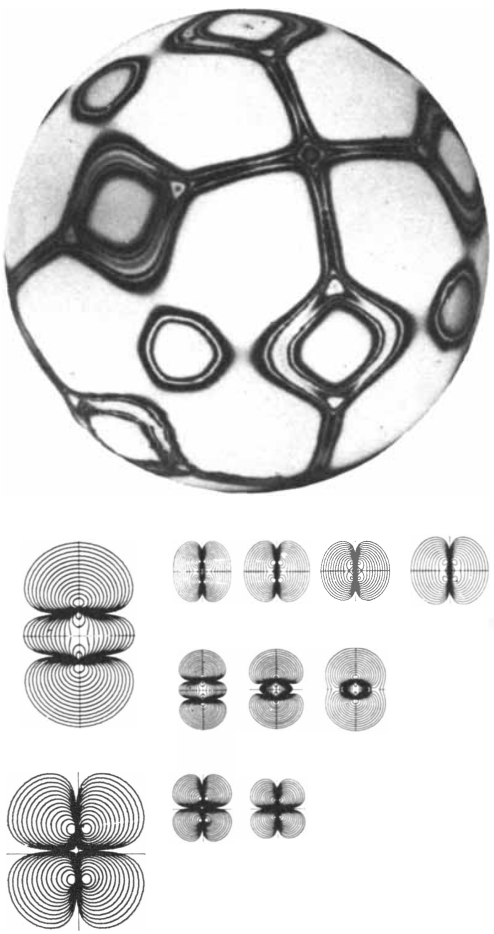
This college textbook in general chemistry—written by a former director of one of the most influential high school chemistry curriculum projects, CHEM Study—is designed for students of varying preparation who have a strong interest in science. Specifically intended for those who plan to specialize in science or engineering, *Chemical Systems—Energetics, Dynamics, Structure* provides a thorough introduction to general chemistry together with enough physical chemistry to serve as background for all further undergraduate science courses these students may take. It contains the fundamental material needed by students with minimal background and, clearly set off in optional sections, a large amount of advanced material that will interest and challenge even the best-prepared students.

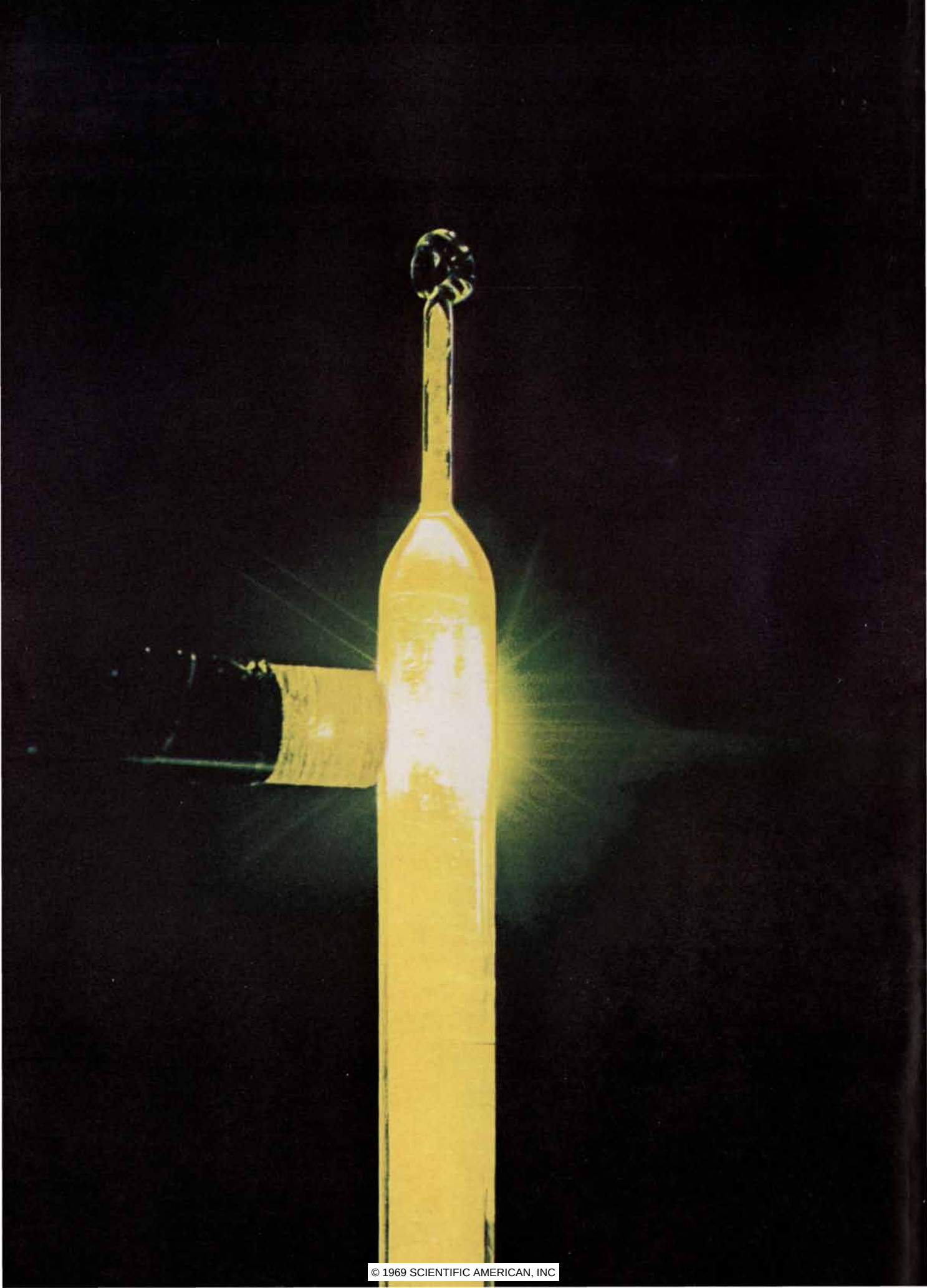
This text offers the teacher a high degree of flexibility in planning his course. It contains enough material for a three-semester course combining reaction chemistry and physical chemistry, but because much of the advanced material (nearly one-third of the text) is not essential to an understanding of the rest, the book can also be adapted to one-year courses.

The author emphasizes the understanding of the properties of matter in terms of molecular behavior. From the beginning he simultaneously develops topics in reaction chemistry and physical chemistry, showing how an understanding of one can help in understanding the other. Important concepts of thermodynamics such as entropy are introduced as early as the first chapter and reappear throughout, with particular emphasis on statistical interpretations. Experimental observations precede and serve as the basis for theoretical interpretations, and the relative strengths of alternative theories are discussed. More than 350 solved exercises illustrate points under discussion, and an additional 700 problems appear at the ends of chapters, grouped according to increasing difficulty.

The book is divided into seven parts, each of which addresses itself to a question that is central to the study of chemistry. A recurring theme is the intimate involvement of chemistry in human affairs.







Venture: How do you tame excited molecules?

Answer that one and you'll open up a whole new field of solid state physics that just might come to be called "excitonics." Because the most exciting thing about excited molecules in solids, right now, is that no one knows what to do with them.

This intriguing state of affairs came about after physicists began firing photons into molecular crystals and observing the results. Which were: "excitons."

An exciton is a conceptual entity that has more "stateness" than "thingness" about it.

When a photon strikes a molecule in an organic crystal with sufficient energy, it bumps an electron to a higher energy level, leaving a "hole" in the molecule.

In the brief interval before it falls back into its hole, the electron releases the energy it received from the photon, which propagates another hole-electron pair in a neighboring molecule, and thus on through the crystal.

This phenomenon is called the "singlet" excited state: or the singlet exciton. Du Pont scientists have produced it with a 150-watt bulb.

In the singlet, an electron is excited without any change in direction of its spin or magnetic moment. It dies quickly, and a light emerges from the crystal. But with an intense light source, such as the laser, an even more interesting excited state has been produced: the "triplet."

In the triplet, the spin of the excited electron is reversed, a magnetic field is produced, and the excited state lasts a million times as long—about a hundredth of a second.

Du Pont researchers have also found that two triplets can combine, producing a singlet exciton with greatly increased energy and a life span of a hundred millionth of a second. Of promising interest is that this tendency of triplets to merge can be sensitively controlled by applying a magnetic field to the crystal.

Perhaps the next step will be the engineering of devices that manipulate light signals directly, bypassing the present need to convert them first into electrical signals and then back into light.

Perhaps too this line of research will lead to greater understanding of the mechanisms of light-energy transfer itself, such as those involved in photosynthesis by living plants.

The possibilities are many.

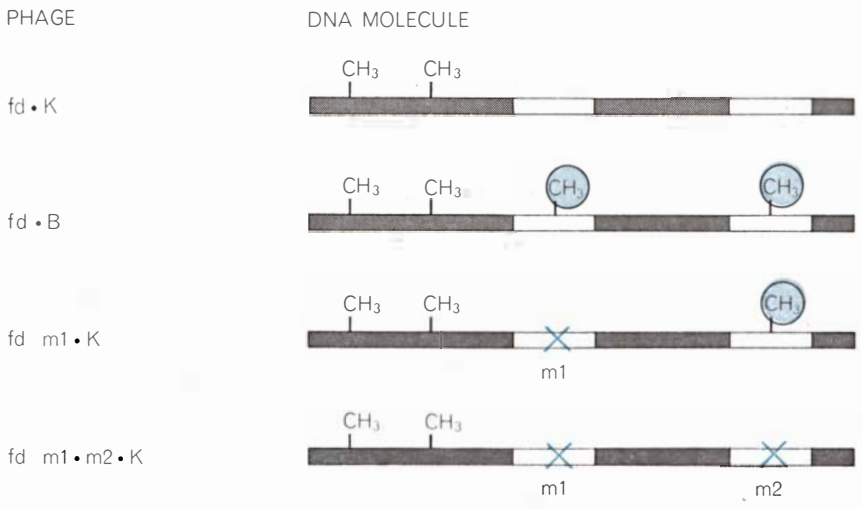
Innovation—applying the known to discover the unknown, inventing new materials and putting them to work, using research and engineering to create the ideas and products of the future—this is the venture Du Pont people are engaged in.

Crystalline organic material in a sealed glass tube is illuminated by a filtered light source from the right, producing "excitons" in the material.

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

Ventures for better living.

PHAGE	CHARACTERISTIC	PROBABILITY OF GROWTH IN *E. COLI* B
fd • K	2 MAP PER DNA MOLECULE	.001
fd • B	4 MAP PER DNA MOLECULE	1.0
fd m1 • K	3 MAP PER DNA MOLECULE	.03
fd m2 • K	2 MAP PER DNA MOLECULE	1.0



VULNERABLE SITES in the DNA molecule of the phage fd are represented by the white regions in the lower part of the illustration. These sites, or sequences of bases, are broken with a probability of 97 percent by the "restricting" enzyme of *E. coli B* unless an A (adenine) base in that sequence has been converted to MAP by the modifying (that is, methylating) enzyme present in *B* cells. There are also two irrelevant CH_3 groups elsewhere in the fd DNA molecule. The table (*top*) shows for various strains of fd the probability of growth in *E. coli B*. Strains of fd · *K* with certain mutations, *m*1 and *m*2 (*indicated by* X *marks*), are insensitive to the restricting enzyme in *E. coli B* even if they are not methylated.

BACTERIAL GENE	FUNCTION	MUTANTS
r	RESTRICTION MECHANISM ("NUCLEASE" COMPONENT)	r⁻: RESTRICTING FUNCTION LOST
m	MODIFICATION MECHANISM ("METHYLASE" COMPONENT)	m⁻: MODIFYING FUNCTION LOST
s	SPECIFICITY (SITE-RECOGNITION COMPONENT)	s⁻: BOTH RESTRICTING AND MODIFYING FUNCTIONS LOST

GENETIC CONTROL OF RECOGNITION SYSTEM seems to involve three closely linked genes in *E. coli*. Gene *r* makes the restricting enzyme that breaks the phage DNA molecule unless it carries the proper MAP marks. Gene *m* makes the methylating enzymes that provide the marks. Gene *s* makes a component responsible for specific recognition of sites where the marks may or may not be present. Presumably this recognition component is part of both enzymes: the one that can break DNA and the one capable of methylating it.

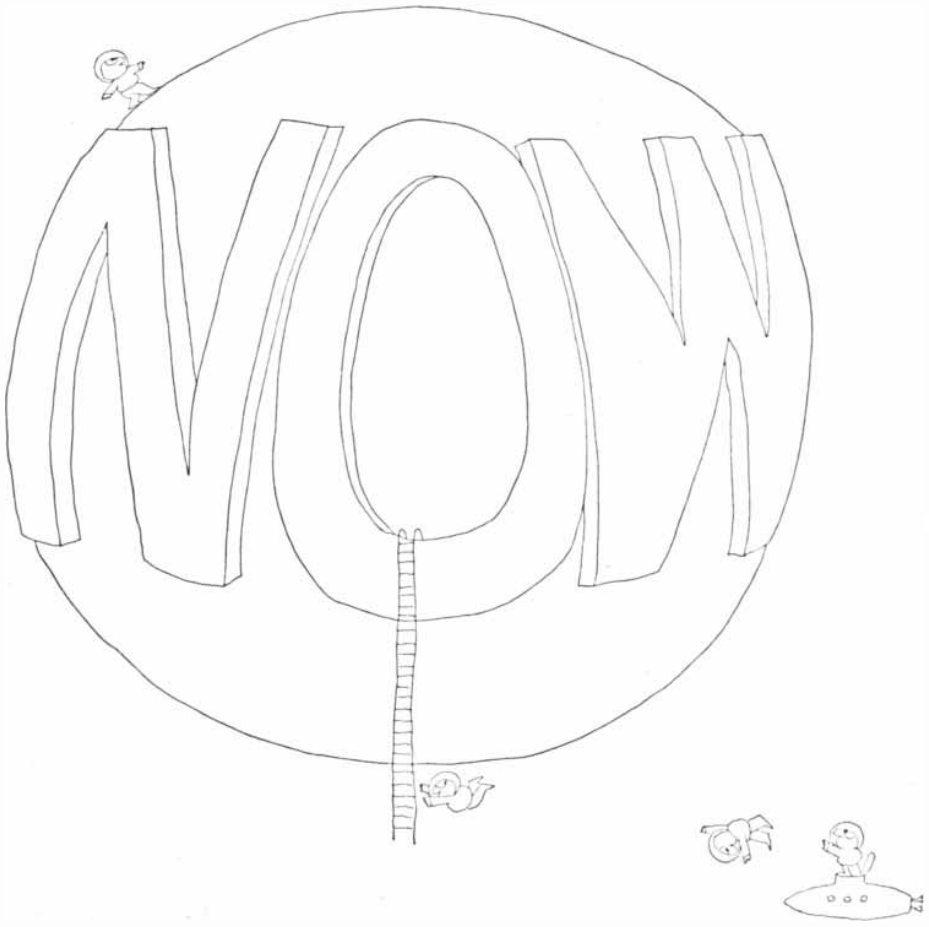
it, however, by a genetic mutation in the phage itself, that is, by an alteration of the phage genes that normally are responsible for production of the enzymes that attach glucose to the HMC [*see illustration on page 102*]. The *E. coli* bacteria, for their part, possess special genes that endow them with the ability to recognize and destroy sour DNA. These genes produce two enzymes, apparently different, that recognize and attack specific unsweetened sites in the DNA molecule. Experiments have shown that mutation of these two genes eliminates the rejection mechanism, so that unsweetened phages can grow in the mutated *E. coli* cells.

The two enzymes responsible for distinguishing between sweetened and unsweetened DNA have not yet been isolated. All we know about them so far (from genetic analysis) is that they are not the same as the enzymes that detect the difference between the methylated and unmethylated brands on the DNA of lambda and fd phages and on the DNA of different strains of *E. coli* bacteria.

How does the enzyme, in each case, recognize the brand? By what mechanism does the enzyme (protein) molecule find and identify the significant chemical markings on the DNA molecule? This is an intriguing question that applies to many other phenomena in molecular biology. For example, the enzymes that bring about the replication of DNA and those that build RNA molecules using DNA as a template must find the right place on the DNA at which to start the construction of the new molecule. How do they recognize these starting points?

We must suppose that the identifying marker on the DNA molecule in each case is a certain sequence of nucleotides, and that the enzyme establishes recognition by temporary attachment to this sequence—by fit and "feel," so to speak. There are good reasons to believe the identifying sequences are generally rather short; the length of a globular protein would not span many nucleotides in their linear array in the DNA molecule. Arber has suggested that the identifying sequences in branded DNA are probably no more than six to eight nucleotides long. It may soon be possible to work out the exact sequence of bases that constitutes the recognition site for at least one of the restrictive enzymes. This would be a big step forward in the study of protein-DNA interaction.

What kind of search do the enzymes carry on? Are the sensitive sites recognized and attacked only when enzymes



Discover the world of now.

The world of now was created by UNIVAC® real-time computer systems that continuously gather, organize, update and communicate information to any level of management. Only what's needed. Only where needed.

The old world of business was slow-moving and leisurely. Annual briefings were often enough. Monthly reports were soon enough. Quarterly summaries were recent enough.

Trouble is, the old world way of business is neither profitable nor efficient in this new age of rapid developments and fast decisions.

So a new world way of doing business has been found.

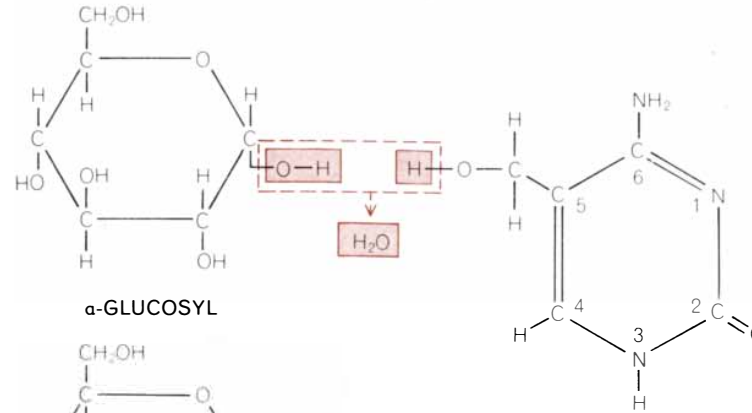
The world of now.

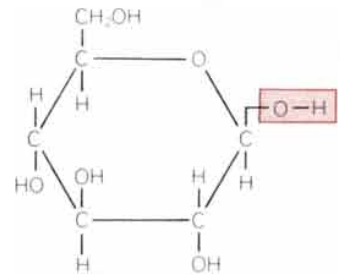
In this world you can enjoy real-time management for the first time. Management in the present. Constant command through constant information.

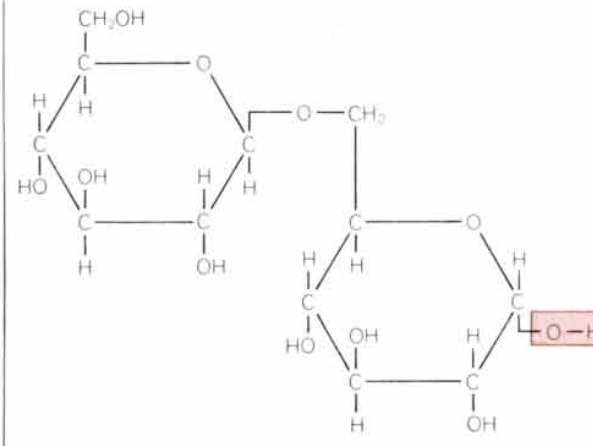
Univac pioneered in real-time information systems and put them to work for our space programs. That's how we found the world of now.

You can discover it for your business. Just call us for the map.

UNIVAC SPERRY RAND
FIRST IN REAL-TIME INFORMATION SYSTEMS







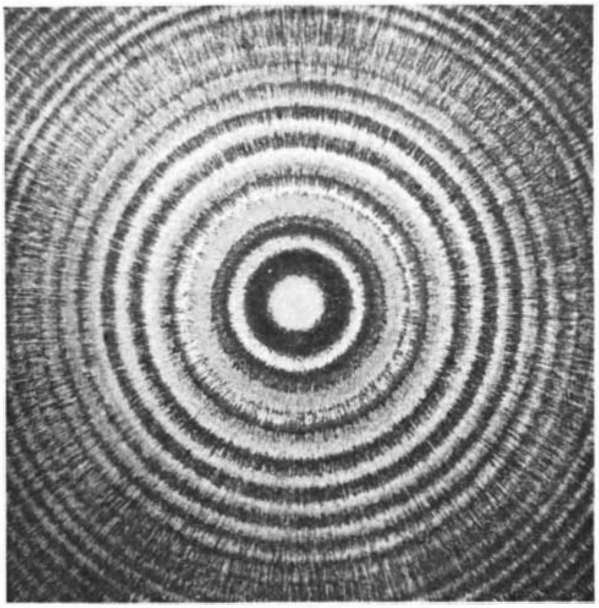
"SWEET" AND "SOUR" LABELS provide another recognition system that enables *E. coli* cells to discriminate among invading molecules of phage DNA. In this system, which applies to the phages T2, T4 and T6, the base cytosine (C) is replaced by 5-hydroxymethylcytosine (HMC), a base formed when a hydroxymethyl group (CH_2OH) replaces hydrogen on the No. 5 carbon atom of cytosine. The normal phage, which is able to multiply in *E. coli* cells, has 70 percent or more of its HMC bases linked to one of the three sugar structures shown at the left. Such DNA molecules can be regarded as sweet. When the sugar units are missing, the DNA molecule is sour and is readily broken down by *E. coli* cells.

happen to fall on them directly? Or do the enzymes browse along the phage DNA molecules, possibly as the latter nose into the bacterium, until they find the telltale markers? A finding by Georgopoulos and Revel in our laboratory suggests that the second alternative may be correct. They found that even a trace of "sweetness" (that is, glucosylation of comparatively few of the HMC bases, such as occurs in certain mutant T2 phages) was sufficient to protect the DNA of these phages from an enzyme that attacked only one particular site on the molecule and then only when it was unsweetened. It seems reasonable to assume that the small amount of glucose in these phages attaches itself to HMC groups at random, and therefore that the HMC groups at the particular site this enzyme attacks may often be unsweetened. We can guess the reason this site usually escapes attack is that the enzyme explores the DNA molecule and stops its exploration or falls off as soon as it encounters any glucose.

Another puzzling question is posed by the finding that even if only one (either one) of the two strands of a phage's DNA carries the protective marking, an

"LASER LIGHT:"

A SCIENTIFIC AMERICAN FILM



Almost everyone has heard of lasers, but relatively few people have seen them in action. The Editors of SCIENTIFIC AMERICAN now present "LASER LIGHT," a 16-millimeter sound film about lasers: what they are, how they work, the marvelously pure and curiously scintillating light they produce, how they are being used and how they may be used in the near future. The film is in color and lasts 37½ minutes. It is now available for sale or rent.

A few highlights of the film are:

- **Computer-generated animation explaining stimulated emission and resonant optical cavities.**
- **Ripple-tank and oscilloscope demonstrations explaining the wave principles underlying laser action and holography.**
- **Holograms, their three-dimensionality dramatically evoked by the moving camera.**
- **A 600-foot, 8.8-kilowatt laser in action.**
- **Tunable lasers.**
- **A television picture transmitted by laser beam.**
- **The laser chalkline for the San Francisco Bay tunnel.**
- **Laser interferometry.**
- **Gas, solid and organic-liquid lasers.**
- **An experiment on the use of holography in a computer memory.**
- **Original musical score.**

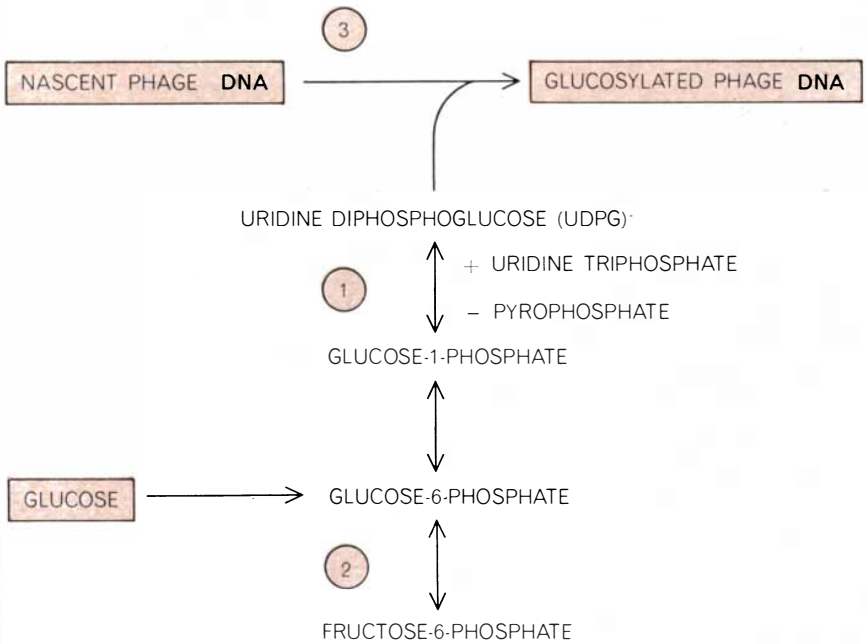
"LASER LIGHT" is recommended for general audiences with an interest in science and technology, and for use in conjunction with the teaching of physics and optics. The film is accompanied by a selection of five SCIENTIFIC AMERICAN articles on lasers and holography, written by leading authorities in these fields.

The sale price per print is $375, the rental price $37.50 for a booking of three days. If the film is purchased after rental, the rental price will be deducted. If rental booking is desired, kindly specify date. Write Motion Picture Department, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017

enzyme will not break the molecule. This indicates that in the case of a vulnerable molecule the enzyme scans both strands separately before breaking the molecule. How does it manage to scan the strands individually?

The entire set of phenomena I have described in this article raises a more general question. What is the evolutionary significance of the DNA-branding system? What function does it serve for the bacteria? One obvious suggestion is that the system gives a bacterium a defense against certain phages. Evolutionary development could, however, have provided the bacteria with more effective defense mechanisms, such as eliminating the surface sites on the bacterial cell to which phages attach themselves. Furthermore, the bacteria that can recognize and destroy branded DNA have no defense against phages that are not branded. It is hard to believe the branding system evolved simply to protect bacteria of one strain against phages coming from another strain. A more plausible speculation is that the system serves primarily to prevent "undesirable" mixing of the bacterial genes (DNA) between the strains of bacteria themselves. Presumably in nature the *E. coli* bacteria do mate or otherwise exchange genetic material. If this is so, the ability of a *B*-strain bacterium to reject *K*-marked DNA (and vice versa) is an effective device for keeping each strain "pure." Thus the branding-and-rejection system facilitates the evolution of bacterial strains in diverging directions, in the same way that isolation mechanisms in cross-fertilization play a role in the evolution of plant and animal species.

The case of sweet and sour DNA seems to tell a clearer and more dramatic story. The T2 phages have the ability to break down the DNA of the bacteria they attack, which contains cytosine instead of HMC. Hence the hydroxymethylation of cytosine in the phages' own DNA may have been an important step in the evolution of their ability to multiply in the bacteria. We can surmise, then, that in reply some strains of *E. coli* by natural selection evolved the ability to break down phage DNA marked with HMC. The phage in turn evolved the capacity to tack glucose onto HMC to protect the vulnerable sites of its DNA. Here, then, the evidence of the branded DNA may be unfolding for us a scene in the dynamic acting out of evolution at the most elementary level: the chemistry of the genetic material itself.



SYNTHESIS OF SWEET DNA requires a series of biosynthetic steps culminating in the addition of glucose units to the nascent DNA of the T-even phages. Mutants of *E. coli* can have blockages in the enzyme systems that carry out either or both of the first two numbered steps. Mutants with a blockage in enzyme No. 1 produce T-even phage with unglucosylated, or sour, DNA (T* phage). Mutants with a block in enzyme No. 2 can make the glucose donor substance, uridine diphosphoglucose, only if glucose is present in the growth medium. The last step, No. 3, is carried out by enzymes not normally present in *E. coli* cells; they are made from instructions coded in the DNA molecules of T-even phages.

THE PEOPLE OF YORK: 1538–1812

The parish registers of three centuries in this English city record changes in such averaged features of human populations as age at death, age at marriage and the season of conception

by Ursula M. Cowgill

Anyone interested in the history of human life and reproduction can hardly find a more fruitful mine of information than old parish registers of marriages, births and deaths. These records, going back for several centuries, are the only source we have for vital statistics on the general population over an appreciable span of man's past. In England there are continuous records of this kind dating from the 16th century. The parish registers of the city of York for the period 1538 to 1812, for instance, are now available in printed form. I undertook a systematic study of this record, with the help of a computer, to see what could be learned about recent trends in human evolution.

The task was not a simple one. It entailed, to begin with, identifying the dates of birth, marriage and death for each individual. As an illustration of the detective work that was sometimes required, consider an individual named Mary Smith. That name appears in the record frequently, and the birth (usually the baptism, which can be taken to approximately represent the birth date) of four or more Mary Smiths may be registered in the parish within a five-year period. Twenty to 30 years later this series of names turns up in the marriage registrations. Which Mary Smith is which? Which one, for instance, married John Henry? Happily a given Mary can sometimes be identified by references in both the birth and the marriage registry that connect her with a particular father named, say, Ambrose Smith.

Similar difficulties arise in finding the date of the same Mary Smith's death. In addition to the confusion among several Mary Smiths who were born at about the same time, there may be Marys who acquired the name Smith by marriage and also Mary Smiths who died in infancy; the death registry may neglect to mention that the deceased was an infant or, if she was an adult, whether Mary Smith was her maiden name or her married name. By searching through the records for all possible identifying references I was able to attach birth, marriage and death dates to some of the Mary Smiths; all those who were not distinguishable from one another were discarded from the study.

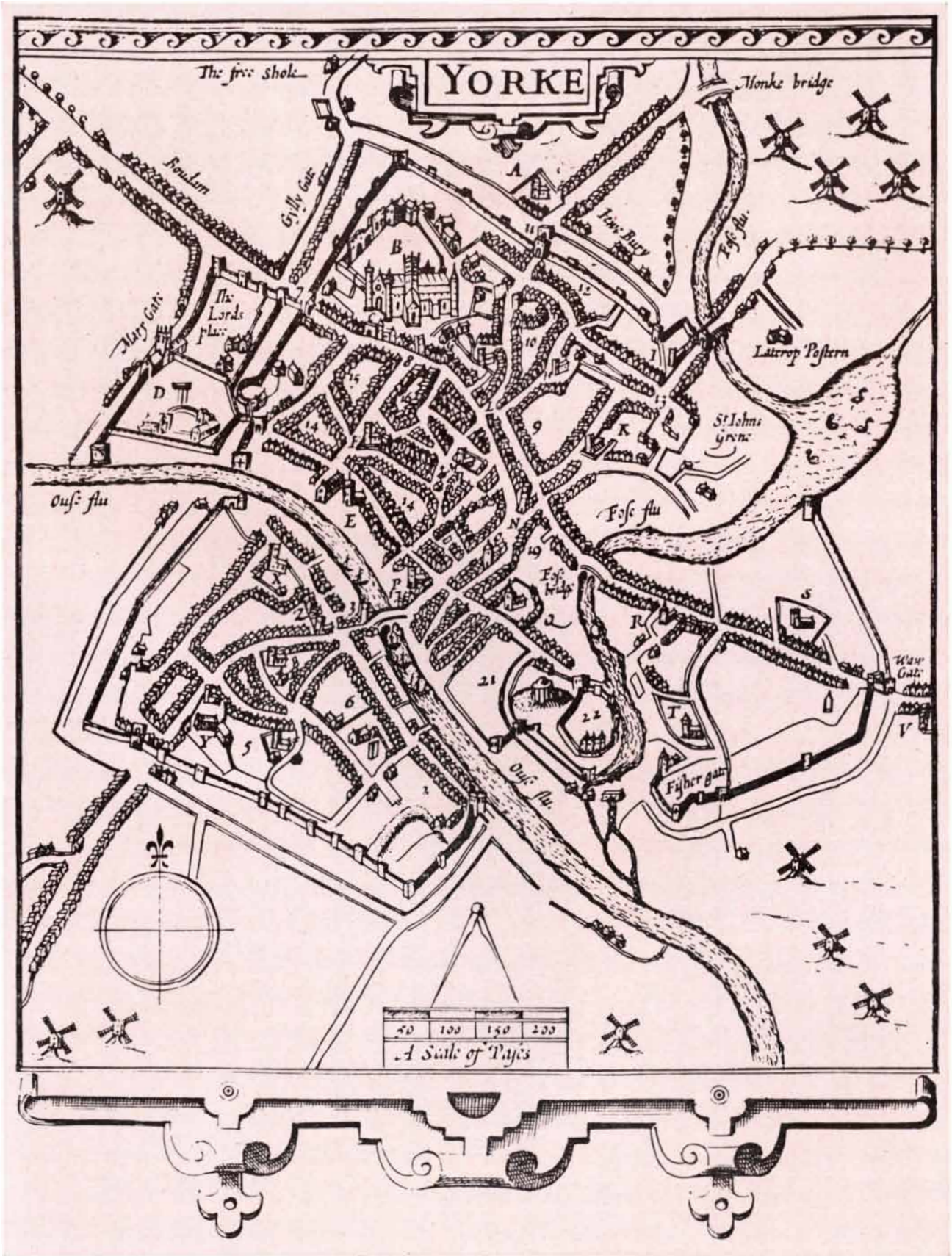
The final collection of usable data included a total of some 33,000 identifiable births and 11,000 marriages over the more than 250 years spanned by the York parish records. In order to follow the changes and the trend of events with time I divided the record into successive periods of approximately half a century each. The data were fed into a computer that was programmed to collate them in various ways, such as determining the relative number of births and the relative number of marriages in each month of the year for each of the half-century periods.

Let us begin with the seasonal cycles in marriage and childbearing. In the first period (1538 to 1601) there was a sharp peak of marriages in November, shortly before Christmas, and a dramatic minimum of weddings during Lent in March and April [*see illustration on page 107*]. Apparently in that era the medieval tradition for suiting marriage dates to the religious calendar was still strong. From the following half-century on, and particularly during the time of Puritan ascendancy, the record of weddings shows a decline in the significance of the religious calendar. The Puritans, after all, believed Christmas should be celebrated by a fast. By the latter part of the 18th century the wedding "season" was fairly well leveled out over the entire year, although there was still a small peak before Christmas and a drop during Lent.

When we come to the record of births, however, we find a marked seasonal rhythm that persists through the centuries. There are two peaks for births: in the spring and in the fall, reflecting respectively conception in the summer and soon after Christmas [*see illustration on page 106*]. The latter maximum is most pronounced in the 16th and early 17th centuries, and this no doubt is in part a reflection of the prevalence of Christmas-season marriages at that time and also of the short average life-span of adults, which would result in a disproportionate number of families that bore only one child, conceived at the time of marriage.

It seems evident, however, that the seasonal pattern of births is determined primarily by meteorological factors—that is, by the weather—rather than by the religious calendar or by mere social custom. Significantly, the pattern in Australia today matches that in England and Wales today (or the 18th-century pattern in York) if one shifts the dates in Australia by six months to reconcile the Southern Hemisphere climatic seasons with those in the Northern Hemisphere. Just how climate affects human fertility (in physiological and psychological terms) is not known.

One may suppose that some seasons are more favorable than others for the survival of a newborn infant; a child born in the spring or fall, for instance, encounters a minimum of exposure to the insect-borne diseases of summer and the respiratory diseases of winter. The York record shows that infant mortality (in the first three weeks of life) was indeed higher in some months than in others, but oddly enough the mortality rate



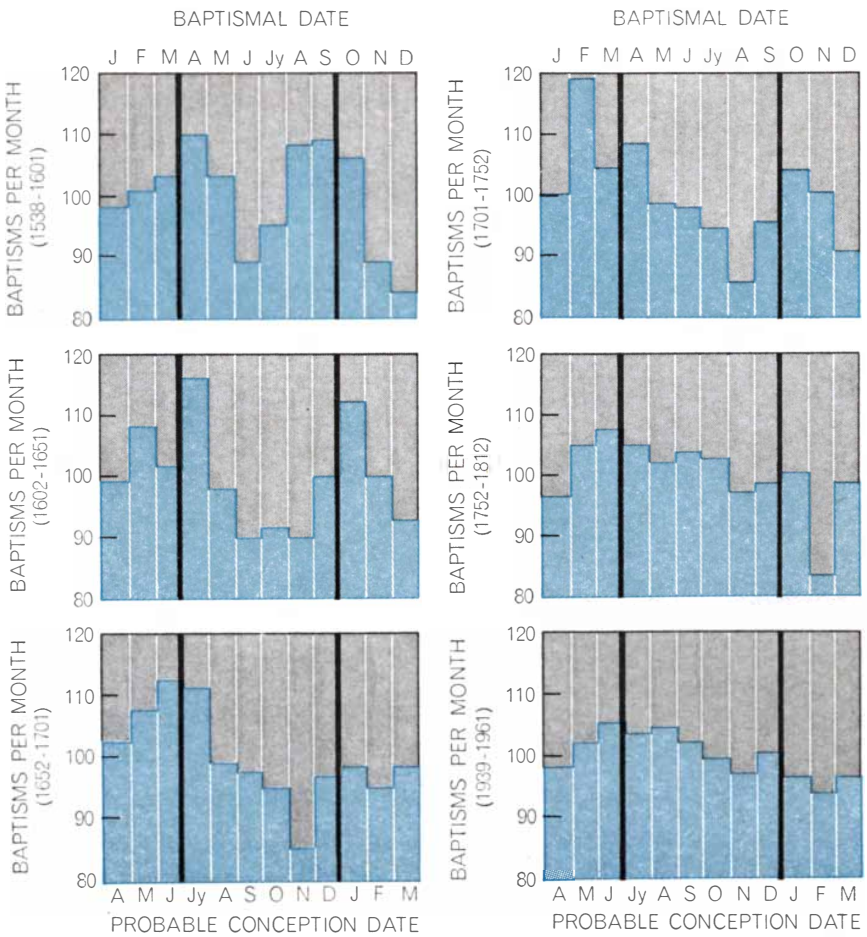
CITY OF YORK is seen in this map published in 1676. The 29 churches of the city, in which the parish records were kept, are indicated by the letters *A* through *Z* and the numbers *3* through *7*. York Minster, the city's cathedral, is at *B*. Scale is given in paces.

was particularly high in the seasons of high birthrate. The percentage of deaths was highest in September, just missing the October peak of births, and infant mortality was also relatively high in April, the peak month for spring births [*see upper illustration on page 110*]. The population somehow managed to give birth to the largest number of children at times that were relatively unfavorable for survival!

As far as longevity is concerned, apart from infant mortality, the York records indicate that the month of birth makes little or no difference. In a representative sample of the population there was no significant correlation between season of birth and length of life [*see top illustration on page 109*].

The parish records show that in the 16th and 17th centuries life expectancy among the people of York was notably brief—considerably shorter than that of the affluent British aristocracy [*see top illustration on page 108*]. During the 16th-century period only about 10 percent of the York population lived to the age of 40, and in the following century the percentage reaching that age was even smaller. The York death registries suggest that females had a shorter life expectancy than males, in contrast to the situation for the aristocracy of that time and the general situation today, in which women generally outlive men. Some allowance must be made for the likelihood that the York statistics do not give a full picture because they fail to include longer-lived women whose death dates were not recorded because they moved away from York after marriage. If, however, we consider only the persons who lived to the age of 20 (before the usual marriage age), we still find that the survival rate was higher for males than for females: in the 16th century in York the ratio among survivors to that age was about 129 men to 100 women, whereas for the contemporary British aristocracy the ratio was 95 men to 100 women. In the 17th century only about 10 percent of the girls in York managed to survive to the age of 20, as against about 25 percent of the boys.

Evidently the people of York in those times took better care of their boys than of their girls [*see bottom illustration on page 108*]. This seems to be still true today in certain nonindustrial nations. In a study of available statistics from such countries G. Evelyn Hutchinson of Yale University and I have found that life is generally more precarious for girls than for boys, particularly between the ages of three and four. Robert Cook and Arthur Hanslip have reported similar findings from a population study in Syria.

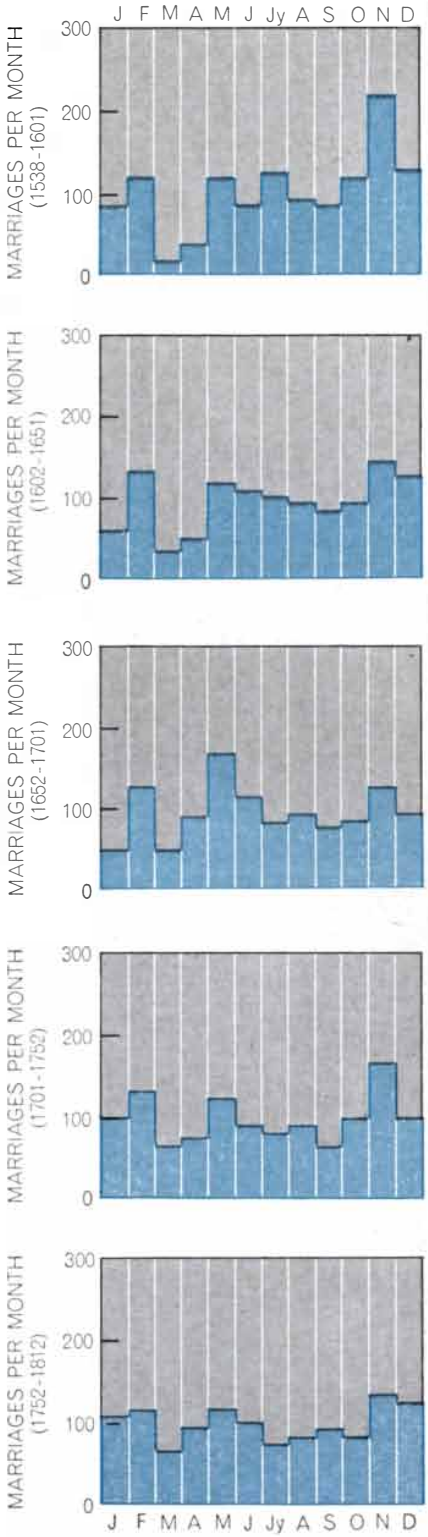


MONTH OF BAPTISM for more than 33,000 inhabitants of the city of York between 1538 and 1812 is shown for five consecutive intervals of approximately 50 years. The sixth graph (*bottom right*) shows the monthly baptisms in England and Wales between 1939 and 1961 for purposes of comparison. At the bottom of each graph are shown the probable months of conception; the black lines mark Midsummer's Day and Christmas. In the 16th and early 17th centuries the chances for successful conception were equally good in midsummer and midwinter. The June minimum in births persisted until 1651; this minimum shifted to August during the next 100 years. The November minimum in births, characteristic of European birth records, was established in York in the interval between 1752 and 1812.

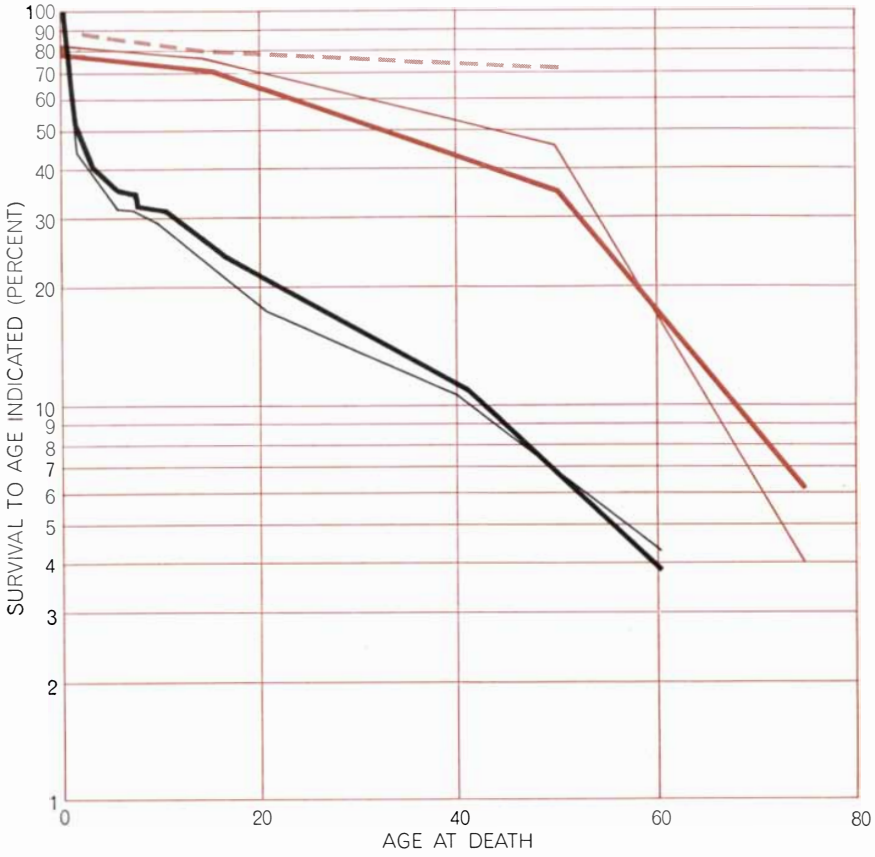
How can one explain the fact that, in spite of such disparities in survival of the sexes, societies generally manage to maintain an equal balance of males and females of reproductive age? The British statistician Sir Ronald Fisher suggested that populations may compensate for unequal death rates by producing more girls than boys or vice versa as the case may require. Is it possible that a population can, consciously or unconsciously, control the sex of its offspring? It is interesting to examine the family statistics of the York population from this point of view.

Certain studies in Finland have indicated that there is a slight but basic incompatibility between a male fetus and the mother's physiology. This suggests that fetal "wastage" in some form (such as stillbirth) is more likely to be male than female. My own studies, both of the York records and of modern statistics, point to a probability that such wastage increases with the age of the mother.

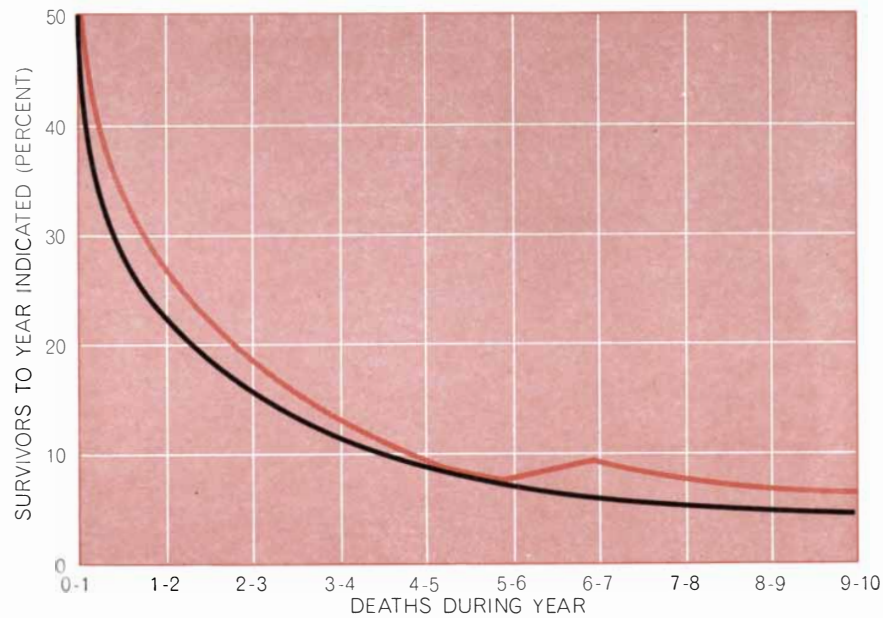
The first baby is more often a boy than a girl, particularly if it is born within a year after the marriage. Thereafter male fetal wastage appears to increase as the mother bears more children. The older the mother, the more likely she is to give birth to girls rather than boys. The York data also show significant statistical relations between the sex of offspring and the interval between births. For instance, the interval between two successive boys tends to be longer than that between two girls or between a boy



NUMBER OF MARRIAGES per month in York has been tallied on the basis of some 11,000 weddings recorded from the 16th century to the 19th century. In the 16th century the number of marriages was at a minimum during March (the Lenten season) and at a maximum in November, as Christmas approached. The Puritan ascendancy in the 17th century was accompanied by a decline in this pattern; evidently religious festivities no longer set the rhythm of the people's year.



EARLY DEATH was the lot of York townfolk during the 16th century. Scarcely 10 percent of men (*thick black line*) or women (*thin black line*) reached the age of 40. English aristocrats of the same period were much longer-lived. Forty percent of the men and 50 percent of the women (*thick and thin colored lines*) lived beyond 40. This is closer to the 1910 survivorship curve for English and Welsh women to age 50 (*broken colored line*) than to their York contemporaries, whose living conditions were obviously less conducive to longevity.



DEATH RATE FOR CHILDREN suggests that parents in York took better care of their boys than of their girls. The number of both sexes dying from year to year is expressed in the graph as a percentage of the survivors at the start of that year. Except in the first weeks and the fourth and fifth year, girls (*color*) survive less successfully than boys (*black*).

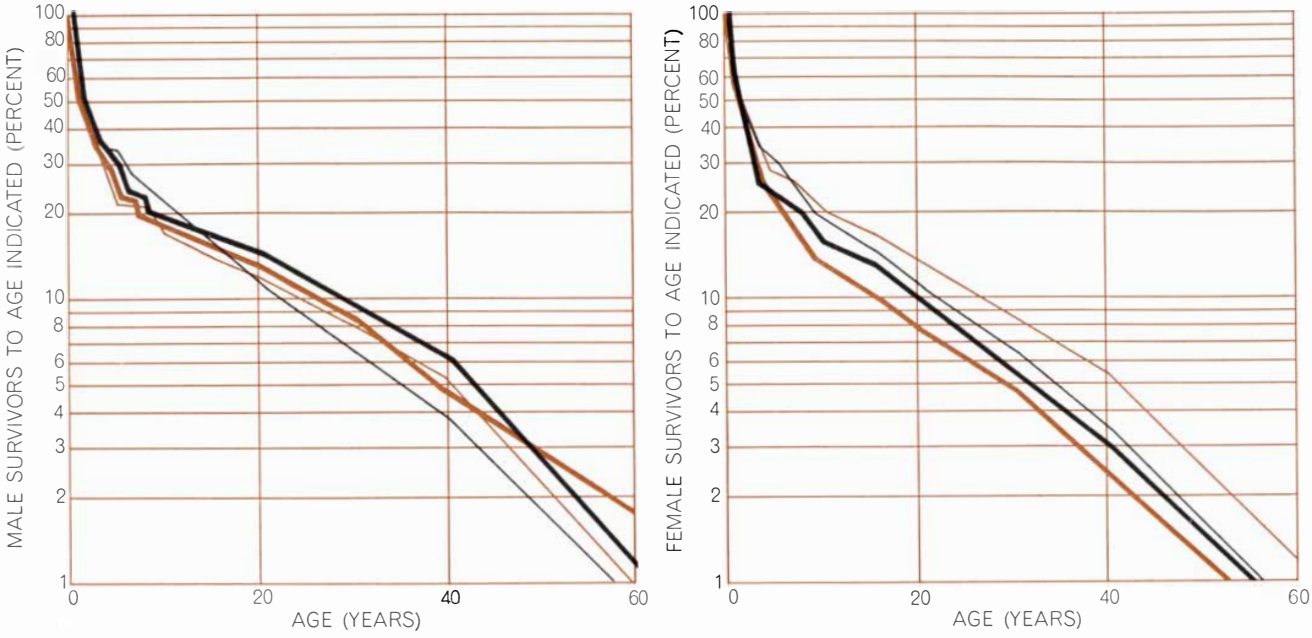
and a girl, particularly in large families and toward the end of the mother's production of children.

From the latter part of the 16th century to the middle of the 18th the York statistics show a steady trend to marriage at a later and later age, both for men and for women. The mean age of first marriage for men rose from about 26 years to 29; for women, from about 24 to about 28 [*see bottom illustration on opposite page*]. (There was a similar trend among the British nobility, among members of the European ruling families and in old Swiss families. In the French peerage, however, the mean marriage age fell sharply during this period.) In England the York trend to late marriage was paralleled by the record in the rural parish of Colyton in Devonshire, according to a study by E. A. Wrigley of the University of Cambridge.

It is amusing to find in retrospect that when (in 1798) Thomas Malthus proposed late marriage to check the alarming growth of population, precisely that had been going on for some time all around him without his knowing it. In York the average family size had shrunk from 4.86 in the 16th century to 3.32 in the 18th.

Why did people tend to marry so late? (Since the 18th century the trend, in Britain and elsewhere, has been to earlier marriage.) An analysis of the York record suggests that part of the reason for late marriage may have been physiological. On purely biological grounds one would suppose that women, like other mammals, will begin to mate and bear children soon after they are able to do so. In York, according to the parish records, during the three centuries from the 16th through the 18th the total number of women who bore infants before the age of 20 was only 34, and the total number of women who married before that age was only 50. Even among girls who became pregnant before marriage the average age of the mother at the birth of the child was no younger than it was among those who conceived the first child after marriage. In Colyton during the same era childbearing apparently was rare before the age of 24. All of this implies that conception was physiologically unlikely until about the age of 20. Some studies have indeed indicated that the beginning of menstruation generally came at a later age then than it does today [see "Earlier Maturation in Man," by J. M. Tanner; SCIENTIFIC AMERICAN, January, 1968].

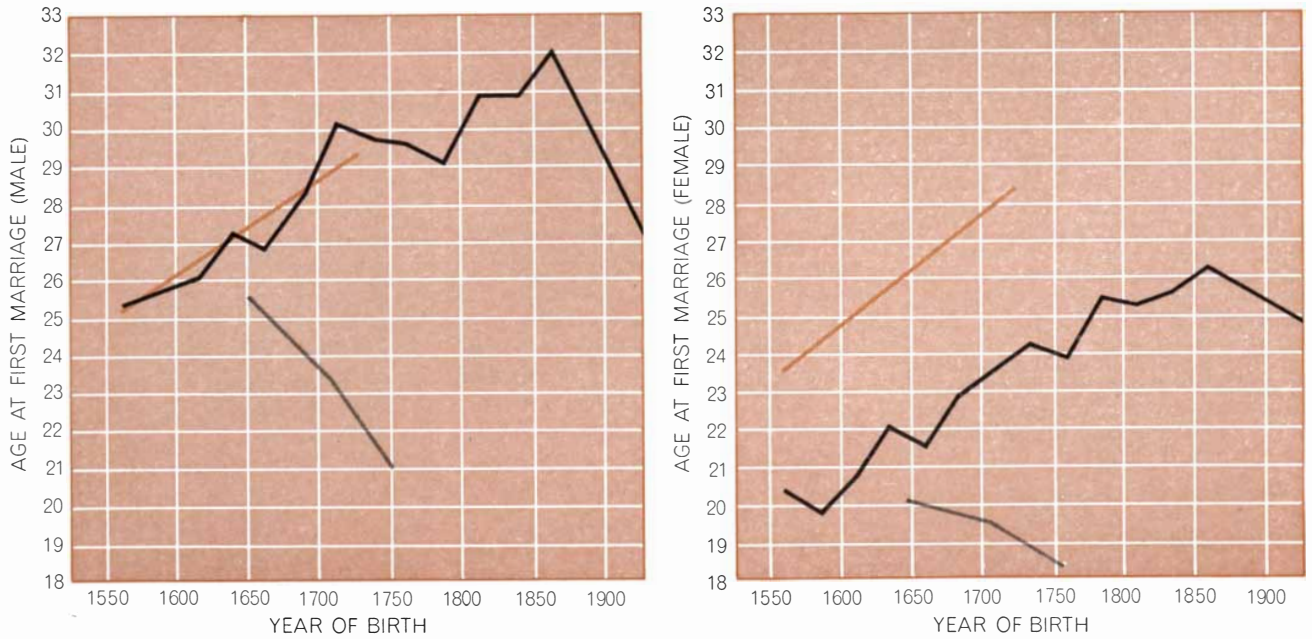
It seems that menopause also came



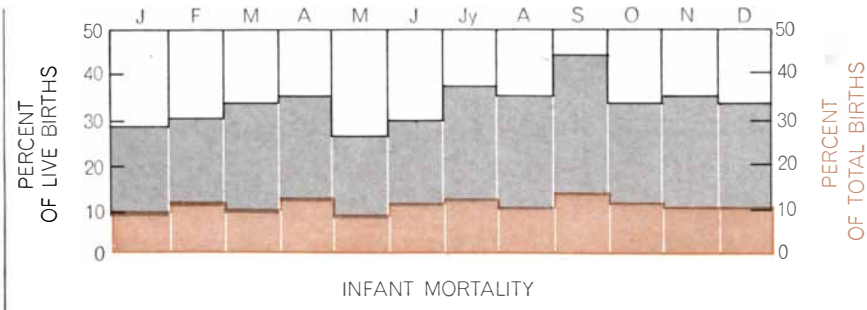
SURVIVORSHIP CURVES for persons born alive in York during the 17th century are shown separately for births during each quarter of the year. Thick colored and black lines are for males (*left*) and females (*right*) born respectively in fall and spring, the quarters with the greatest number of births. Thin colored and black lines are respectively for winter and summer, the quarters with the fewest births. There is little difference in longevity between either males or females born during different quarters of the year.

later in those days, so that the fertility span of women had about the same duration as it has today. In York nearly 30 percent of the married women were still bearing children after the age of 40, compared with only 10 percent in an equivalent present-day population (Catholic women in Australia). One can suppose there may be a natural mechanism that operates, through genetic selection, to maintain a minimum fertility span enabling the population to replace itself. This idea, however, requires further investigation, as there are some suggestions the span is now becoming longer, with female maturation coming earlier and menopause arriving later.

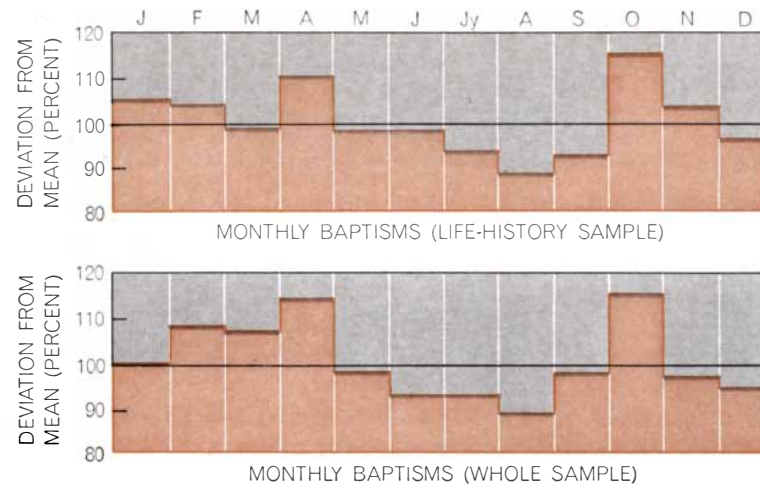
Both early menstruation and late menopause would seem to be disadvantageous, because the risks of infant and maternal mortality, prematurity and still-



AGE AT FIRST MARRIAGE is shown (*color*) for men (*left*) and women (*right*) of York at successive dates during the 16th, 17th and 18th centuries. For both men and women the mean age increases over the centuries. For men the increase closely parallels similar data for the British peerage (*black*). The York women's mean marriage age is even later than the marriage age of British noblewomen (*black*). Among French nobility (*gray*) in the years from 1650 to 1750 the trend instead was toward earlier marriage.



INFANT MORTALITY, high in 17th-century York, shows a peak in April, a trough in May, a major peak in September and another trough in October. April and October are the months with birth maximums. The October maximum is evidently related to a peak of marriages in the Christmas season. Some human factor, apparently response to the climate, favors successful conception in midsummer and the resulting April birth maximum. The factor is unknown, but was selectively disadvantageous for the population of York in this period. Mortality up to three weeks after baptism is shown in gray; stillbirths are in color.



BIRTH PEAKS in April and October in 17th-century York are reflected in the record of baptisms. The upper graph shows monthly deviations from the mean number of baptisms for the limited number of persons whose complete life histories could be reconstructed. The lower graph shows the same deviations, this time utilizing all the baptisms recorded in York during the century. It is evident that the partial sample closely matches the whole one.

birth are particularly high when the mother is very young or in her forties. I was unable to find any relation in the York statistics, however, between maternal age and survival of the living offspring. Neither the age of the mother nor the size of her family had any measurable effect on the longevity of the child she bore at any age.

As a mother grows older, the interval between children tends to increase. Presumably this is due in part to a decreasing production of ova as her age advances. After the birth of several children menstruation is not resumed as soon as it is after the first child. Lactation—that is, nursing the infant—is believed to delay the resumption of both ovulation and menstruation. I found evidence in the York records, and French demographers have also reported, that if a baby dies within its first year, the interval to the birth of the next baby is usually shortened, apparently because the mother's lactation and delay of ovulation are shortened. In York in the 16th and 17th centuries, when all mothers presumably nursed their babies for long periods, the mean interval between babies was about two and a half years.

The parish registries yielded other interesting findings. They gave evidence, for instance, on the extent of migration of the population in those times. In the two centuries between 1538 and 1751 there were 8,510 marriages and 27,956 baptisms (that is, births) in York.

ENJOY THIS SPECTACULAR NEW

Color Slide Art Lecture

IN YOUR HOME FOR $1

You will view 20 famous masterpieces by the great LEONARDO DA VINCI each one projected on your wall in THE FULL GLORY OF THE ORIGINALS.

You will receive fascinating commentary on each painting and its place in the life of the artist. You will discover a new way to increase your enjoyment and understanding of the world's great art.

Here is what you receive for $1

LEONARDO DA VINCI, a handsome Album with 20 brilliant color slides, including the beautiful "Madonna and Child with St. Anne" (shown above) ... the famous "Mona Lisa," radiant in their true colors and actual sizes ... stunning details of the legendary "Last Supper" ... and other priceless art treasures by Leonardo. The Album also contains an illustrated 40-page guided lecture by Renaissance authority Heilmut Wohl, who gives you revealing background on the paintings and the enigmatic genius who created them.

A special demonstration offer from the new Color Slide Program of the Great Masters

THERE IS NO EXPERIENCE in the world of art more thrilling than to stand before a magnificent painting—and to learn about it from someone who knows the work well. Suddenly everything you see takes on new meaning, as you begin to understand what the artist is communicating through his choice of color, form, brush stroke, and theme.

Now, your family can share this exciting experience—and important cultural advantage—at home, through the entirely new *Color Slide Program of the Great Masters.* You view world-famous works of art projected on your own wall *in the full glory of the original canvases*—while a noted authority points out the significant aspects of each painting, and gives you fascinating background on the man behind the masterpiece.

This method of art education—the color slide art lecture—is widely used by leading museums and universities. It has never before been made available to families at home.

A new way to deepen your appreciation of art and artists

As a subscriber, you are offered a series of unusual albums, each containing 20 color slides of priceless paintings by a celebrated master. These superb 35mm slides were created by specialists in art photography working in leading museums and collections throughout Europe and America. The authentic colors of the original paintings, every subtle line and detail, are brilliantly revealed on these slides. They can be shown on *any standard home slide projector.* (If you do not own a projector, you may obtain one at low cost with your trial Album. See the special offer at the right.)

The color slides, however, are only one part of the Album. Bound into the center of each Album is an illustrated 40-page guided lecture which discusses the artist's life as well as each of the 20 paintings presented; its place in the development of the artist, its importance in the history of art, its reflection of the tastes and attitudes of the period.

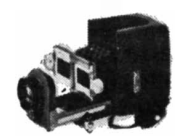
As you view the paintings projected on your wall and read the absorbing commentary, you and your family will discover *a whole new dimension in the enjoyment of art.* If you have been disappointed by the inadequacies of small prints and art reproductions, you will be delighted with the thrilling visual experience offered by the *Color Slide Program of the Great Masters.* It is very much like taking your own "private tour" with an art expert guiding you through the world's finest collections.

The Program is flexible—the cost is low

Approximately every six weeks, you are offered a complete new Color Slide Album of 20 distinctive slides and an illustrated lecture. Forthcoming Albums will be devoted to the lives and works of such great masters as *Michelangelo, Rembrandt, Goya, Gauguin,* and *Picasso,* as well as *Rubens, Caravaggio, Van Gogh, Lautrec, Chagall,* and other outstanding artists from every major period.

If the slides were available from museums, you would expect to pay as much as $15 a set. Yet, as a member of this new Program, you pay only $6.95 for each complete Album—including 20 color slides and 40-page illustrated lecture. You may take as few or as many as you like, and may stop whenever you wish.

IF YOU DO NOT OWN A PROJECTOR. We have obtained a limited supply of the sensational Minolta Mini 35-II, with Rokkor F2.5 wide angle projection lens. This top-rated portable projector shows all 35mm slides. List price $36.45—members' price $17.95. If you wish the projector included, please enclose remittance with coupon. Full refund guaranteed if projector is returned within 10 days.



Accept this $1 demonstration offer

To introduce you to the Program, we will send you the Color Slide Album, *Leonardo da Vinci* (described above), for 10 days trial. If you are delighted with the demonstration, and wish to continue with the Program, send only $1, plus a few cents for shipping. Thereafter, you will be offered a new Album approximately every six weeks at the low price of only $6.95. If not thrilled, however, simply return the Album within 10 days, tell us you do not wish to continue, and owe nothing. Mail the coupon today.

McGraw-Hill Color Slide Program
of the Great Masters, Dept. BC-107
330 West 42nd Street, New York, N. Y. 10036

Please send me the Color Slide Album: *Leonardo da Vinci* for 10 days trial, and enroll me in this new Program. Bill me only $1, plus a few cents for shipping, for the Album. If not completely delighted, I may return it within 10 days, cancel my membership, and owe nothing.

If I do continue, you will send me a new Album of slides by a famous master approximately every six weeks (for 10 days trial) at the low price of only $6.95, plus shipping. I am not obligated to take any minimum number of Albums, and may stop whenever I wish.

Name .....

Address .....

City .....State.....Zip.....

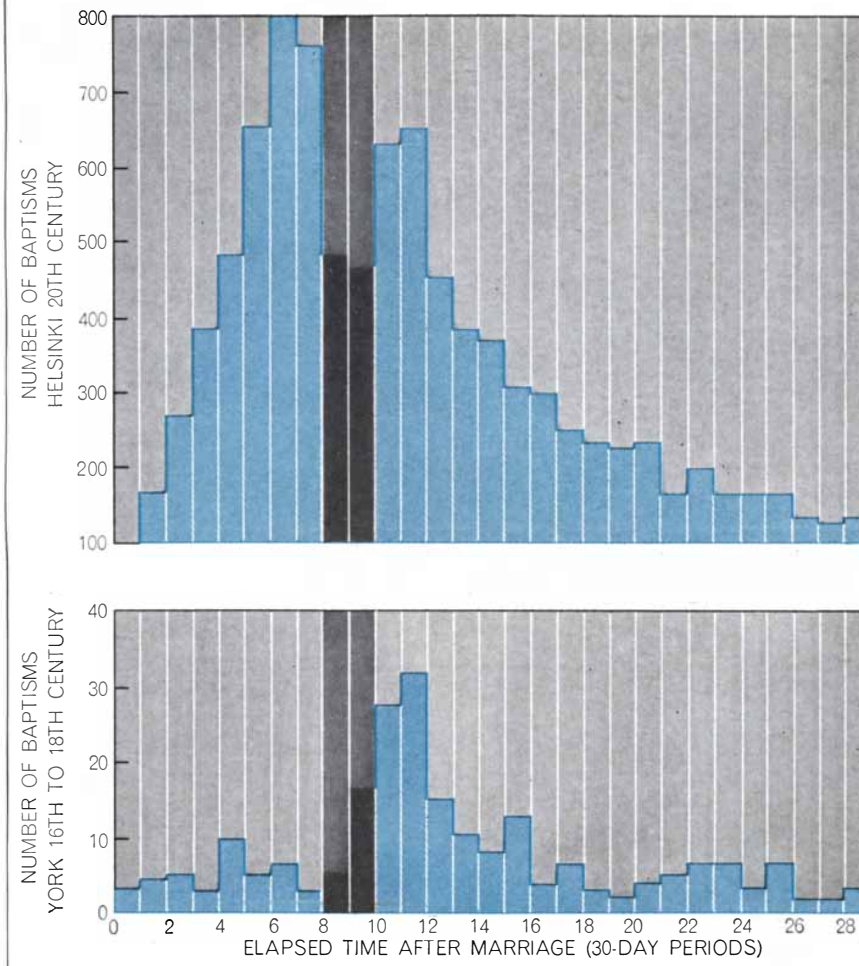
☐ Check here if you wish the Minolta Mini 35-II Projector included and remit $17.95 with this coupon for projector. If you are not delighted, return within 10 days for full refund.

This offer applies to U.S. and Canada only

This implies that the average family size should have been 3.29; actually my census of the families themselves indicated the average size was 3.56. The difference no doubt reflects substantial changes in the population by way of movement of families into and out of the city. There are comments in the parish records indicating that some of the births occurred in families that were temporary visitors to York from London, and that some of the York residents had houses in London, where they spent much of their time. A history of Yorkshire shows that in the 17th century there were many more burials than baptisms in the county, which, in view of the fact that the county's population actually increased in that period, again shows that there must have been considerable immigration into the county.

It is interesting to note from the parish records that premarital conception of children had at least as high an incidence in that era as it does in comparable populations today [*see illustration below*]. Assuming that all births occurring within nine months after the marriage were conceived before the wedding, we find that 13 percent of the brides in York, and a third or more of those in rural Colyton, came to the wedding in a pregnant condition. The corresponding figure in England as a whole today is about 8.5 percent; for Helsinki, Finland, about a third. In France, according to a study in one locality, conception frequently occurs a month or two before marriage.

Plainly the parish registries, recording only the stark events of family life, have much to tell us about the human condition and recent population history. Further study of these records may yield more information, particularly concerning the trends in human fertility.



TIMES OF CONCEPTION AND MARRIAGE in 20th-century Helsinki (*top*) are compared with those in York between 1538 and 1799 (*bottom*). The peak for baptisms of children conceived before marriage in York fell in the fourth month following marriage. Most York children were conceived in wedlock, the 11th month after marriage being a peak month for baptisms. One-third of Helsinki children are conceived premaritally; some 25 percent more are born in the sixth and seventh month after marriage than in the 10th and 11th month.

"To many executives, this free book has been worth $1000 a page."

By James M. Jenks

James M. Jenks, President of the Alexander Hamilton Institute, is an outstanding authority on all phases of business management and has written numerous magazine articles on the subject.

IF you are making at least $12,000 a year you will, almost certainly, earn more in the normal course of events. As your experience grows, you can expect raises every year or so, in proportion to what you are making now.

But what about the big jump to the $20,000 or $30,000 a year job? Does your present job *logically* lead to such a salary? Or is it limited by the top salary of your own department? If so, how do you move up into broader fields where the rewards are so much higher?

A remarkable little book, "Forging Ahead In Business," has the answer. It describes a program which has been instrumental in the business advancement of a long and distinguished list of this country's top executives: the President of one of the world's leading tire and rubber companies; the Chairman of a multi-million dollar, internationally known aircraft corporation; the President of a food company whose name is a household word.

In our offices, we have letters from many outstandingly successful executives like these—men who have reached the very top of the business ladder—affirming the fact that this 32-page book can indeed be worth "$1000 a page."

If you have not already "settled" for the salary you are making now... if you still dream and desire and plan for your future, "Forging Ahead In Business," can be of inestimable help to you. Here is a brief glimpse of what you will find in this remarkable little book:

- Why just a little increase in your business knowledge can lead to a big increase in your salary?
- What is the stumbling block that may be keeping you from getting ahead as fast as your business ability warrants?
- What is the quickest, smoothest path to greater earning power?
- Should you wait to be told what you must do to qualify for promotion?
- What is the secret of leisure that can be used to increase your efficiency?
- What business principles must you master to move smoothly from one industry to another in order to escalate your salary?
- Where is the new technology leading business? How can you stay abreast of the trend?
- Will growing automation make your job obsolete? How can you protect yourself?
- What are the characteristics chief executives of companies—large and small—have in common?
- What five practical steps can you take now that will help you the most?

These are just a few of the provocative business questions "Forging Ahead In Business" takes up. This famous booklet is designed to help you evaluate your progress and the direction in which you are going. More important, it tells you specifically what you must know and what you must do if you are to reach your business goals in the shortest possible time.

Make An Important Decision!
Send For Your Free Booklet Today!

"Forging Ahead In Business" is yours on request. There is no charge and no obligation. It is offered to you to introduce you to one of the most complete and practical executive-training programs ever devised.

It is a program that helps you attain success by exposing you to success! You have a chance to test yourself in a "top-management job," and see how you measure up. You familiarize yourself with the problems, the decisions, the viewpoints of such a job—and see if you can cope with the problems and acquire the viewpoint.

Your successes give you self-confidence. The gaps in your business knowledge are filled in. Then, when the real opportunity comes along, you are ready to "step in and take over."

But the first step is to send for your complimentary copy of "Forging Ahead In Business." Simply fill out and mail the coupon below. The booklet will be mailed to you promptly.

ALEXANDER HAMILTON INSTITUTE
235 East 42nd Street, New York, N. Y. 10017

ALEXANDER HAMILTON INSTITUTE
Dept. A-996, 235 E. 42nd St., N. Y., N. Y. 10017

Please mail me, without cost, a copy of the 32-page book – "FORGING AHEAD IN BUSINESS."

Name_____

Firm Name_____

Business Address_____

Position_____

Home Address_____ Zip Code_____

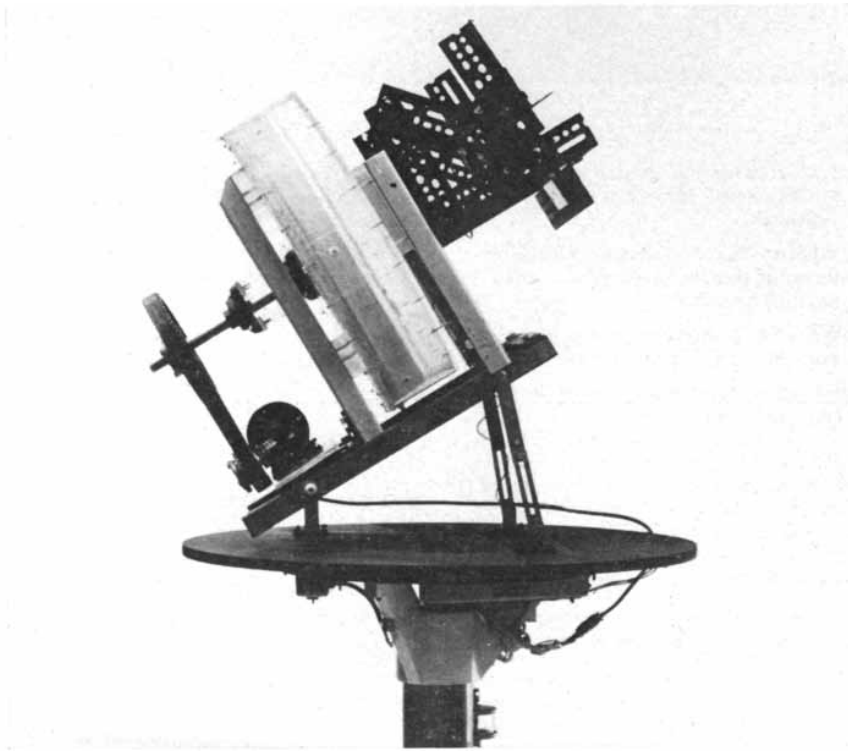
MODELS OF OCEANIC CIRCULATION

Analysis of the ocean's response to the forces that move its waters is aided by small models that isolate major features of the physics of the ocean currents. One such model has given encouraging results

by D. James Baker, Jr.

How does the ocean respond to the forces that set its waters in motion? This response, the general circulation of the ocean, cannot be analyzed solely by direct observations; the system is too complex. One way to simplify it arbitrarily is to build a laboratory model of the ocean. Professor Allan Robinson and I have developed several such models in our laboratory at Harvard University. With the newest of them, which generates currents and makes them visible with a dye, we have obtained some significant results.

Our model is not a large tank of water, as one might expect it to be. Only 40 centimeters in diameter, it basically consists of two circular blocks of clear plastic, one above the other, with a space of one centimeter between them. The upper surface of the lower block is spherically convex and the lower surface of the upper block is correspondingly concave. The space is filled with the "ocean," one centimeter deep. The model therefore represents a segment of the surface of a sphere, as though a large circular portion of the North Atlantic had been lifted out of the earth, and it is operated in a nearly vertical position to correspond with the orientation of the North Atlantic as seen from a point in space above the Equator. The model is mounted on a turntable that simulates the rotation of the earth [*see illustration on this page*].



MODEL OF OCEAN is set up in the author's laboratory at Harvard University. The water is contained in the circular plastic blocks, where it is held in a spherical shape to reproduce the curvature of the North Atlantic Ocean as seen from a point in space above the Equator. The tilt of the model is based on the same perspective. Motion is imparted to the water by the lower plastic block, which is driven by the motor and belt at left. Framework at right is a camera mounting. Model is mounted on a turntable to simulate the rotation of the earth.

In studying ocean currents with models we are taking an approach that has been fruitful in the investigation of other large-scale phenomena of nature. This approach involves three closely interrelated enterprises: observation, theorizing and laboratory experiment. On the basis of careful observation of the natural phenomenon one can formulate a theory to explain what is happening. (The complexity of the phenomenon and inadequate knowledge of its basic physics make it necessary to start with a simplified theory that incorporates only the physics believed to be crucial to the phenomenon.) Armed with such a theory, one can construct simple laboratory models that also isolate the essential physics. Since a model can be controlled, the investigator can gain a good understanding of how it works. He uses the results from the model to frame better questions to ask during his observation of the original phenomenon, and the answers from the observation enable him to refine both the theory and the model. In this way he can hope at last to reach an adequate understanding of the natural system he set out to investigate.

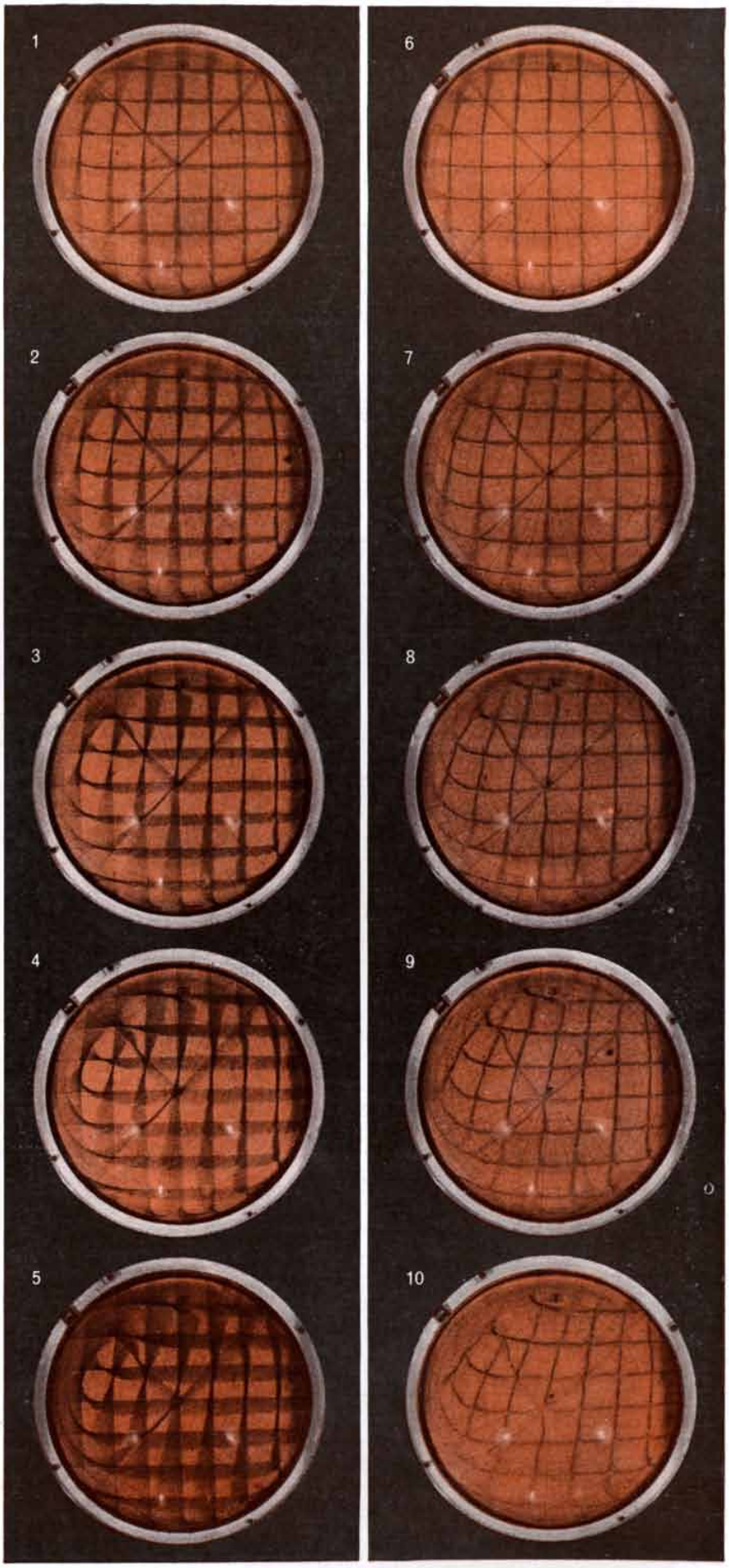
Models can be dangerous. If the results from a simplified theory or experiment agree with observation, one is tempted to think that the true explanation is in hand. The fact is that another

simplified theory might have yielded equally good agreement. One must be careful not to draw unwarranted conclusions. The more of the significant physics that is included in the model, the less likely one is to be led astray.

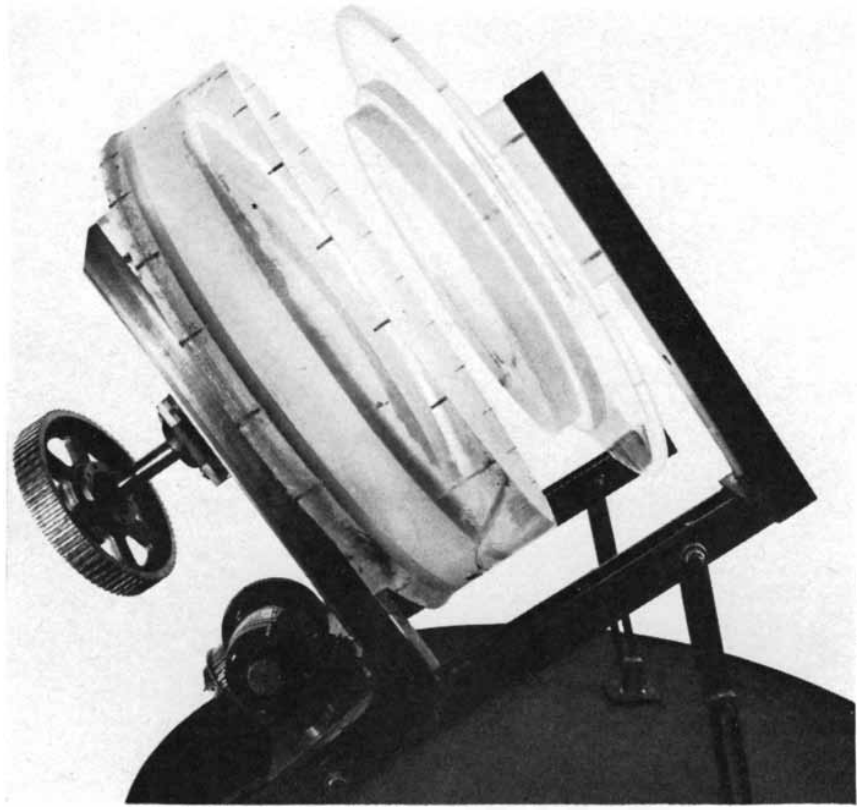
In the general circulation of the world ocean the input of heat from the sun is converted into large-scale motions: the broad, slow equatorial currents, the narrow oceanic jet streams and the abyssal flows. The currents are produced either directly by the unequal heating of the Equator and the poles or indirectly by the conversion of the sun's heat into winds [see "The Atmosphere and the Ocean," by R. W. Stewart; SCIENTIFIC AMERICAN, September, 1969]. However they are produced, the ocean currents move so slowly and over such great distances that both the curvature of the earth's surface and the daily rotation of the earth play a fundamental role in their dynamics. Other factors that influence the currents are the shape of the ocean floor and the basic vertical stratification of the water from least dense at the top to most dense at the bottom.

The wind-driven currents are the relatively rapid flows in the general oceanic circulation. They are usually strongest at the surface and at the western side of the oceans. The narrow, swift western currents, fed by the broad equatorial flows, include the Gulf Stream, the Japan Current (or Kuroshio) in the Pacific and the Somali Current in the Indian Ocean. Such currents have been known to man ever since he began sailing the high seas.

In 1947 Harald U. Sverdrup, who was then director of the Scripps Institution of Oceanography, showed that the broad equatorial currents in the Pacific could be explained by the action of the wind and the rotation and curvature of the earth. Henry M. Stommel of the Woods Hole Oceanographic Institution and Walter H. Munk of the Scripps Institu-



FLOW IN MODEL is made visible by the dark lines of dye. At left from top to bottom is a series of photographs (*1–5*) starting 15 seconds after the dye was created and made every 10 seconds thereafter. The driving block was being operated slowly, so that friction rather than inertia dominates the flow. A deep southward drift is evident, as observed in the Atlantic Ocean, and on the west side flows the mass-conserving western boundary stream that resembles the Gulf Stream. A similar series of photographs (*6–10*), made every 10 seconds after the beginning of flow and employing a somewhat different procedure with dye, appears at right.



SEPARATED PARTS of the model basin reveal the configuration whereby the water is held in the shape of a segment of the surface of a sphere, which is the ocean's configuration. Bottom block is convex and top one concave; their normal separation is one centimeter.

tion of Oceanography later showed that the longitudinal barriers presented by the continents force the wind-driven equatorial currents in the Northern Hemisphere to turn northward to form the western boundary currents. A combination of wind and topography then turns the western boundary currents to the east, where they broaden, slow down and eventually turn south to join the equatorial flow again. Thus the circulation is closed in large gyres, or circular motions.

These early models of oceanic circulation were consistent with observations up to that time, but they left a number of features of the system unexplained or ambiguous. For example, the early models predicted the transport of water (its velocity averaged over depth) in terms of the effects of wind stress, the curvature of the earth and the rotation of the earth. The angular momentum put into the water by the wind was assumed to be dissipated by friction developed through contact between the water and the ocean bottom or continental boundaries. The inertia of moving water was neglected. The details of friction were left unspecified. In theoretical calculations the magnitude of the frictional effect could be determined by adjusting the width of a hypothetical western boundary current to equal the observed width of the Gulf Stream or the Japan Current. It was only by assuming a fairly large amount of friction that the theoretical equations could be solved. Nonetheless, agreement with observation, at least for the qualitative nature of the overall flow and the transports of the western boundary currents, was reasonably good.

Then subsequent studies by Stommel of the observational data showed that friction was small compared with inertia in the region of the Gulf Stream. Indeed, he found that a better approximation of the observed situation could be achieved by neglecting friction altogether in favor of inertia. Jule G. Charney of the Massachusetts Institute of Technology and George W. Morgan of Brown University were able to show that reasonably good theoretical models of the Gulf Stream could be made by including inertia instead of friction.

The inertia of the moving water, that is, its tendency to keep going in the original direction or at the original speed when it is forced to change its direction or speed, has thus replaced friction as a mechanism for redistributing momentum in the newer models. Hence the newer models are known as inertial models. An understanding of this process, which is unique to fluid flow, requires a review of the simple physics of the oceanic circulation, so that the inertial models can be seen in their proper perspective.

The first point to be noted is that most ocean currents have a motion that is geostrophic, or affected by the turning of the earth. One can visualize the effect in terms of a large rectangular block in the North Atlantic Ocean [*see top illustration on page 119*]. If the water slopes slightly upward from south to north, a gradient of pressure is set up that would make the water flow toward the south in order to equalize the difference in height, provided that no other forces were present. On the rotating earth, however, particles of water in the Northern Hemisphere "feel" a thrust to the right of their motion because of the Coriolis effect. (Anyone can observe this effect by getting on a merry-go-round with a companion and attempting to toss a ball to his companion over a distance of a few yards. On a merry-go-round that is rotating counterclockwise as seen from above the ball will appear to curve to the thrower's right because the merry-go-round rotates out from under it. The ball will miss the companion unless the thrower has compensated for the effect.) In the block of water an equilibrium would be reached when the pressure-gradient force balanced the Coriolis force, and the motion of the water would be at right angles to the slope, or to the west in the present example. This final, balanced motion is the geostrophic flow.

On the earth the Coriolis effect is greatest near the poles, where the earth turns out from underneath a moving object most rapidly. The effect decreases to zero at the Equator, since the curvature of the earth makes the surface of the earth parallel to the axis of rotation there. This change in the Coriolis factor with latitude, caused by the curvature of the earth, is the fundamental reason for the existence of the western boundary current, as will soon become apparent.

Now let us consider the average circulation and wind stress in the North Atlantic. The simplest model is a square basin with a wind that blows to the east in the northern part and to the west in the southern part; the wind is at a maximum at the northern and southern edges and is zero halfway between them. When the wind is turned on, its westerly direction in the southern part of the basin tends to push the water there

toward the west, but the water is deflected toward the right, or north, by the Coriolis effect. The uppermost slab of water exerts a frictional force on the next-lower slab, which is thereby set in motion in a direction still farther to the right. The process is repeated until, at a depth of perhaps 100 meters, friction becomes negligible. The average flow of this entire layer, which is named the Ekman layer after the Swedish oceanographer V. Walfrid Ekman (who first described it nearly 70 years ago), is at a right angle to the wind direction.

Thus the wind in the southern half of our square basin representing the North Atlantic transports water to the north in the thin Ekman layer. Correspondingly the wind in the northern half of the basin transports water to the south. The water therefore tends to pile up in the middle [*see bottom illustration on page 119*]. The effect of this tendency, since water seeks a level, is a downward thrust that acts through the entire depth of the water. As a result of the thrust, water in the northern part of the basin tends to flow to the north and water in the southern part to the south. But again the Coriolis effect is felt, directing the average deep flow in the northern part of the basin to the east and in the southern part to the west.

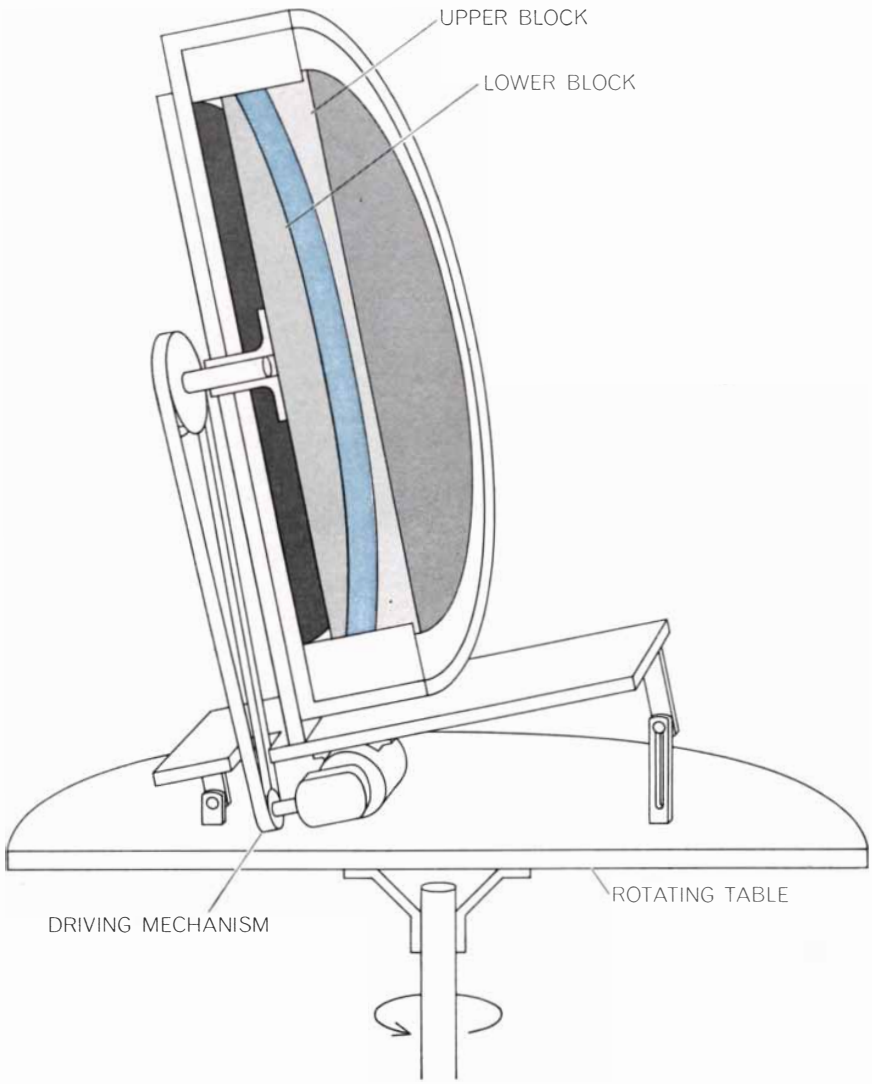
Since the average deep flow in the southern part of the basin feels a weaker Coriolis effect but the same downward thrust, however, the amount of water transported in that part of the basin is larger than it is in the northern part. Hence there is a net transport of water to the west, which causes a net slope downward from west to east. As a result the net geostrophic flow over the entire basin is to the south (a basic eastward tendency deflected to its right by the Coriolis effect). Without the decrease in the Coriolis effect between the North Pole and the Equator there would be no net southward flow.

Obviously the water cannot move south over the entire basin; if it did, the basin would soon empty. There has to be a return flow. This requires a narrow northward stream with a transport equal to the southward transport that results (in a roundabout way) from the action of the wind. The northward stream is the western boundary current, which is seen in every ocean with such a wind system. If there were no southward transport, no western boundary current would be needed. Thus the curvature of the earth, as reflected in the changing Coriolis factor, is essential for the existence of the Gulf Stream and similar western boundary currents.

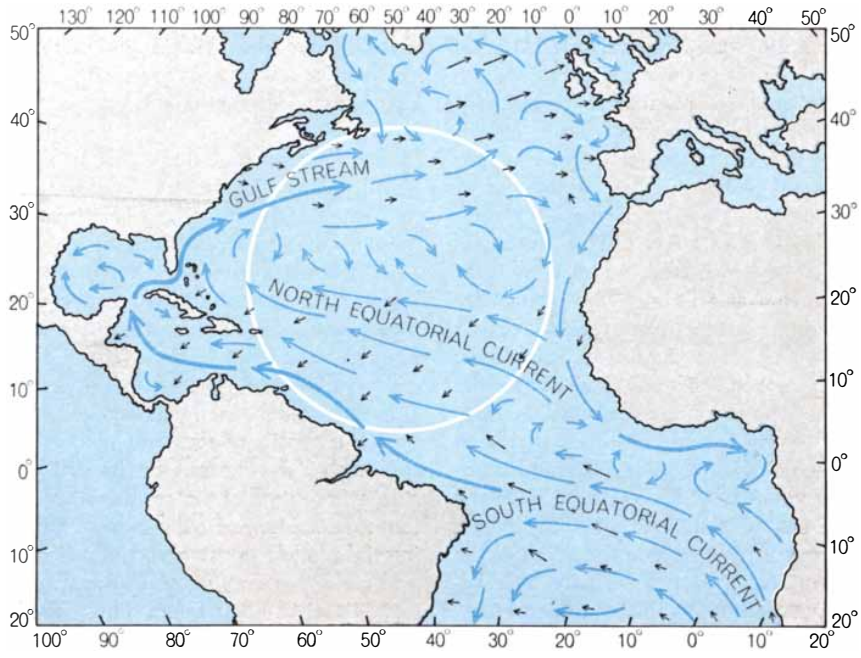
The net geostrophic flow to the south in a basin such as the North Atlantic also conforms to the requirement for the conservation of angular momentum or vorticity. (For fluids it is more convenient to speak of vorticity, which is proportional to the angular momentum of a spherical particle of fluid centered on the point of interest. The vorticity is equal to twice the angular velocity around an axis through the point.) Before the wind acts, every vertical column of water has the angular velocity of the earth, which as seen from above the North Pole is counterclockwise. Another way to put it would be to say that such a column of water in the Northern Hemisphere has positive vorticity. Since the direction of the wind over the North Atlantic is clockwise on the average, the wind puts in negative vorticity. The water must adjust to this condition either by spinning more slowly or by moving south, where the spin of the earth is slower. The southward movement, as we have seen, is what actually takes place.

The western boundary current also must conserve vorticity. At the outset its vorticity is positive, but small, since the current is near the Equator. As the current flows northward it moves into a region with larger positive vorticity. It therefore needs a source of positive vorticity to achieve the balance required by conservation.

In the older frictional models this source of vorticity was provided by a rubbing of the current on its western side, where it adjoins a continent, or on the ocean bottom. In the more realistic inertial models positive vorticity is carried in by the flow entering the stream from its right-hand edge. Thus where



WORKING FLUID of model is represented in color. The fluid is sealed between the upper and the lower plastic block when the model is in operation. By means of the linkage at lower right the tilt of the model can be changed to move the equator in relation to the fluid.



CURRENT AND WIND PATTERNS in the North Atlantic, which the model represents, are mapped. Currents are in color and winds are in black; in each case higher intensities are indicated by longer arrows. Large circle shows a typical area represented by the model.

the deep geostrophic flow is toward the Gulf Stream, that is, westward, a continuous source of positive vorticity is available. It was here, in the lower half of the basin, that the calculations of Charney and Morgan neglecting friction in the Gulf Stream were successful in relating observation to theory.

In the upper part of the basin, however, the flow is away from the stream, and such a balance of vorticities is not possible. What actually happens? It is probably in this region that the dissipation necessary for a steady state takes place. Although the mechanism of dissipation can be ignored when one is studying part of the oceanic circulation, any model of the circulation that includes all its features must provide for dissipation, otherwise the system would never reach its observed steady state. Most of the observed streams break away from the coast and meander in this region. Theory has not yet come abreast of the problem. Although there are many speculations, there is still no consistent, unambiguous theory for a general circulation closed by an inertial stream.

It was the difficulty of studying fully inertial schemes either analytically or by computer that led us to try to construct a laboratory model of oceanic circulation. In the ideal model the variables could be manipulated so that we could first make a circulation dominated by friction (for comparison with the well-understood theory) and then move into the inertial range. We could also branch out into other problems, such as the effect of oscillating winds.

We cannot, however, make a perfect model of the ocean. There are two major problems. The first is a problem of scale. For example, the Reynolds number for the circulation (which may be defined here as the characteristic size of the basin times the characteristic velocity of the fluid divided by the viscosity) measures the relative importance of inertia and friction. For the ocean the number is large: typically 10^{11}. In the laboratory it is difficult to achieve a Reynolds number larger than about 10^4 because the scale is small and it is not possible to find useful fluids with a viscosity much lower than the viscosity of water.

The second problem is that the stratification of the ocean cannot be modeled satisfactorily. The ocean itself is held to the spherical surface of the earth by the earth's gravitational field. The equipotentials, or surfaces of constant density, are therefore essentially spherical, modified slightly by the earth's rotation. The vertical distance between any two is essentially constant. The stratification tends to constrain the water to move along equipotentials, or horizontally rather than vertically.

It is unfortunately not possible to produce spherical equipotentials in the laboratory. When a fluid is rotated in the laboratory, the equipotentials are paraboloids of revolution, or paraboloidal rather than spherical. The distance between any two of them, measured perpendicularly to the free surface, is not constant. In fact, the change in distance between equipotentials exactly cancels the effects due to the curvature of the free surface. Since, as I have pointed out, the curvature of the earth, represented by the changing Coriolis factor, is essential in producing western boundary currents, a stratified model rotated in the laboratory is not a good model of oceanic circulation. So far we have not been able to build a model of a stratified ocean and still retain the effects of curvature.

There is one way to avoid this problem: one can use a homogeneous fluid instead of a stratified one. A homogeneous fluid has a constant density, and so there is no tendency for the fluid to move along equipotential surfaces. Motion will be determined by rotation, wind stress and surface curvature. Still, the effect of the lack of stratification is difficult to assess. The homogeneous model should be considered as just the first step in a series of models, each one including more of the important effects.

When we came to design the model, we had to consider the important fact that the dynamics of the ocean are constrained by the overall geometric shape of the ocean. The first point is that the oceans are thin, so thin that the relative vertical and horizontal scales are in a ratio of about one to 1,000, much like the paper on which this article is printed. Hence accelerations in the vertical direction are small.

A second constraint is the importance of curvature in that the currents move over such distances that the change in the Coriolis factor is significant. There also have to be boundaries so that the broad equatorial flows can be turned northward or southward. A final restriction is that the total depth of the water must be much greater than the depth that is directly under the influence of the winds (the Ekman layer).

Within these constraints Robinson and I, with the financial support of the Office of Naval Research, designed and built our model ocean. We have tried to observe the constraints, but our model is not as thin as the ocean; the ratio of vertical to horizontal is about one to 40 rather than one to 1,000. The reason is that we have to keep the horizontal dimension within the bounds of what we can handle easily in the laboratory while still allowing a minimum depth of water to accommodate our devices for measuring fluid flow. Nonetheless, the geom-

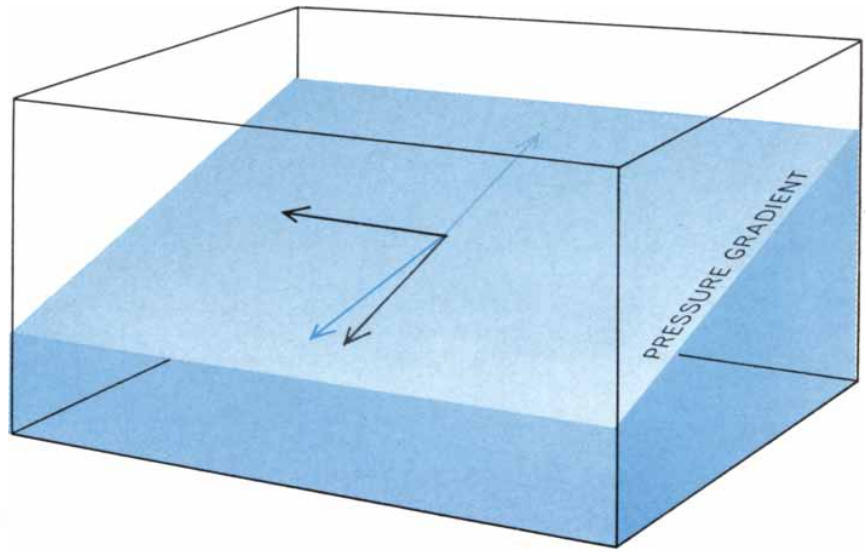
etry of the model is close enough to the earth's so that the theory applicable to the ocean is also applicable to the model.

The fluid is held in the shape of a spherical shell by the two nested plastic blocks. As a result we cannot blow a wind over the free surface, because there is no free surface. We can achieve a velocity in the water, analogous to the velocity imparted to ocean water by wind, by rotating the lower block.

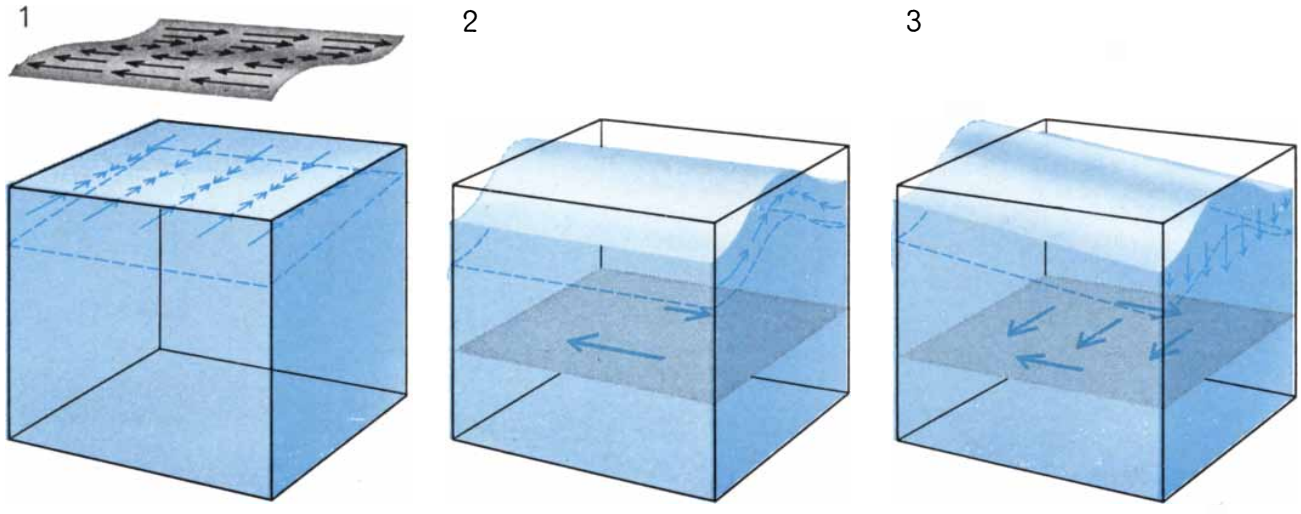
Our scheme for making the flow visible employs a solution of .04 percent thymol blue, which is often used as a *p*H indicator: it is yellow when the solution is acidic and brownish-blue when the solution is basic (alkaline). When two sets of electrodes are placed in the solution and an electric current is passed through the water from one electrode to the other, the solution becomes acidic near one of the electrodes and basic near the other. If the solution used at the outset is acidic but almost at the point of becoming basic, the slight change of *p*H caused by the electric current will change the color of the solution near the basic electrode. The darkened fluid created in this way will move with the local velocity of the water, as can be seen on the cover of this issue and in several of the photographs accompanying this article.

For our model we made one of the electrodes a grid of wires that is located midway between the two plastic surfaces, that is, halfway down in the water. The second electrode, which is another grid of wires, is attached to the upper plastic block. With this system we can measure both longitudinal and latitudinal flow in any part of the basin at half the depth of the water. Therefore the patterns of flow that appear in the accompanying photographs represent the deep geostrophic flow in the ocean.

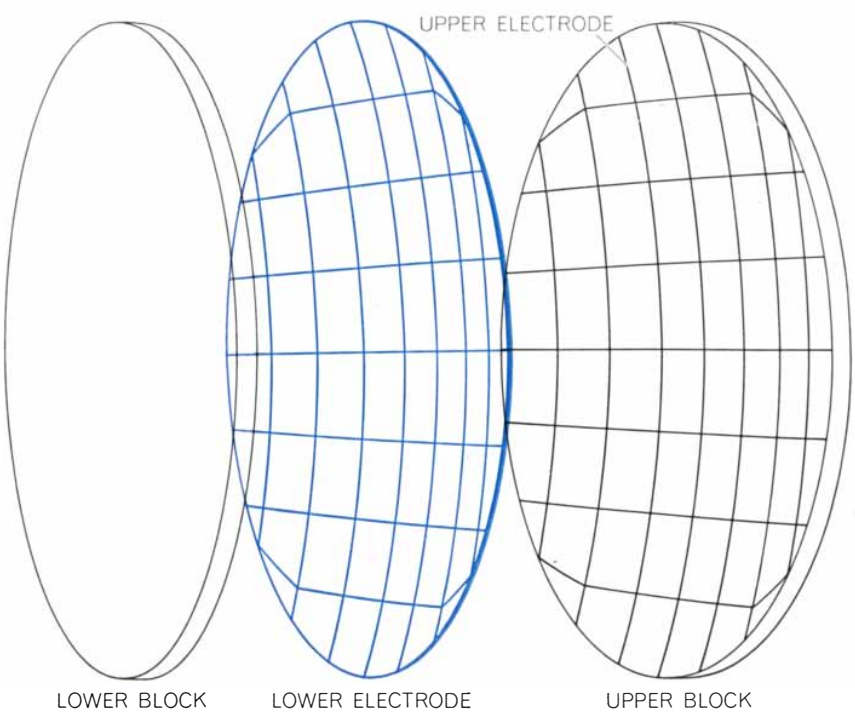
Our model is a segment of the surface of a sphere; if the entire sphere existed, it would have a radius of 53.5 centimeters. The lower block, which is our "wind," rotates typically at a speed of about .06 revolution per minute. The rotation of the entire model by the turntable, to simulate the rotation of the earth, is typically at a rate of about 60 revolutions per minute. At this rate the thickness of the Ekman layer is about one millimeter, which is in fact small



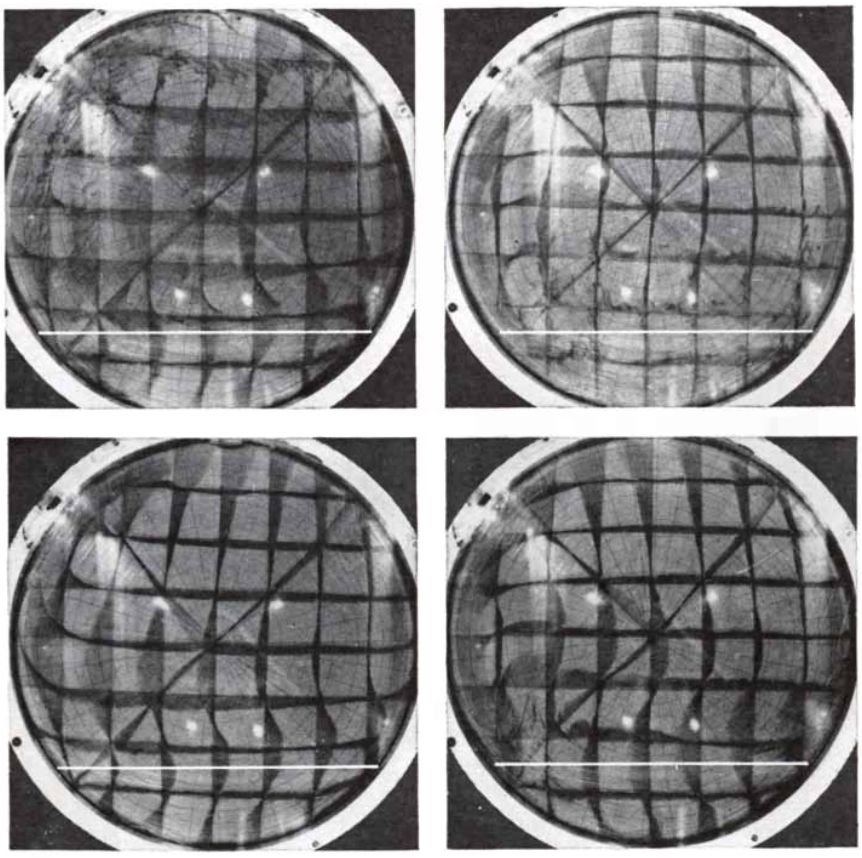
GEOSTROPHIC FLOW, which is westward here, results from a balance between the Coriolis effect (*light color*) and the pressure gradient (*gray*). Coriolis effect arises from the rotation of the earth, which is counterclockwise as seen from above the North Pole. Pressure gradient reflects slope of water. Because of the gradient, the water tends to flow south, but the Coriolis effect deflects it to the right (*dark color*), producing net westward flow.



EFFECTS OF WIND are portrayed in a square block of water representing the Atlantic Ocean between about 15 degrees and 55 degrees north latitude. The typical wind pattern (*1*) is easterly in the northern part of the basin and westerly in the southern part; intensity is indicated by arrows. The winds push the water in the same directions, but the water is deflected to the right by the Coriolis effect, so that in an upper layer known as the Ekman layer the water is transported to the north in the southern part of the basin and to the south in the northern part. Hence the water tends to pile up in the middle of the basin (*2*), producing a downward thrust that tends to make the water flow northward in the northern part of the basin and southward in the southern part. The average deep flow, however, is to the east and west respectively, because of the Coriolis effect. Since the average deep flow in the southern part of the basin feels a weaker Coriolis force but the same downward thrust, more water is transported in that part of the basin than in the northern part. The net transport is therefore to the west, producing a slope downward from west to east (*3*). The resulting eastward flow is deflected to its right or southward by the Coriolis effect, so that the net geostrophic flow in the basin is toward the south.



ELECTRODE SYSTEM for the model consists of two wire grids, one in the top plastic block and one halfway down in the water. Electric current in the grids darkens the color of the water, so that patterns of flow in the water can be seen and also readily photographed.



EQUATORIAL FLOW changes as inertial effects increase. The photographs at bottom have the minimum inertial effects and the ones at top have the maximum inertial effects. In the photographs at left the driving block was rotating clockwise; in the photographs at right, counterclockwise. The white lines show the equator. In each case the undercurrent at the equator moves in a direction opposite to the direction of the model's forcing velocity.

compared with the total depth of the water (one centimeter).

Results from the model have been highly encouraging. By rotating the lower block very slowly we have been able to produce a circulation that is predominantly frictional, that is, the inertial effects are negligible compared with the frictional ones. Hence we have a basis for testing the frictional theory of oceanic circulation. Theory and experiment have shown good agreement in this range. One can see in the photograph on the cover, for example, the major features of a typical gyre. The predicted deep southward drift is evident, and on the left side appears the mass-conserving western boundary current or "Gulf Stream," which gains the required positive vorticity by rubbing on the bottom.

It is also possible to study more than isolated gyres with this model. On the second day of experimentation, when we adjusted the latitude so that the equator went through the lower half of the basin, a current appeared at the equator and moved in the direction opposite to the velocity of the rotating block. This was an equatorial undercurrent, a phenomenon that is also evident in the ocean. For example, the Cromwell Current in the Pacific moves eastward along the Equator below the surface in the direction opposite to the surface velocity.

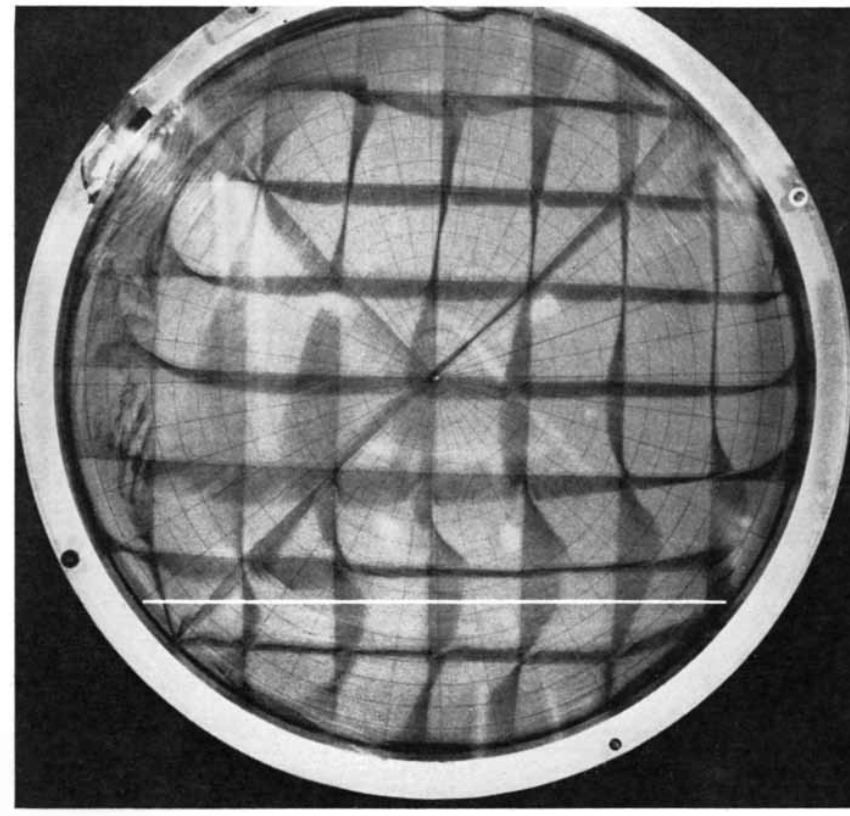
Still, we must be careful here not to draw unjustified analogies or conclusions. The circulation we have achieved is dominated by friction and is a first step toward the ultimate model, where friction will not predominate. It is certain now that the Gulf Stream is not dominated by friction, and it is probable that equatorial currents are not either. Moreover, the stratification of the ocean plays an important role in the dynamics of equatorial currents. For these reasons the physics of equatorial undercurrents in our model that look like real ocean currents must be studied carefully before their relevance is established.

Even if our currents are not directly relevant to the earth, we gain a helpful insight into general equatorial dynamics. We have observed that in the model the equatorial undercurrent is always in the direction opposite to the velocity of the block, that is, the current can flow either east or west [*see bottom illustration at left*]. As the forcing velocity is increased, however, the inertial efforts become more important and we find that the behavior of our currents is not so symmetrical. As the inertial effects increase, the undercurrent that flows westward breaks

up and disappears. At the moment it is not clear whether the current is flowing too fast to be clearly visualized by our technique or whether it becomes unstable. We plan to use more sophisticated methods of visualizing and measuring flow in order to clarify the matter.

It is particularly interesting that the eastward equatorial undercurrent remains stable in the model. Perhaps the explanation of the difference between the eastward and the westward current when the model is in the inertial range lies in the Coriolis effect. If the eastward current deviates to the north of the equator, the Coriolis effect, which is to the right, forces it back toward the equator. In the case of a westward current an instability could arise from the fact that if the current deviates slightly to the north, the Coriolis effect turns it farther to the north, and if the current deviates to the south, the Coriolis effect turns it farther in that direction.

What happens to equatorial undercurrents on the earth? In the Pacific and the Atlantic the equatorial undercurrent flows eastward and appears to be stable. In the Indian Ocean, however, the winds reverse direction every six months. Observations there show that an undercurrent exists during only one season; it is an eastward current. During the other months the equatorial flow is generally weak and variable and possibly unstable. We are studying our model carefully to see what light can be shed on the apparent instability of the westward undercurrent.



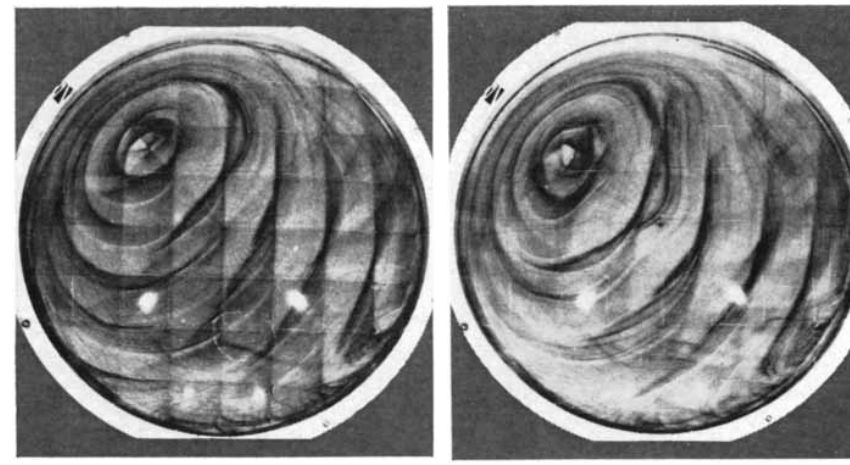
EASTERN BOUNDARY CURRENT, rather weak and flowing northward, gives evidence of inertial effects as the driving block is rotated more rapidly. A western boundary current, a southward interior flow and an equatorial undercurrent also appear. The white horizontal line represents the position of the equator; center of basin is 13 degrees north latitude.

It is highly encouraging to see that several basic features of oceanic circulation appear in our model. Nonetheless, we still do not have a model of a fully inertial oceanic circulation. We have seen several qualitative changes in the circulation, however, as we have stepped up the velocity in order to increase the inertial effects. Three effects that can be attributed to inertia have appeared.

The first one was the migration of the center of the gyre toward the northeast. Such a migration is to be expected, because as the inertia of the water becomes important the fastest part of the western boundary current tends to move farther north. The center of the gyre thus is also shifted.

The second inertial effect that we have observed is the appearance of a relatively weak northward boundary current on the east coast [*see top illustration on this page*]. Although eastern boundary currents have been observed in the ocean and are probably inertial, the dynamics of such currents are poorly understood. The model apparently provides a framework for studying them.

An unsteadiness of the circulation is the third major inertial effect observed. From motion pictures we found that the pattern of flow oscillated irregularly when the speed of the rotating bottom block was high enough [*see illustration below*]. We found the estimated period to be in rough agreement with the free-oscillation period predicted by theory. A clearer picture of the oscillatory nature of this rapid, inertial flow will be possible with new procedures that we are now developing for the model.



EFFECTS OF INERTIA appear when the driving block is rotated at high speed. The photograph at right was made .3 second after the one at left. In that time the configuration of the gyre, which is the closed and basically circular pattern of flow, has changed appreciably.

CalComp finally steps out of line.

For years, friends of our CalComp plotters have been waiting for CalComp to make something else.

Well, friends, this is the day you've been waiting for.

Now CalComp brings you, in addition to the world's leading computer graphics systems, two major new product lines:

Disk drives.

And Punchmaster.

And we think you'll be pleased about both.

Our disk drives work twice as fast. For about half as much.

CalComp's first disk drive is called the CD-1. And it's available today.

Thanks to a special electromagnetic detent and positioner, the 6-disk CD-1 affords several advantages over other disk drives.

Since it has no gears or hydraulics, the CD-1 gets by with fewer moving parts. For easier maintenance and unsurpassed reliability.

And because the CD-1 is utterly simple, it's a lot faster, too. With an average access time of just 30 milliseconds.

CalComp's first disk drive is also compatible with any IBM 360 system.

It stores 7.25 million bytes with easy conversion to higher capacities.

You can buy it for about half the price of comparable IBM equipment.

And you can lease it for less, too. With 7-day-per-week, 3-shift service included.

Of course, if our CD-1 interests you, so will our bigger CalComp CD-12/14, an 11-disk drive system available early in 1970.

With a CalComp controller and multiple units, the CD-12/14 offers an on-line capacity of up to 233 million bytes. And it's compatible with IBM 360 systems too.

Our Punchmaster makes three keypunch units work like four. Or more.

Then there's the new CalComp Punchmaster, a buffered memory device (6Kbits), that enables keypunch machines to accept data as fast as the fastest operator can key it.

And no keyed input system can do better than that.

What's more, a Punchmaster improves card format program capacity from 2 to 22. (Allowing any document to be punched or verified on just one pass.)

Its input buffer lets an operator keep keying at all times.

It handles constant data from memory. Reducing keystrokes sharply.

And it does all these things without changing your present computer system.

Today, these new products from CalComp are available in six metropolitan areas:

New York (212) 838-0402.
Washington, D.C. (202) 223-2920.
Chicago (312) 631-8492.
Dallas (214) 637-0040.
Houston (713) 771-3821.
And Los Angeles (714) 774-9141.

Meanwhile, plotter customers will be pleased to hear we also have several new graphic output systems available. Plus important new application software.

And as always, you'll find CalComp plotters, software support and service in 34 cities. So call or visit your CalComp man today.

He's lined up to see you.

CALCOMP

California Computer Products, Inc.
Dept. SA-1, 305 N. Muller Street
Anaheim, California 92803.

MATHEMATICAL GAMES

The abacus: primitive but effective digital computer

by Martin Gardner

The word "abacus" has identified three dissimilar calculating aids. The earliest and simplest, employed in many ancient cultures, including that of the Greeks, was no more than a board dusted with a thin layer of dark sand on which one could trace numerals and geometric figures with a finger or stylus. Archimedes was said to have been calculating on such a "sand board" when he was killed by a Roman soldier. The Greek word *abax,* which meant in general a flat board or legless table, may have come from *abaq,* the Hebrew word for dust.

A later type of abacus, known as early as the fourth century B.C. and still in use during the Renaissance, was the counting board. This was a true calculating instrument, as genuine a digital computer as the slide rule is an analogue computer. The board was marked with parallel lines representing the "place values" of a number system, usually a system based on 10. The lines were drawn on parchment, etched on marble, carved in wood or sometimes even stitched in cloth. Loose counters were moved back and forth on these lines to perform simple calculations. The Greeks called the board an *abakion;* the Romans called it an *abacus.* The counters were round pebbles or similar objects that were moved along grooves, and the Latin word for pebble, *calculus,* is therefore the origin of such words as "calculate" and "calculus." Several pictures, one on a Greek vase, show the counting board in use, but only one Greek counting board survives: a marble rectangle measuring about five by six inches that was found on the island of Salamis. During the Middle Ages checkered counting boards were in general use, and that explains the origin of such words as "check" and "exchequer."

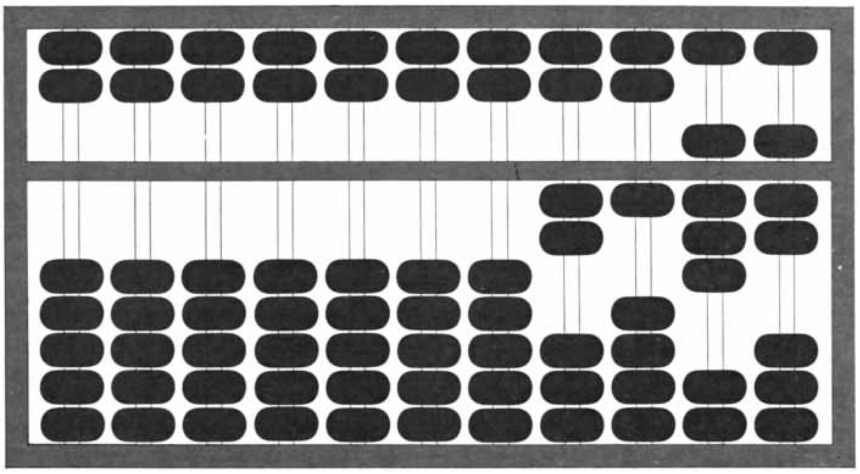
An "abacist" (right) competes against an "algorist" in a 16th-century print

The device we now know as an abacus is essentially a counting board modified so that the counters are set in grooves or slide along wires or rods. It is of unknown origin. The ancient Greeks probably did not have such instruments; the earliest references to them are in Roman literature. The counters, which the Romans called *claviculi* (little nails), moved up and down in grooves. The Romans had several forms of the device. A small bronze abacus used in Italy as late as the 17th century is of particular interest because its basic structure is the same as today's Japanese abacus. Each vertical groove stands for a power of 10, the powers increasing serially to the left. Four counters in each groove below a horizontal bar represent unit multiples of the place value. One counter in each groove above the bar represents five times the place value.

Here we encounter a curious state of affairs stressed by Karl Menninger, the German mathematician, in his beautiful and encyclopedic work *Number Words and Number Symbols,* translated and published last year by the M.I.T. Press. For more than 15 centuries the Greeks and Romans and then Europeans of the Middle Ages and early Renaissance calculated on devices with authentic place-value systems in which zero was represented by an empty line or groove or by an empty position on the line or groove. Yet when these same people calculated without mechanical aids, they used clumsy notational systems lacking both place values and zero. It took a long time, as Menninger says, to realize that in writing numbers efficiently it is necessary to draw a symbol to indicate that a place in the number symbolizes nothing.

Perhaps the main reason for this cultural mental block was that papyrus and parchment were hard to come by. Because calculating was done almost entirely on abaci there was no pressing need for a better written notation. It was Leonardo of Pisa, the Italian who was known as Fibonacci, who introduced the Hindu-Arabic notation (with its 10 digits including zero) to Europe in his famous arithmetical compendium *Liber Abaci* (1202). This led to an acrimonious struggle between the "abacists," who clung to Roman numerals in written computation but calculated on abaci, and the "algorists," who discarded Roman numerals altogether for the superior Hindu-Arabic notation. "Algorist" derives from the name of a ninth-century Arabic writer on mathematics, al-Khowârizmî, and is the ancestor of the modern word "algorithm." (In the illustration on the opposite page an abacist is shown competing against an algorist. The print is from a 16th-century book, *Margarita Philosophica*.) In some European countries calculating by "algorism" actually was forbidden by law, so that it had to be done in secret. There was opposition to it even in some Arabic countries. Not until paper became plentiful in the 16th century did the new notation finally win out, and soon after that the shapes of the 10 digits became standardized because of printing.

The abacus was discarded gradually in Europe and England. Remnants of it survive in the U.S. today only as colored beads on playpens, as devices for teaching decimal notation in the early grades and in such counting aids as the rosary and the overhead sliding beads for recording billiard scores. In a way this is a pity because in recent centuries calculating with the abacus has been developed into an art in Eastern countries and in Russia. It is a multisensory experience: the abacist sees the beads move, hears them click and feels them, all at once. Surely no digital computer has such high reliability in proportion to such low cost of purchase and maintenance.



Chinese suan pan shows the number 2,187

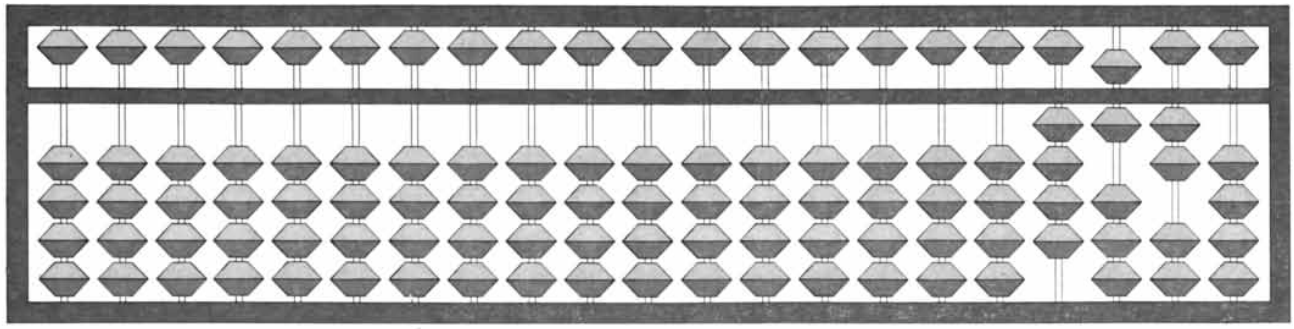
Three types of abacus are in constant use today. The Chinese suan pan [*see illustration above*], also used in Korea, has beads shaped like tiny doughnuts that move almost frictionlessly along bamboo rods. Each rod has five beads (ones) below the bar and two (fives) above. The Chinese symbol for *suan*, "calculate,"

is reproduced from Menninger's book; it shows an abacus held by two symbols for "hand" above the symbol for "bamboo." The suan pan's origin is unknown. Precise descriptions go back to the 16th century but it is surely centuries older.

The Japanese soroban [*see illustration below*] also can be traced to the 16th century, when it was probably borrowed from China. Its counters are sharp-edged: two cones joined at their bases. Each rod has only one bead above the bar in a region the Japanese call "heaven," and only four below in the "earth." (The device originally had five beads below, like its Chinese counterpart, but the fifth was dropped about 1920. The two extra beads on each rod of the suan pan are not essential for modern abacus calculating, and discarding them produced a simpler instrument.) Japan still has yearly abacus contests in which thousands participate, and the soroban is still used in shops and small businesses, although it is rapidly being replaced in banks and large firms by modern desk computers.

There have been many contests in which a Japanese or Chinese abacist was pitted against an American operator of a desk computer. The most publicized was in 1946 in Tokyo, when Private Thomas Wood matched skills with Kiyoshi Matsuzaki. The abacist was faster in all calculations except the multiplication of huge numbers. One reason for the great speed of Oriental abacists, it should be admitted, is that they do a lot of work in their head, using the abacus mainly to record stages of the process.

The principal defect of abacus computation is that it preserves no record of past stages. If a mistake is made, the entire calculation has to be repeated. Japanese firms often ensure against this by having three abacists do the same

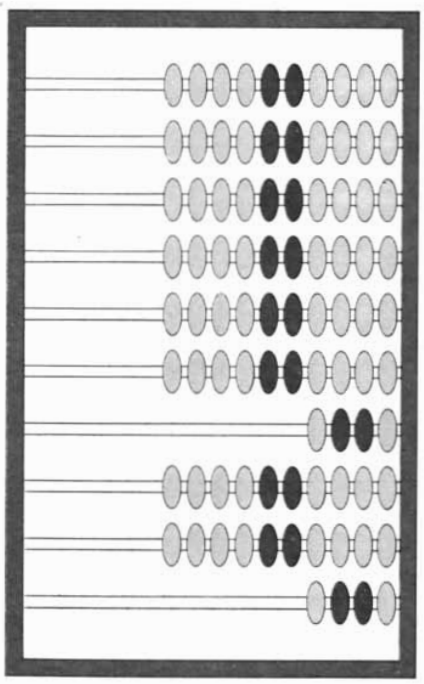


Modern Japanese soroban with the number 4,620 displayed

problem simultaneously. If all answers agree, it is assumed, following the rule given by the Bellman in Lewis Carroll's *The Hunting of the Snark*, that "What I tell you three times is true."

Russia's *s'choty* [*see illustration below*] is markedly different from Oriental abaci. The Russians probably acquired it from the Arabs, and it is still used in parts of India and in the Middle East, where Turks call it a *coulba* and Armenians a *choreb*. In modern Russia the situation is the same as it is in Japan: almost every shopkeeper still uses an abacus, although it is being replaced in the accounting departments of large firms by modern desk calculators. The *s'choty* has horizontal wires or rods, most of them holding 10 beads; the two middle beads are of a different color to make it easy to see where to divide them. The four-bead rods on the one shown in the illustration are used for fractions of rubles and kopeks.

Many Western mathematicians enjoy operating an abacus. My own preference is for the Japanese soroban. Good manuals explaining the best finger motions are available: Takashi Kojima's two books, *The Japanese Abacus* and *Advanced Abacus* (Charles E. Tuttle, 1954 and 1963), and a more elementary manual, *The Japanese Abacus Explained*, by Y. Yoshino (Dover, 1963). On the Chinese suan pan two good books in English are by F. C. Scesney, *The Chinese Abacus*, 1944, and Chung-Chien Liu, *The Principles and Practice of the Chinese Abacus*, 1958.



A Russian s'choty

In recent years the obvious value of the abacus for teaching arithmetic to blind children has been recognized and special abaci have been developed to reduce friction. Terrance V. Cranmer devised a soroban with foam rubber and felt under spherical beads that is available from The American Printing House for the Blind, 1839 Frankfort Avenue, Louisville, Ky. 40206. The firm also sells a manual in braille by Fred Gissoni. Victor E. Haas uses gravity to keep the beads of a soroban from accidentally sliding together by putting them on wire loops that curve upward in semicircles, a principle used in a less extreme way in some Russian abaci.

The easiest kind of calculation to master on the abacus is addition. For readers who lack the time or interest to learn the finger movements for subtraction (abacus movements must be automatic reflexes; it will not do to stop and think how to make addition movements in reverse) there is an old method of subtracting on the abacus by adding. Instead of subtracting the smaller number you add the "complement" of each of the digits with respect to 9. For example, you wish to take 9,213 from 456,789 on an Oriental abacus. Place 456,789 on the abacus. Mentally put two zeros in front of 9,213 to make it the same length as the other number. Then add pairs of digits in the usual manner, but from left to right (not the other way, as on paper), except that for each digit in 009,213 you substitute its difference from 9. In brief, to 456,789 you add 990,786. The result, 1,447,575, must now be given a final adjustment. Remove the single bead on the left and add one bead to the end digit on the right. This gives 447,576, the correct answer. In actual practice this final adjustment is sidestepped by not pushing up the bead on the left when you make the first addition and by raising an extra bead on the final addition. Supplying extra zeros at the left of a short subtrahend can also be avoided by remembering to remove a bead not from the extreme left but from the first digit to the left of the number of digits in the subtrahend.

Subtracting by adding complements is the method used in Comptometers as well as in high-speed electronic computers. The method applies to any number system, provided, of course, that the complements are with respect to the system's base less one. Thus for a 12-base system you add complements with respect to 11. For a computer using the binary system, complementation is simple because it is the same as changing every 1 to 0 and every 0 to 1. It goes without saying that abaci can be constructed for any base notation. The Oriental abaci adapt easily to certain other bases. For the binary, use only the heaven portion of the soroban. Its earth region can be used for the 5-base system. The suan pan can be similarly used for systems based on 3 or 6. For a 4-base system confine your attention to the top three beads below the bar of either device. For a 12-base system use the Chinese abacus, assigning a value of 6 instead of 5 to the beads above the bar.

3	4	1	2
3	1	5	1
2	1	3	4
2	4	1	3

2	1	4	3
2	4	0	4
3	4	2	1
3	1	4	2

Magic-square solutions

An excellent practice exercise for abacus addition is linked to an old number stunt sometimes used by grade school teachers. The "magic number" 12,345,679 (note the missing 8) is chalked on the blackboard. A child is asked to step forward and name any digit. Suppose he picks 7. The teacher writes 63 below 12,345,679 and then asks the child to do the multiplication. It turns out, one hopes to everyone's amusement, that the product consists entirely of 7's. (To determine the multiplier the teacher simply multiplies the chosen digit by 9.)

To use this magic number as an abacus exercise, put 12,345,679 on the abacus and add the same number to it eight times, the equivalent of multiplying it by 9. If your eight additions are done correctly, the abacus will show a row of 1's (single beads against the bottom of the bar). Add the magic number nine more times to produce a row of 2's. Nine more additions form a row of 3's, and so on until you finish, after 80 additions, with a row of 9's. Every finger movement is called into play by this exercise. Moreover, you can easily check the accuracy of your work at nine stages along the way, and by timing each stage you can tell how your speed improves from day to day.

An infinity of other magic numbers have the same property as 12,345,679 when multiplied by a product of any digit, d, and a certain constant. The product of 37 and $3d$ consists entirely of d's—for example, $37 \times (3 \times 8) = 888$.

For $7d$ the smallest magic number is 15,873, for $13d$ it is 8,547 and for $99d$ it is 1,122,334,455,667,789. It is not hard to find such numbers. As an easy question to be answered next month, what is the smallest magic number for $17d$? In other words, what number when multiplied by $17d$, where d is any digit, gives a number consisting entirely of d's?

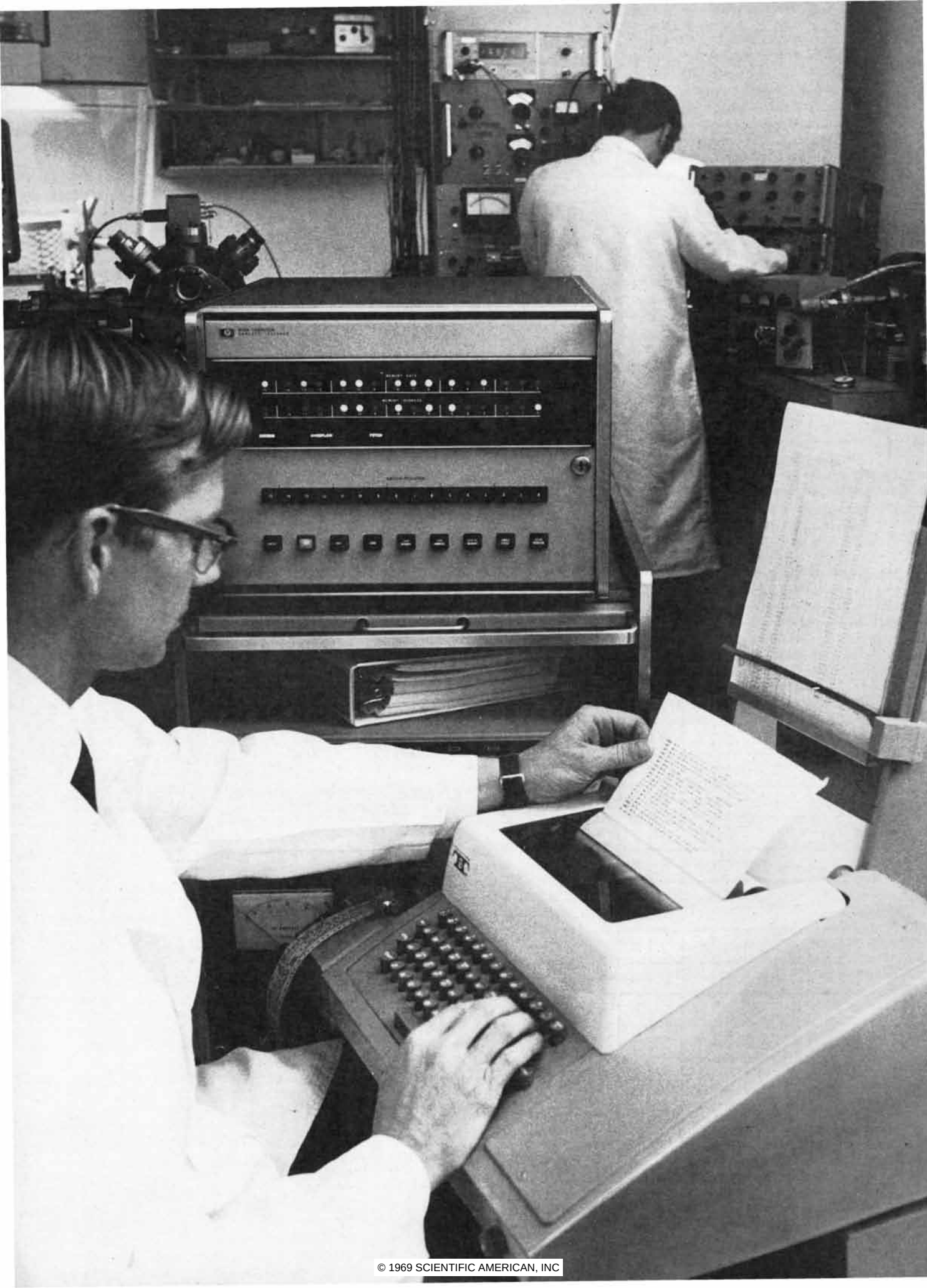
Two of many solutions for the domino magic-square problem of last month are given in the top illustration on the opposite page. The patterns are complementary with respect to 5. The answer to the first domino grid problem is unique [*see top drawing in illustration below*]. The solution to the second [*bottom*] is not unique because the two tiles in the shaded square can be placed horizontally as well as vertically. There are also other, quite different solutions.

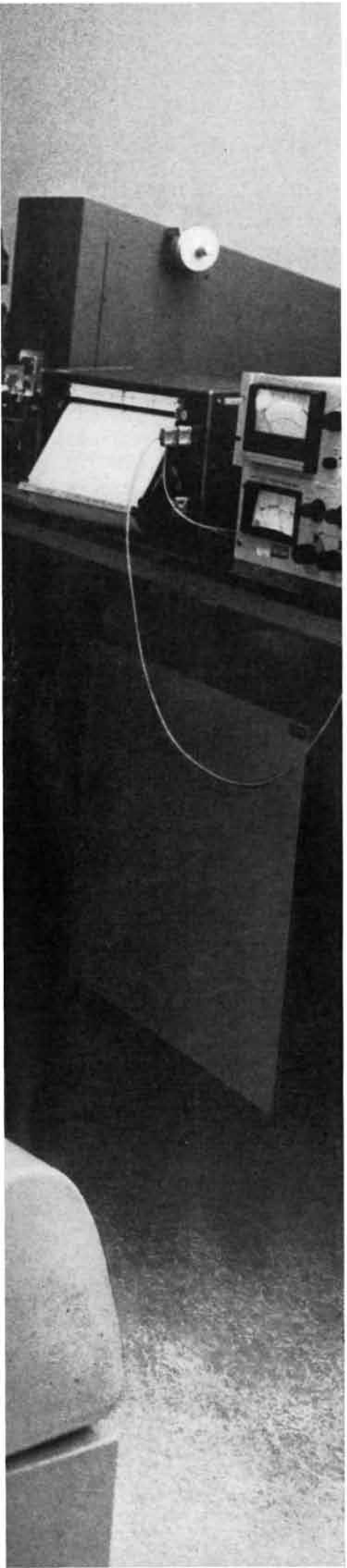
Michael Goldberg was the first to inform me that the solution to last October's moon-base problem, when the number of bases is 10, was given by Ludwig Danzer, but his proof has not yet been published. It was given at a colloquium in Germany in 1962, and is illustrated on page 232 of *Regular Figures*, by L. Fejes Tóth, Pergamon Press, 1964. The smallest number for which no solution has yet been proved is 13.

2	3	3	1	6	6	0	4
5	2	3	0	4	6	1	1
1	4	6	1	3	3	0	1
1	0	2	5	6	6	3	2
5	5	2	0	5	4	4	5
5	5	1	3	2	0	0	3
4	4	4	0	2	2	6	6

6	5	1	1	3	5	3	3
2	4	1	4	3	2	2	4
1	2	5	0	0	2	1	1
6	1	0	0	0	0	6	3
6	5	4	0	0	1	6	2
5	2	4	6	3	3	6	4
4	2	4	3	5	5	5	6

Domino grid solutions





Our computer should work perfectly with your instruments.

Because we probably made many of them in the first place.

That's the big advantage we had when we designed our small computers.

We knew the instruments they would be working with inside out. So we designed computers that start to work the minute they check into your laboratory.

Take our new HP 2114B for example. It features a direct memory access option which provides a high-speed data channel to as many as seven instruments. And, with our optional multiplexed I/O system, you can interface with up to 56 devices.

This beautiful versatility is matched by our computer's beautiful language. With HP BASIC, talking to our computers is as easy as talking to people. And, if you need it, you can use ALGOL and FORTRAN too.

Although the HP 2114B is very compact, it's no lightweight. It does things you'd expect from the big computers. Like memorizing 16-bit words. Storing 4096 (or 8192) of them at a time. And recalling them in 2.0 μsec. For more demanding applications, you may want our HP 2116B. This computer is the heart of our powerful time-share and real time executive systems. It has 1.6 μsec core memory, expandable to 32,768 words. And its specially designed input/output structure makes it easy to integrate into complex instrumentation systems.

So now you can get a computer for as low as $8500 that will let you spend all your time working on *your* problems. For all the details, call your local HP computer specialist. Or write: Hewlett-Packard, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

HEWLETT hp PACKARD

DIGITAL COMPUTERS

22924A

THE AMATEUR SCIENTIST

Experiments in generating the constituents of living matter from inorganic substances

Conducted by C. L. Stong

No one has created life in the laboratory. The possibility is vanishingly small that a viable organism can be compounded. Yet that slender chance continues to intrigue some experimenters, and occasionally progress is reported. For example, a particularly dramatic experiment that amateurs can perform was described 17 years ago by Stanley L. Miller, then one of Harold Urey's students at the University of Chicago. Miller circulated a sterile mixture of water vapor, methane, ammonia and hydrogen through an electric spark. At the beginning of the experiment the mixture was crystal clear. Within 24 hours the condensed liquid turned noticeably pink, and after a week it became deep red, turbid and slightly viscid. Chemical analysis disclosed that the fluid contained a number of organic substances, including several amino acids, which are the building blocks of proteins.

Miller had not compounded these substances by controlled chemical synthesis. He merely established a physical environment that favored their spontaneous generation. It was the kind of environment that might have existed on the primitive earth.

Other experimenters have since reported similar achievements. Heat and various forms of electromagnetic radiation have been substituted for Miller's energizing spark to generate various constituents of living organisms, including purines, pyrimidines, protein-like polymers and nucleic acid polymers. In addition techniques have been devised for encouraging some of these materials to unite spontaneously into ordered structures. As such experimentation continues there is a minute but growing probability that a structure will eventually appear that feeds on the nutrients in its surroundings and reproduces itself. As the biologist George Wald has pointed out: "However improbable the event in a single trial, it becomes increasingly probable as the trials are multiplied. Eventually the event becomes virtually inevitable" [see "The Origin of Life," by George Wald; SCIENTIFIC AMERICAN, August, 1954].

Fascinated by this promise, the experimenters keep trying. Even amateurs are beginning to get in on the fun. One is Carl Fromer of Staten Island, N.Y., who is a premedical student at Columbia University. Fromer explains how to do Miller's experiment and discusses a few others:

"Any experiment that is designed to generate from inorganic substances the constituents of living organisms must provide two basic conditions in the reaction vessel: the vessel must be devoid of life and lacking in free oxygen. The first of these conditions was mentioned more than a century ago in an obscure letter by Charles Darwin: 'It is often said that all of the conditions for the first production of a living organism are now present, which could ever have been present. But if (And, oh, what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed!'

"The second basic condition, the absence of free oxygen, was first emphasized by the Russian biologist A. I. Oparin in his classic volume of 1936, *The Origin of Life*. Essentially Oparin pointed out that free oxygen, a highly reactive gas, would promptly combine with and destroy all organic compounds of interest. The reaction vessel must be sterile and airtight.

"Miller's apparatus consisted of two glass bulbs interconnected by a pair of glass tubes in an *O* configuration so that it was a closed system. Vapor from boiling water in one bulb rose through the outlet tube and entered the second bulb. The outlet tube of the second bulb contained a spark gap and was cooled just below the spark gap by a surrounding water jacket. Condensation that formed in this region drained through a *U* trap to the boiler, ready for another trip through the apparatus. Reaction products that formed in the vicinity of the spark gap accumulated in the water. Miller's construction involves some rather tricky glassblowing. The configuration did not seem critical, and so I made a simplified version that works just about as well.

"My apparatus consists of a closed tube of Pyrex glass 3.5 centimeters in diameter and 60 centimeters long fitted with a homemade heating mantle, a cooling jacket and platinum-wire electrodes for the spark gap [*see illustration on opposite page*]. Access to the interior is provided by a side arm of eight-millimeter Pyrex tubing supplied with a stopcock. The tube operates vertically, with the spark gap at the top. Vapor rises by convection from boiling water at the bottom. Some vapor circulates through the spark gap, where the enclosed gases react, condenses on the chilled wall below and trickles back to the boiler. As in Miller's apparatus, the reaction products accumulate in the water.

"The tube is homemade. I used an ordinary gas-air blowtorch for softening the glass. The air supply was enriched with oxygen to develop the temperature required for working Pyrex. If the experimenter does not have access to glassblowing facilities, arrangements could be made to have the tube assembled by a neon-sign shop.

"One end of the 35-millimeter tubing was collapsed in the flame and blown into a hemisphere. A small hole was then blown in the side, and the access tube was sealed to the hole. After welding a brace of glass rod to support the access tube, I collapsed the remaining open end of the 35-millimeter tubing and expanded it into a hemisphere by blowing into

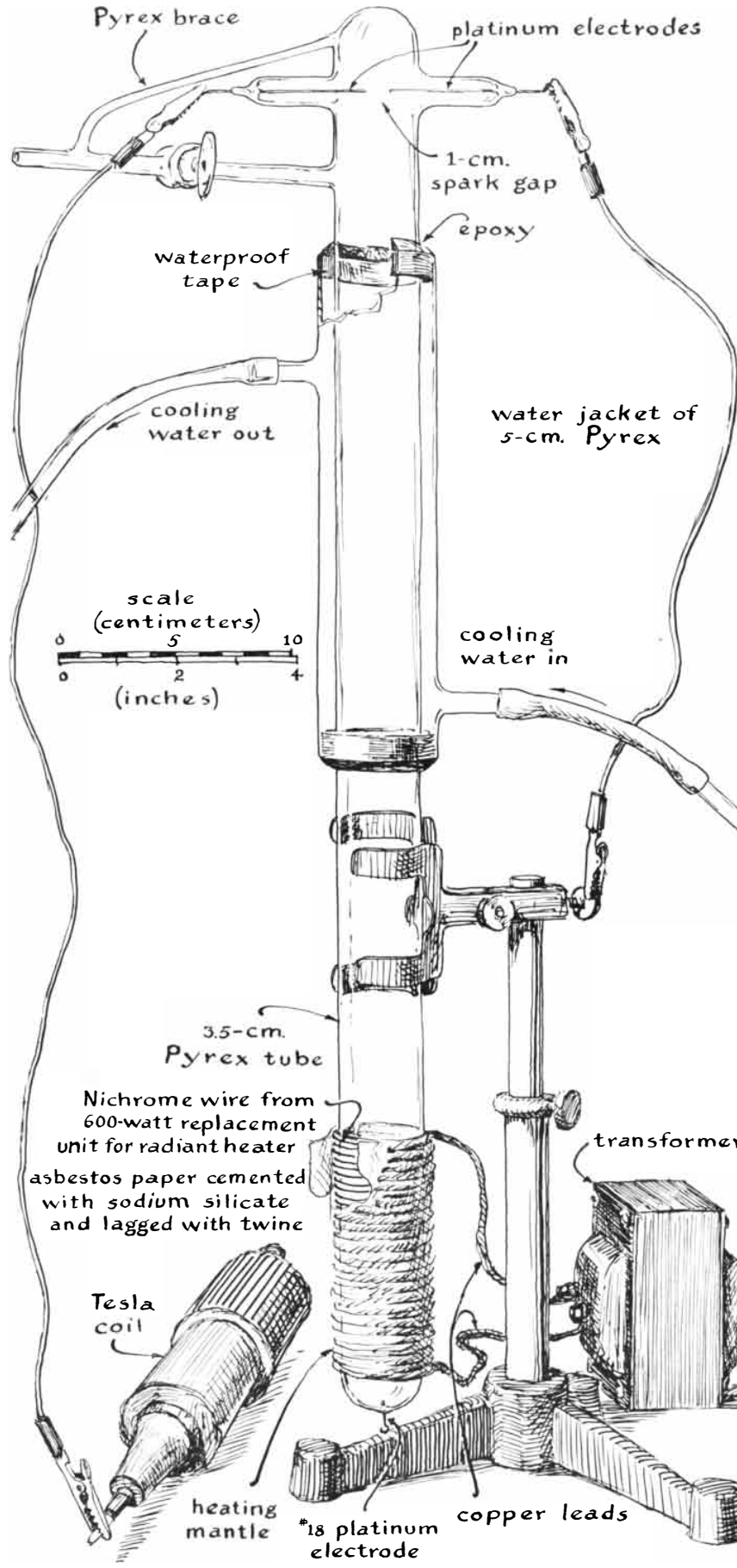
the access tube. The electrodes were sealed to a pair of opposing holes blown near the top of the tube and in the center of the hemispherical bottom. Platinum does not make a vacuum-tight seal with Pyrex, and so I dabbed epoxy cement around each wire at the point where it emerged from the glass.

"The water jacket consists of a 22-centimeter length of Pyrex tubing five centimeters in diameter equipped with eight-millimeter inlet and outlet tubes. The ends of the jacket were closed with rings of plastic tape wrapped around the 35-millimeter tube. The rings make a snug fit with the jacket. I sealed the rings to the jacket with a thick coating of epoxy cement.

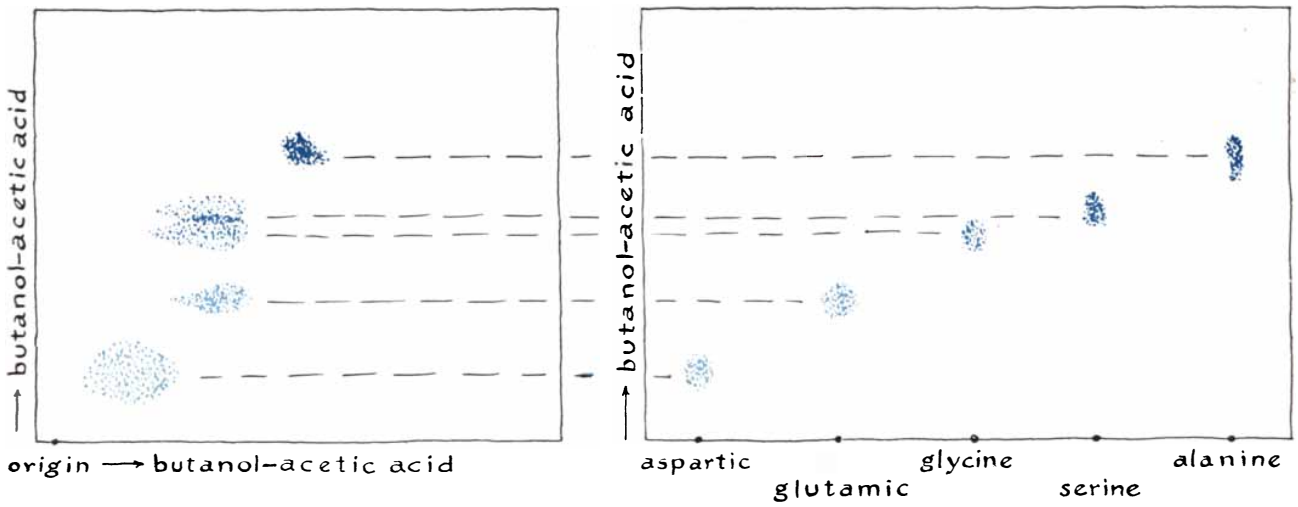
"The heating mantle was made by winding a coil of Nichrome wire, along with asbestos insulation, around the lower end of the tube. A strip of asbestos paper 11 centimeters wide was cemented around the glass with sodium silicate (water glass). A flexible copper lead, insulated with asbestos, was crimped to one end of the Nichrome wire and lashed to the paper with twine near one edge. A layer of wire was wound over the paper at a turn spacing of five millimeters. Four layers of wire and paper were applied. After a flexible lead was attached to the outer end of the wire and lashed to the end of the final layer the coil was completed with a cover of asbestos paper lagged in place with twine and cemented.

"The finished tube was exhausted to the limit of a mechanical air pump. I used the compressor from a discarded electric refrigerator for an air pump, connecting the tube to the inlet of the compressor. The tube was then sterilized by electron bombardment. One terminal of a 15,000-volt, 60-milliampere transformer from a neon sign was connected to both spark-gap electrodes; the other terminal was attached to the electrode in the bottom of the tube. Increasing potential was gradually applied to the input terminals of the high-voltage transformer by a variable transformer until the tube filled with glow discharge. The tips of the electrodes became red-hot. The bombardment was continued for five hours, after which the stopcock was closed.

"The apparatus was transferred to a sterile chamber for filling, along with a pressure cooker containing about a liter of distilled water that had been boiled at a pressure of 15 pounds per square inch for 30 minutes. Some 500 milliliters of the cooled water was transferred to a sterile beaker. The access tube was ster-



Carl Fromer's apparatus for generating amino acids



Chromatogram of known (right) *and unknown* (left) *amino acids*

ilized briefly in a flame and, when it had cooled, was dipped into the water. Water rushed into the tube when the stopcock was opened. I filled the tube to the upper edge of the heating mantle, using about 100 milliliters of water.

"The experiments were made with gases of reagent grade that come compressed in lecture bottles. The gases and the other required materials, including the glass, are available from distributors of scientific supplies. The gases are mixed in the proportion of one part hydrogen and two parts each of anhydrous ammonia and methane (by volume). The proportions need not be exact. I had no precise gauges, and so I measured the gases with three toy rubber balloons that expand into approximate spheres.

"After the balloons had been sterilized in the pressure cooker one was coupled to the outlet of the hydrogen cylinder and filled to a diameter of six inches. The remaining two balloons were similarly filled to a diameter of 7.5 inches with ammonia and methane respectively. The gases were combined in one of the balloons by coupling, with a short glass tube, the balloon containing hydrogen to the one containing ammonia. The balloon containing hydrogen was squeezed to force the gas into the ammonia. The methane was combined with the ammonia in the same way.

"The balloon now containing all three gases was coupled to the access tube of the apparatus and the stopcock was opened to admit the mixture. After the stopcock was closed and the balloon (still containing a substantial amount of gas) had been removed, an empty balloon was coupled to the access tube. When the stopcock was opened, the trapped gas expanded to atmospheric pressure. A more elegant technique for metering the gas can doubtless be devised, but this one works and is inexpensive.

"The filled tube was supported upright by an apparatus stand. After power was applied to the heater, the water came to a gentle boil in about two hours. In the meantime a Tesla coil was connected to one of the spark-gap electrodes and the companion electrode of the spark gap was grounded. When the water reached the boiling point, the coil was turned on and adjusted to an output potential just sufficient to jump the spark gap. Coils of this type are designed for locating leaks in vacuum systems made of glass and are available commercially.

"Within 24 hours the water assumed the color of weak tea, and in seven days it became dark brown. A brown waxlike deposit formed in the upper portion of the tube. After the power was turned off and the tube had cooled, I transferred the fluid under vacuum to a sterile flask. The flask had been fitted with a sterile rubber stopper containing two holes, one of which made a snug fit with the access tube of the apparatus. A hose attached the air pump to the other hole.

"The apparatus was placed in the horizontal position so that the fluid would drain into the flask when the air was pumped out. The fluid was concentrated by evaporation under vacuum in the flask to a volume of approximately 20 milliliters and transferred to a sterile test tube of known weight in which it was evaporated to dryness under vacuum. The net weight of the solid reaction products was 816 milligrams.

"The material was analyzed for amino acids by thin-layer chromatography and by an ion-exchange column. To make the chromatographic analysis I dissolved 25 milligrams of the dried material in 100 milliliters of distilled water to which 364 milligrams of hydrochloric acid was added. Similar solutions, each containing one of 20 known amino acids, were prepared by the same procedure and stored in separate, labeled containers.

"The specimens were applied, as small spots with a micropipette, to an Eastman Chromagram sheet coated with cellulose. To minimize the area covered by the spots and thus improve the resolution of the chromatogram I applied a third of a microliter of each specimen to the cellulose, dried the spot thoroughly and then made similar applications on top of the first one until one microgram had been deposited.

"The unknown material was placed near one corner of a Chromagram sheet at a distance of three centimeters from the edges. The known specimens were spotted in a row on another sheet, two centimeters apart and three centimeters from one edge of the sheet. Both sheets were then placed for development in a rectangular, closed glass dish that contained wash solution.

"The wash solution was prepared by shaking together 100 milliliters each of distilled water, acetic acid and butanol. After standing for a few minutes this mixture separates. Fifty milliliters of the top layer was transferred to the rectangular container. The container was lined with a sheet of filter paper saturated with wash solution. The Chromagram sheets were inserted in the rectangular container with the specimens at the bottom.

"Wash solution migrates upward by capillary attraction and carries the acids along at characteristic rates that vary with the affinity of the acids for cellulose. Development was continued until the wash solution migrated to within five millimeters of the top edge. Both developed sheets were dried.

"The sheet containing the unknown substances was then redeveloped by turning it 90 degrees and again inserting it into the wash solution with the specimen at the bottom. The specimen substances migrated at right angles with respect to their first transit and separated still more. The dried chromatograms appeared blank to the eye, but the amino acids became visible as purple spots after the sheets were sprayed with ninhydrin solution and baked at 100 degrees Celsius in a kitchen oven for five minutes. I made up the solution by dissolving 200 milligrams of ninhydrin in 100 milliliters of acetone to which one drop of collidine was added immediately before use.

"Five spots of color appeared on the sheet of the unknown substances. The distance through which each spot migrated matched the migration distance of one acid of the sheet that had been spotted with known acids. A third sheet was spotted with these five known substances, developed and compared with the unknown substances. The unknown substances were identified as aspartic acid, glutamic acid, serine, glycine and alanine, in the approximate proportions of one aspartic acid, two glutamic acid, 15 glycine, 12 serine and 13 alanine [*see illustration on opposite page*].

"At about the time the chromatograms were made a biochemist volunteered to run a sample of the material on an automatic ion-exchange analyzer. In this instrument compounds are washed through a vertical tube of glass packed with granular ion-exchange resins. The compounds migrate at characteristic rates and emerge from the column separately into a stream of clear fluid that reacts with the fractions to become colored.

"For the analysis of amino acids the clear fluid is ninhydrin solution. Color changes are monitored by a photoelectric cell that actuates a pen recorder. The emergence of each amino acid appears as a peak in the graph that is plotted automatically by the recorder. The machine includes several columns that can be operated simultaneously for plotting slightly displaced graphs of two or more mixtures, for example a known and an unknown mixture of amino acids. A graph of the amino acid mixture that had been synthesized by my apparatus, combined with a superposed graph of known amino acids, confirmed the chromatographic analysis and also indicated the proportionate yields mentioned above [*see illustration below*].

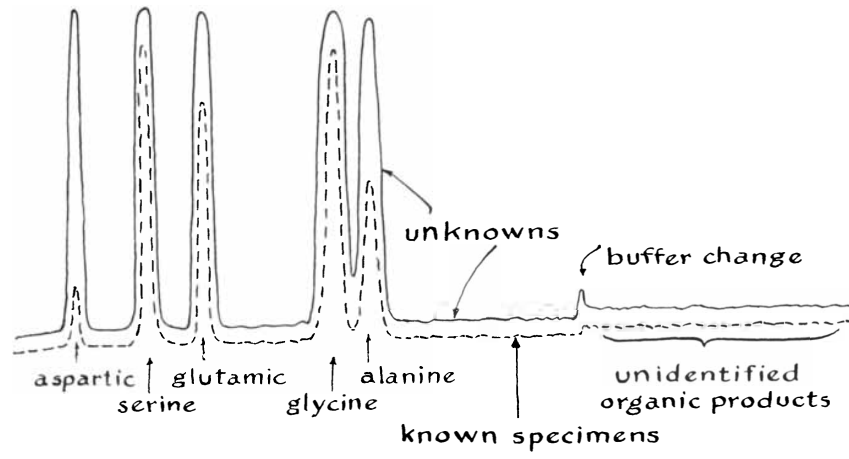
"The synthesized amino acids can be used to perform a fascinating experiment. About 10 years ago Sidney W. Fox of the Institute for Space Biosciences at Florida State University developed a simple technique that encourages the amino acids to unite spontaneously in the form of well-organized structures that he refers to as microspherules. Fox shared the opinion of some experimenters that amino acid molecules, which formed in the vaporous atmosphere of the primitive earth, tended to be carried into the oceans by rain. These compounds did not break down readily, and the oceans became an increasingly rich mixture of organic compounds. Fox reasoned that some of the compounds would occasionally be washed onto hot lava, where they would dry, cook and subsequently be washed again into the sea. How would the compounds respond to this sequence of events? Fox put the question to nature by an experiment. The answer turned out to be that the amino acids would organize themselves into microspherules!

"His experiment sounded interesting, and so I decided to try it. Hot lava is scarce on Staten Island, but I own a flat plate of ceramic that contains a number of hemispherical depressions about a centimeter in diameter and half as deep. I placed about 50 milligrams of the dried reaction product from my apparatus in each of four depressions and the same amount of a mixture (in one-to-one proportions) of commercially prepared aspartic and glutamic acids in four other depressions to serve as a control. The ceramic plate was put in an electric oven at a temperature of 85 degrees C. At the end of about an hour the powdered materials became a highly viscous mass resembling dark brown tar.

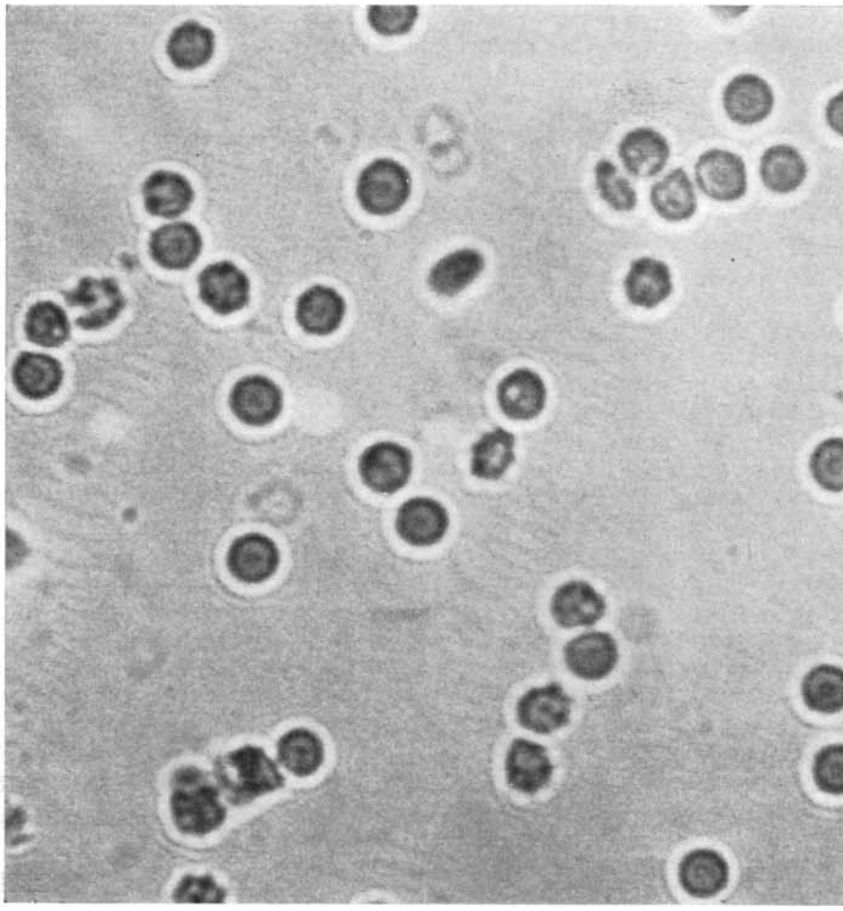
"I then filled each depression with a 1 percent solution of salt water to simulate the concentration of sodium chloride in the primordial sea and thereafter, for six hours, replaced the evaporating fluid from time to time with distilled water. Finally, with a pipette I transferred the end products (the synthesized amino acids and the control) to separate centrifuge tubes and rotated them for 25 minutes at 2,600 revolutions per minute. Smears of the dense fraction of both specimens that settled to the bottom of the tubes were examined with a microscope. Both contained microspherules that were identical in appearance, but the population in the control specimen was substantially larger. The accompanying photomicrograph [*top of next page*] depicts microspherules made with the synthesized amino acids.

"Microspherules appear to consist of an inner core enclosed by a transparent membrane. A careful study of the structures would require the use of a phase-contrast microscope. I do not have one, and so I stained a smear of the specimen with bromophenol blue and examined it with a conventional microscope at a magnification of 1,000 diameters. For some minutes following their preparation microspherules appear to be jellylike in consistency and somewhat tacky. Later they solidify and retain their spherical shape for weeks.

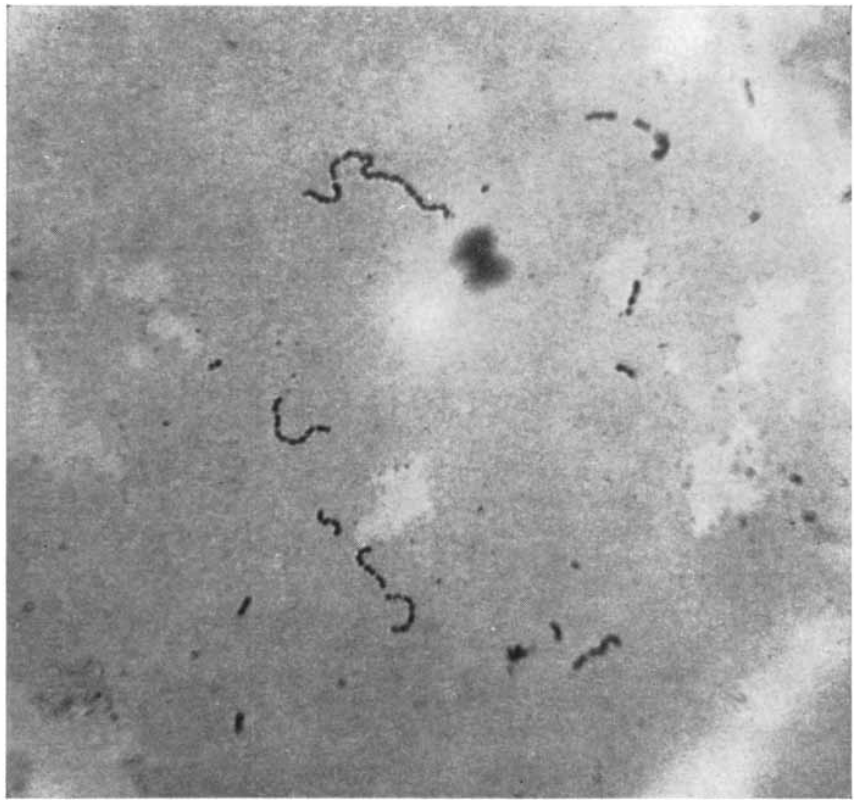
"Fox demonstrated that freshly made microspherules tend to unite into long chainlike bodies that resemble a string of microscopic beads. To encourage the formation of these structures Fox ap-



Ion-exchange graph of five amino acids



Microspherules of synthesized amino acids



Chainlike structures formed by microspherules of synthesized amino acids

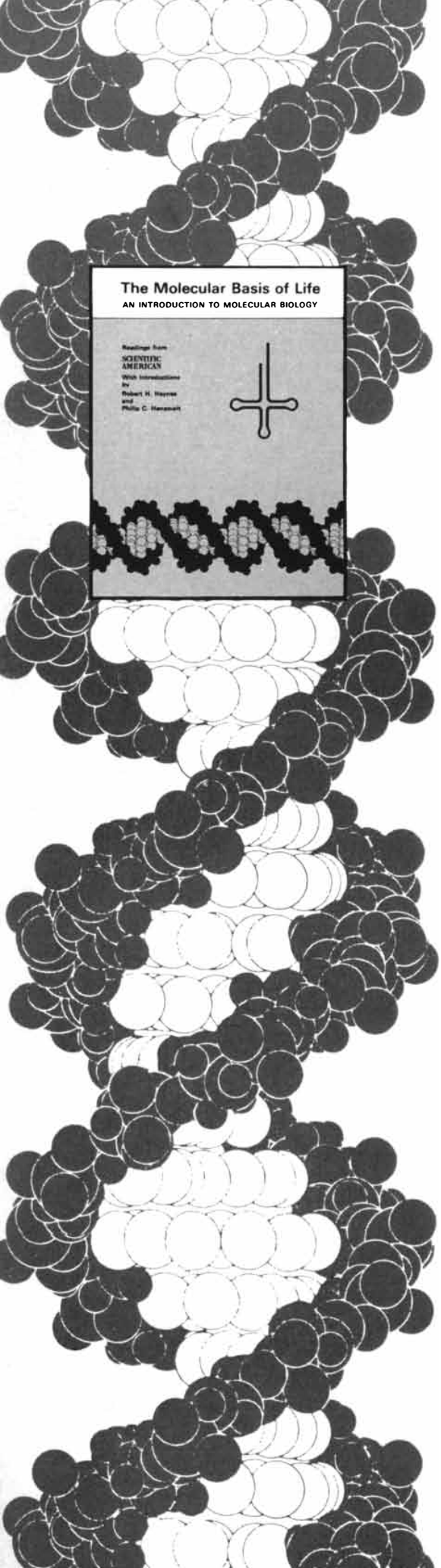
plied slight pressure to the freshly cooked mixture. I made them by first depositing a thin ring of a cement known as gold size on a microscope slide. In the resulting shallow cavity I placed a drop of freshly made microspherule solution. The cavity was closed with a cover slip. When pressure was applied to the cover slip by the point of a needle, the microspherules linked into chains [*see bottom illustration at left*].

"Fox has also demonstrated that various organic compounds, including amino acids, can be generated by exposing a mixture of the same gases to heat. His apparatus resembles Miller's in that it consists of a closed loop containing a cooling jacket and a pair of bulbs, one of which serves as a boiler. For the spark gap Fox substituted a reaction vessel of quartz that contains hot sand. Unreacted gases flow through a Pyrex tube to the bottom of the vessel and migrate upward through the sand to an outlet tube for another transit through the apparatus. The sand is maintained at a temperature of 900 to 1,100 degrees C. by an electric furnace that surrounds the quartz reaction vessel [*see illustration on page 139*].

"The gases must be forced through the sand by pressure, which is developed by an aspirator that Fox inserted in the system immediately above the boiler. Condensed fluid is admitted to the boiler periodically by opening a stopcock in the return line. So far Fox has produced with quartz sand 13 amino acids, including aspartic acid, threonine, serine, glutamic acid, proline, glycine, alanine, valine, alloisoleucine, isoleucine, leucine, tyrosine and phenylalanine. Twelve of the substances have also been produced by packing the reaction vessel with silica gel. On the other hand, *b*-alanine, sarcosine and N-methylalanine have not been synthesized by heat although they appear in Miller's apparatus.

"In a typical experiment Fox passes methane gas through concentrated aqueous ammonia and transfers the resulting mixture to the apparatus. After the gases have circulated through the heated sand for various periods of time that may range from minutes to hours, they are transferred to a closed flask and absorbed by a cold solution of 3 N aqueous ammonia. The cold solution is then heated to 75 degrees C. for various lengths of time in a closed flask and finally evaporated under vacuum. A solution of 4 N hydrochloric acid is circulated through the dried residue (refluxed) for five hours.

"The resulting hydrolysate is evaporated to dryness under vacuum and dis-



"All the classics are there, with their profuse illustrations. . . There can be few better introductions to the literature of molecular biology."

"This book needs no introduction; it will automatically appear near the top of every biology student's reading list, in multiple copies on the shelves of student libraries and in more than a few of their lecturers' bookcases. Like its predecessors, the book contains an invaluable selection of articles on various aspects of molecular biology which have appeared in *Scientific American* over the past dozen or so years.

"The thirty-four papers are grouped into five sections dealing with increasingly complex levels of organization and function: macromolecules, the virus, gene action in protein synthesis, modification of gene action, and radiant energy and the origin of life. Each section has a short historical introduction by either R. H. Haynes or P. C. Hanawalt outlining the state of understanding at the time each article was originally published and subsequent developments. But the meat of the book is, of course, the articles themselves. All the classics are there, with their profuse illustrations; there are the papers of Perutz and Phillips on hemoglobin and lysozyme, of the Delbrücks, Stent, Horne and Benzer on viruses, of Crick, Spiegelman, Nirenberg and Yanofsky on the gene in action, and so on.

"There can be few better introductions to the literature of molecular biology. . ." —From a review by J. Tooze in *Nature*, 11 January 1969

The Molecular Basis of Life

An Introduction to Molecular Biology

Readings from **SCIENTIFIC AMERICAN**

With Introductions by Robert H. Haynes, York University, and Philip C. Hanawalt, Stanford University

1968, 368 pages, 351 illustrations (217 in color), clothbound $10.00, paperbound $4.95

From your bookseller, or from Dept. K

W. H. Freeman and Company

660 Market Street, San Francisco, California 94104

Warner House, Folkestone, Kent, England

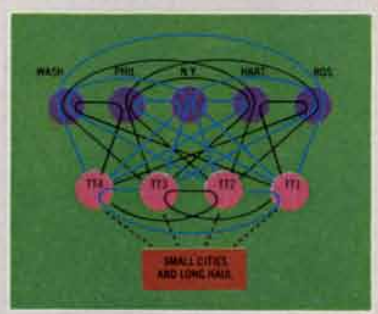
Lockheed has better ways to make better decisions.

Plan for future air travel involves new route concept • Disaster simulator prepares decision makers for crises • Computerized loading model predicts airlift flights per mission • Airline fleet economic analysis evaluates proposed routes

Making a decision involves making a choice. And to make the best decision, all options must be looked at logically and objectively. But the more complex the situation, the harder this becomes. Lockheed, by applying scientific techniques and analytical tools to decision-making situations, is able to approach them more systematically—helping government and business make better decisions with fewer headaches. Some brief examples follow.

Air travel plan for 1980. With air transportation demand increasing geometrically, with airlines ordering more and bigger jets, with airport expansion programs under way, how will all of tomorrow's passengers, planes, and airports best be integrated?

Certainly, a more logical and systematic approach than today's is called for. And one such concept was recently developed by analysts at Lockheed.



Transfer terminal route concept.

They chose the heavily populated Northeast Corridor (Washington, Philadelphia, New York, Hartford, Boston) in 1980 for study. They used the well-known MIT demand equation, modified to include origin incomes and destination attractiveness, to determine 1980 intracorridor travel demand. Applied to 46 corridor cities, the model indicates over 215,000 intercity passengers daily. Of these, 55% will travel between major cities, 5% between minor cities and 40% between major cities and minor cities. Long-haul traffic entering and leaving the corridor is projected at almost 400,000 passengers daily, apportioned among cities by population.

LOCKHEED
LOCKHEED AIRCRAFT CORPORATION

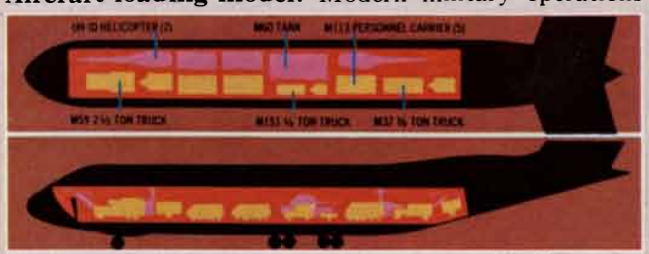
The concept would establish 4 transfer terminals, each situated on low-cost land midway between the 5 major cities. Several intracorridor airline routes (as illustrated) would connect the transfer terminals with each other and with convenient airports and vertiports in and around the major cities, and would connect the major cities with each other. All nonstop. Shuttle service by VTOL or V/STOL would be provided between the transfer terminals and their surrounding small cities. Long-haul passenger traffic would enter and leave the corridor only through the transfer terminals, while long-haul cargo shipments would use major-city airports.

The transfer terminal concept would assure good load factors for the airlines and provide 90% of all passengers —both intracorridor and long-haul—with fast, frequent, nonstop or one-transfer service.

Training for disasters. In disaster situations—floods, fires, riots, earthquakes, even military attacks—quick and often irrevocable decisions must be made. Yet the men whose job it is to make them may never have experienced such situations before.

Providing experience in crises is the main purpose of Lockheed's disaster environment simulator. Developed under contract to the Texas Hospital Association, it is a computer system that dynamically simulates the medical effects of disasters. Personnel responsible for managing medical and transportation resources can use this gaming instrument to try out various disaster-control plans for different situations without the real-life consequences. By systematically evaluating the results, effective operational policies can be formulated.

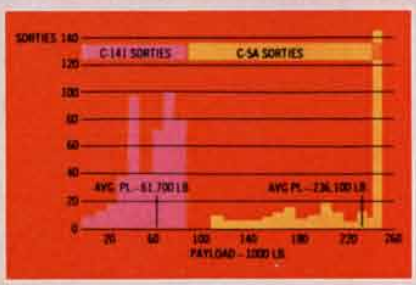
Aircraft loading model. Modern military operations depend increasingly on successful airlift. And airlift success depends greatly on accurate estimates of the number of sorties (aircraft loads) needed. So Lockheed analysts have developed a computer model that simulates and thereby predicts the results of aircraft loading.



Typical C-5 vehicle load generated by Lockheed's loading model.

The loading model can work with any 2 aircraft types (for instance, the C-141 and the C-5) simultaneously and in any ratio. It considers the dimensional and weight limitations of the aircraft, then selects items for placement in cargo compartments by a heuristic procedure that simulates manual load planning. (See 1st illustration.)

The program output shows the vehicles, troops and palletized cargo comprising each load, plus payload and area utilization. A summary gives the payload frequency distribution for each aircraft type. (See 2nd illustration.)



Payload frequency distribution between C-141 and C-5.

In practice, this means that with a given amount and mix of cargo to be airlifted, the number of sorties needed by available transports can be predicted accurately.

Airline fleet planning. Any endeavor as complex as operating an airline, no matter how well managed, can benefit greatly from a more organized method of making decisions. With this in mind, Lockheed has developed a series of computer programs that airlines are using to help analyze their air transportation operations.

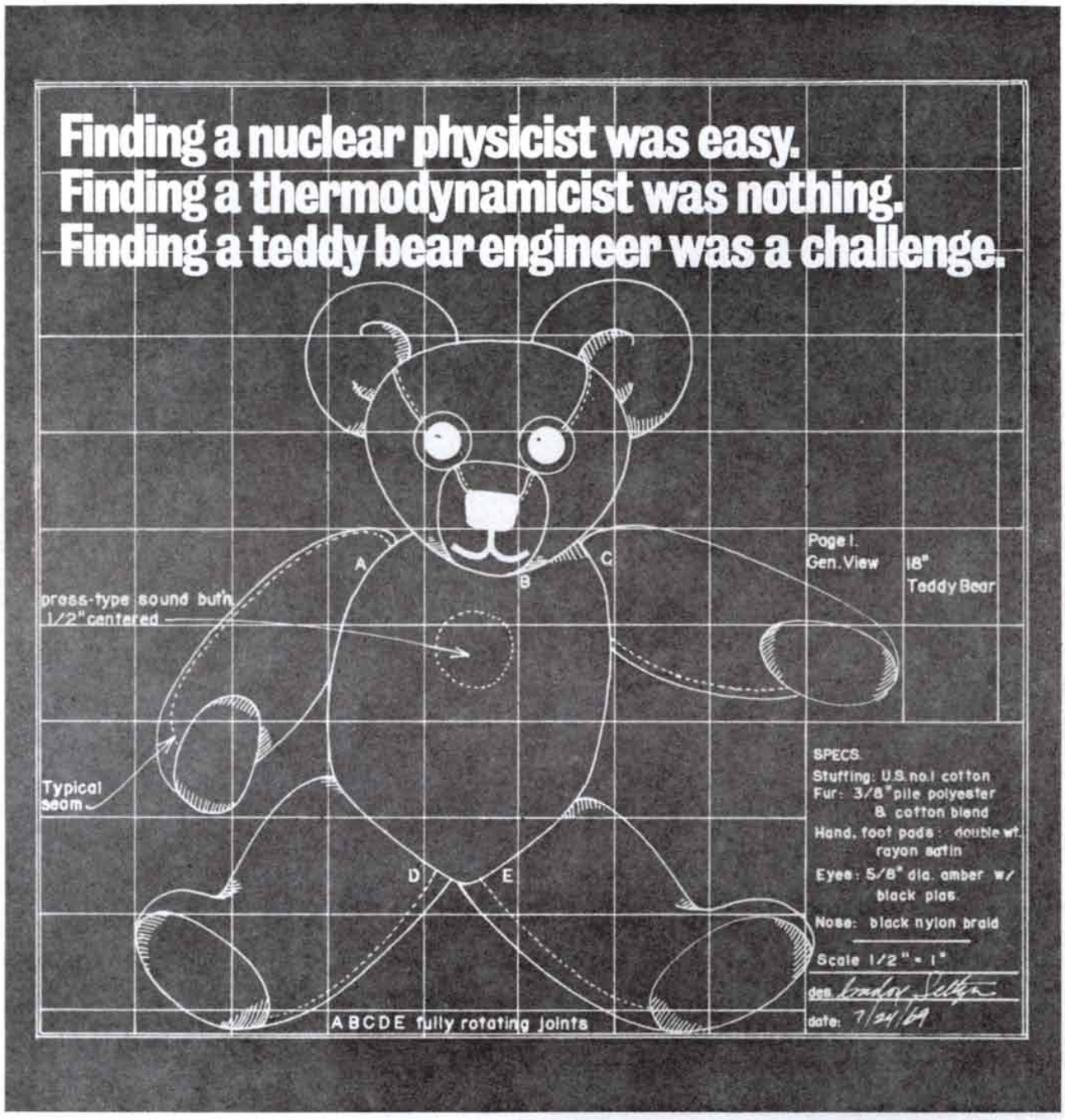
At the heart of these programs is an airline system simulation model, whose inputs are coordinated with the airline. The simulation model is then coupled with men who have airline planning experience.

The model is put into motion by balancing 2 sets of factors. One is passengers seeking to satisfy their travel needs from an array of potential services. The other is the desire of the airline to offer service, motivated by a profit objective. Because it simulates a real-world situation, the model also takes into consideration expansion of service needed to meet competition as well as compliance with government regulations.

What comes out is the number of flights required by different types of aircraft to serve an airline's total route system, the operating expenses incurred to offer this level of service, and the revenue generated. Based on this information, flight schedules, the total aircraft requirements, system load factors and utilization, earnings, and discounted cash flow return on investment are optimized.

The activities mentioned here are only a few of Lockheed's current R&D efforts in problem-solving. If you are an engineer or scientist interested in this type of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.

Finding a nuclear physicist was easy. Finding a thermodynamicist was nothing. Finding a teddy bear engineer was a challenge.



Manpower, Inc. supplies technical help for projects of all orders.

In short order.

We've got over 450 local offices around the country. So when an aerospace company in Buffalo needed a thermodynamicist, they just called our Buffalo office.

And our office wasn't buffaloed.

They sent the request to the Monster, our central IBM file. In it is information about our 15,000 available specialists. (Not just thermodynamicists and physicists. Architects, engineers, designers and draftsmen too.)

Then the Monster acted like a dating service. It matched the assignment with our most suitable thermodynamicist.

He worked for the aerospace company for two years, till the assignment was over. But all that time Manpower was his employer, and we paid him. Every week, right on time. We're a big, solid company and we can afford to be efficient about things like that.

But even we can run into trouble.

When a toy company called us for a teddy bear engineer, the Monster drew a blank. But we put all our offices on the alert. And in three weeks, Milwaukee had tracked our man down.

Nothing's too tough for Manpower, Inc.

Even teddy bears.

Manpower® Technical Services Division

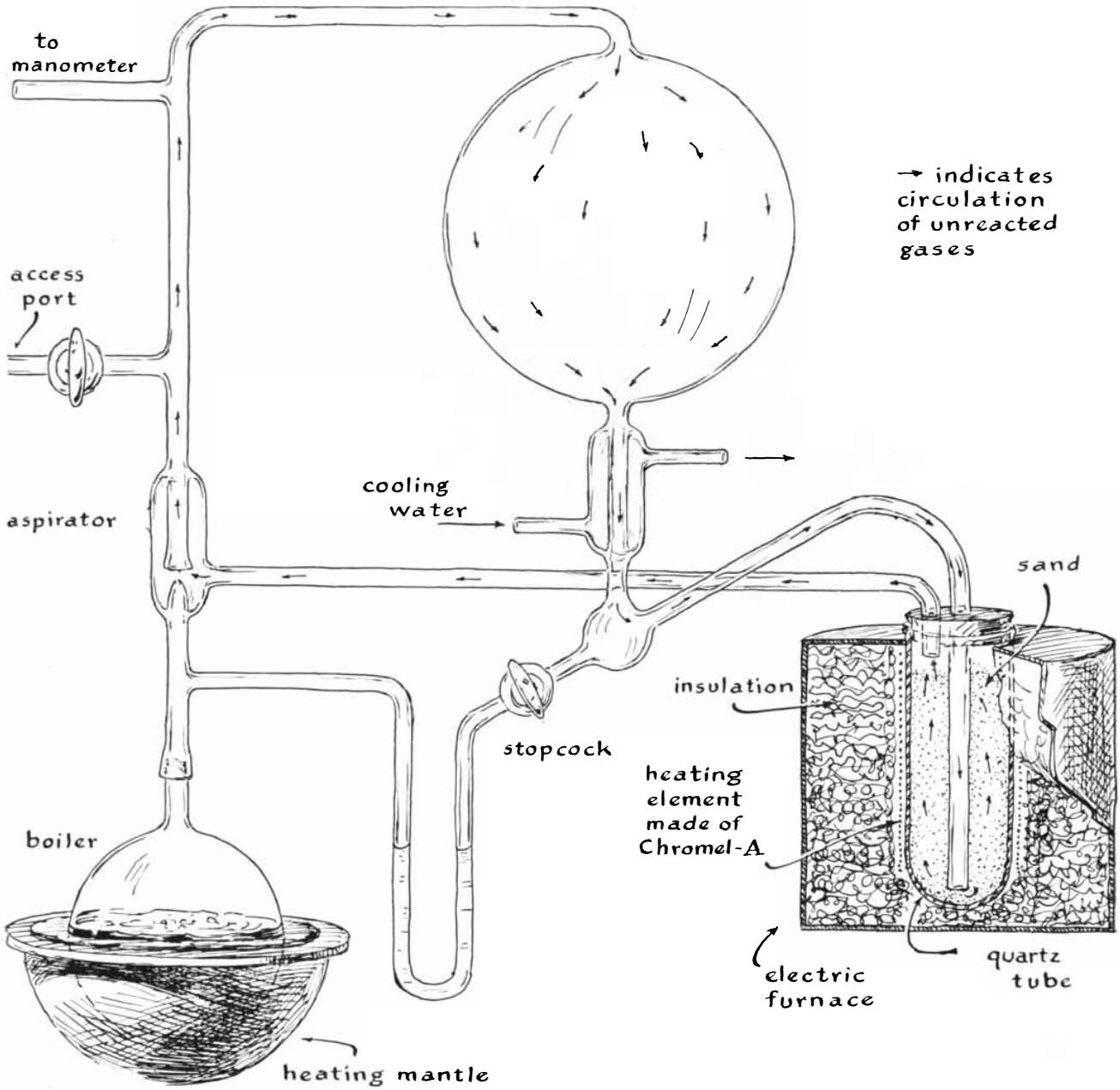
If we could come up with a teddy bear engineer, we can come up with the man for your project.

solved in a citrate buffer at *p*H 2.2. The mixture is then ready for analysis and use. Fox found that the yield of different amino acids varies with the materials in the reaction vessel and with the temperature of the vessel. For example, when the reaction vessel is packed with quartz sand maintained at a temperature of 950 degrees C., aspartic acid constitutes 3.4 percent of the final product, but when silica gel is used at the same temperature, the production falls to 2.5 percent. When the temperature of the silica gel is raised to 1,050 degrees, the production of aspartic acid rises to 15.2 percent but the production of glycine falls from 68.8 percent to 24.4 percent.

"In undertaking these experiments I made a point of keeping the hazards in mind. Hydrogen and methane form explosive mixtures with air. Anhydrous ammonia is toxic and can burn the skin. Ideally the gases should be handled in a fume hood. I filled the balloons and transferred the gases to the apparatus in my backyard. Ammonia migrates slowly through rubber. If you squeeze the balloon with your bare hands, the gas may burn your palms. I wore neoprene gloves. The cooling jacket prevents explosive steam pressure from building up inside the apparatus, *but only if a continuous stream of cold water circulates through the jacket.*

"As time permits I intend to continue the experimentation by including phosphoric acids in the mixture, in the hope of synthesizing some of the nucleic acid polymers and perhaps inducing them to combine with the protein-like bodies."

In discussing the liquefaction of gases in this column last November, I stated correctly that methyl chloride is a harmless gas. A number of readers subsequently pointed out that methyl chloride combines explosively with aluminum and should not be admitted to the sealed compressors of home refrigerators. Most of these machines contain parts made of aluminum to which the gas is exposed.



Apparatus for synthesizing amino acids with heat

44240. ELEMENTARY QUANTUM MECHANICS. *David S. Saxon.* Leads step by step from a statement of concepts to mathematical formulation of the twentieth century's most important theory—quantum mechanics. $12.50/**8.95**

35000. THE AUTOBIOGRAPHY OF BERTRAND RUSSELL, 1944-1969. The distinguished mathematician and philosopher sums up a lifetime of service to science and humanity. He recollects a quarter century of controversy during which he received the Nobel Prize for literature. $8.95/**6.50**

40860. CREATIVE GLASS BLOWING. *James E. Hammesfahr and Clair L. Stong.* Clear step-by-step drawings of every process needed for making glass objects. For the creative hobbyist and the scientist who needs and uses laboratory equipment. $8.00/**6.25**

75710. SCIENCE NEWS YEARBOOK 1969/1970. *Science Service.* Latest reports on every area of science. Illustrated with photographs, drawings, diagrams. Completely indexed. A unique and invaluable reference. $9.95/**7.50**

60900. MATHEMATICAL HANDBOOK FOR SCIENTISTS AND ENGINEERS: Second Edition. *Granino A. Korn and Theresa M. Korn.* A comprehensive reference collection of mathematical definitions, theorems, and formulas for scientists, engineers, and students. $25.00/**16.95**

45260. ENGINEERING AND THE LIBERAL ARTS. *Samuel C. Forman.* A practical reading program for the scientist and technologist who wants to keep up with the world of literature, history, philosophy and the arts. $8.95/**6.95**

56140. INTRODUCTION TO OPERATIONS RESEARCH. *Frederick S. Hiller and Gerald J. Lieberman.* The basic methodology and techniques of operations research. A survey which emphasizes motivation and simplicity of explanation. $14.75/**10.50**

All these books to choose from at low member prices!

(Retail prices light type, member prices **bold type***)*

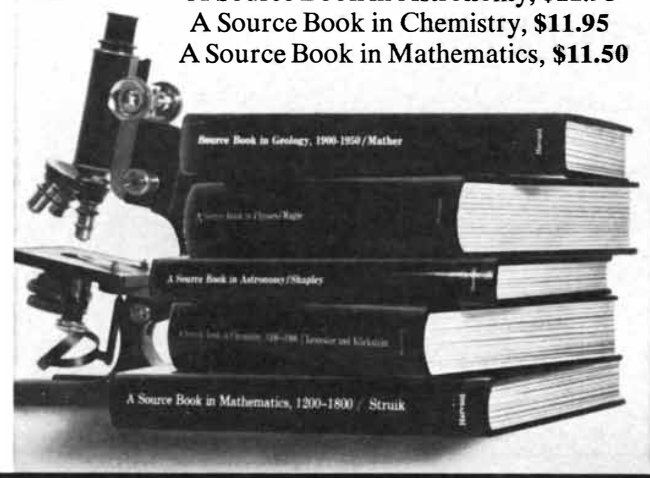
69830. PREHISTORIC EUROPE. *Philip Van Doren Stern.* The well-known historian brings together the results of modern archeological research on the latest findings about early man and his culture. $10.00/**7.50**

70710. PROGRAMMING: AN INTRODUCTION TO COMPUTER LANGUAGES AND TECHNIQUES. *Ward Douglas Maurer.* Presents the latest programming techniques, with specific reference to current makes of machines. Clear and comprehensive work for self-tuition. $11.50/**8.25**

66060. OPTICAL PHYSICS. *Stephen G. Lipson and Henry Lipson.* Principles of optics, and their influence in other branches of physical theory. A brilliant new analysis, written with clarity, insight and wit. $12.50/**8.50**

85960. IN THE WAKE OF THE SEA SERPENTS. *Bernard Heuvelmans.* Is there such an animal? Eyewitness accounts, from 1693 to 1965, seem to prove the existence of not one, but seven distinct types of marine monster. Profusely illustrated. $10.00/**7.50**

Source Book in Geology, **$12.50**
A Source Book in Physics, **$12.50**
A Source Book in Astronomy, **$11.95**
A Source Book in Chemistry, **$11.95**
A Source Book in Mathematics, **$11.50**



54090. HUMAN SEXUALITY. *James Leslie McCary.* The definitive marriage manual. Authoritative, detailed information on all aspects of sexual behavior. $9.75/**6.50**

78730. SO HUMAN AN ANIMAL. *René Dubos.* A famous biologist and Pulitzer Prize winner gives warning: runaway technology is destroying man's environment. This is must reading! $6.95/**5.75**

87310. THE WIND AND BEYOND. *Theodore von Kármán.* The autobiography of a scientific genius, the father of aerodynamics and rocketry, first winner of America's National Science Medal. $10.00/**7.50**

85890. VENOMOUS REPTILES. *Sherman A. Minton, Jr. and Madge Rutherford Minton.* All about poisonous snakes and their venoms. Identification, methods of treatment of snake bites, uses of snake venom in medicine and research. Fascinating! $7.95/**5.75**

32530. ALGEBRA. *Saunders MacLane and Garrett Birkhoff.* A completely new standard work by the eminent authors who revolutionized the study of algebra. Here are the new approaches, the new vocabulary indispensable for today's students. $11.95/**8.50**

44190. ELEMENTARY PARTICLES AND THEIR CURRENTS. *Jeremy Bernstein.* A highly acclaimed new presentation which concentrates on the interaction of currents. The author is Professor of Physics at Stevens Institute of Technology. $12.00/**8.50**

36280. A BIOGRAPHICAL DICTIONARY OF SCIENTISTS. *Trevor I. Williams.* Encyclopedic 600-page new work—the lives of more than 1000 scientists in fields ranging from agriculture to zoology. $9.95/**7.50**

66120. ORCHID FLOWERS: THEIR POLLINATION AND EVOLUTION. *L. van der Pijl and Calaway H. Dodson.* A demonstration of ecology and adaptive evolution in action. Lavishly illustrated with drawings and magnificent color photographs. $12.50/**8.95**

Take any or all of these invaluable source books

(Total retail price, $60.40)

for only $1 each

with your first selection as a trial member of

THE LIBRARY OF SCIENCE

An extraordinary opportunity to own and enjoy the important Harvard University Press Source Book Series. They're not only delightful to read, but you'll find them most valuable reference books. And where else would you get such a value but from The Library of Science—the *one* book club that brings you the very best books in all scientific disciplines, at worthwhile discounts. Your membership is the easy, money-saving way to keep up with the most meaningful works in your own and related fields. Why not take advantage of this opportunity now?

TRIAL MEMBERSHIP APPLICATION

2-809

Name.....

Address.....

City.....

State.....Zip.....

Offer good in Continental U. S. and Canada only

THE LIBRARY OF SCIENCE
P.O. Box 2222, Riverside, N.J. 08075

Send me the Source Books in *(check)*

___Physics ___Geology ___Chemistry

___Astronomy ___Mathematics

My first selection is:

_____
(write in number)

Please enroll me as a trial member, and send the Source Books checked ——— as well as the first selection I have noted. Bill me only $1 each for the Source Books, member price for my first selection, plus shipping and handling. If not delighted, I will return them all within 10 days, and my membership will be cancelled. As a trial member, I need accept as few as 3 more selections during the next 12 months, always at reduced member prices, plus shipping and handling, and I may cancel membership any time thereafter. Each month, I will receive a newsletter describing forthcoming selections, along with a convenient form for requesting alternate selections, or no book at all. I understand that I may choose a free bonus book for every 4 selections purchased.

BOOKS

The games children play, the physical control of the mind, and other topics

by Philip Morrison

CHILDREN'S GAMES IN STREET AND PLAYGROUND: CHASING, CATCHING, SEEKING, HUNTING, RACING, DUELLING, EXERTING, DARING, GUESSING, ACTING, PRETENDING, by Iona and Peter Opie. Oxford University Press ($9.50). Voltaire was delighted by Newton, who stayed home with his calculations and yet found the figure of the earth as well as did the Paris astronomers who voyaged to Peru and to Lapland with their costly instruments. Modern ethnographers working deep in the bush, and we who read them, may even more excusably envy and admire the Opies, who extract the details of a marvelous culture from the children in the streets around them. That learned and tireless couple devoted the decade of the 1950's to collecting and recording the lore and the language of schoolchildren, and the 1960's to assembling less verbal parts of that culture. This volume (we are promised another one on games, such as ball games and marbles and hopscotch, that depend on special equipment) is concerned "solely with the games that children, aged about 6–12, play of their own accord when out of doors, and usually out of sight." The string of participles in the subtitle is as good as a review. More than 10,000 children have been their informants, and "there is no town or city known to us where street games do not flourish." Adults, even boys of a ripe 14 years, sometimes maintain that the games are past, because the games are past for them. Even perceptive novelists and professional students of the street have had this illusion, but although the games change, they remain robust and ubiquitous.

Adult interference does weaken a game, and the games given official place in park and playground by well-intentioned people become less popular. There has been a decline of games in which one player is repeatedly buffeted by the others. Novelties arise too, so that the knife game split the kipper has all but driven out mumblety-peg, at least in Britain, after more than 400 years. (The older game is played from New Zealand to Poland, and you can find it in Brueghel's painting.) Conkers, a battle fought with strings of horse chestnuts, is a new version of the game played with hazelnuts until a century or two ago, when the newly introduced horse-chestnut trees provided a better (and inedible) basis for the game.

The Opies provide an account of each game, its rules and its names variorum, its appeal and circumstances of development, and a passage of historical and foreign parallels. The seeking game kick the can (tin-can tommy is its basic name in London) is the game that most commonly disturbs the "repose of the back streets"; the catching game Farmer, farmer, may we cross your golden river? ("fascinating to little girls, partly, it seems, because of the way it draws attention to item after item of their clothing") is the most popular game in British streets today. The U.S. is knowingly treated, although Britain is the main site of the fieldwork.

The authors are indignant that this free culture of children is restricted, both by unneeded efforts to domesticate it to school and other adult-dominated uses and by physical elimination of the complex and obscuring environments in which the games best flourish. These ritual romances and combats thrive alike in the fresh greenwood and in the shabby warrens of the alleys and streets of the city, but they cannot thrive in aseptic, flattened, unobstructed areas of paving called playgrounds or school yards.

Like all human culture, the culture of children is self-perpetuating, but it is not aloof from other cultures. Television has had a marked impact. Games have spread with armies of occupation, with emigration, under a hundred influences. Games arise too from the witness children bear to what we do. In Auschwitz the children "were seen playing a game that proved the most terrible indictment ever made against man, a game called 'Going to the Gas Chamber.'"

There are several interesting maps and some excellent photographs of children at play.

PHYSICAL CONTROL OF THE MIND: TOWARD A PSYCHOCIVILIZED SOCIETY, by José M. R. Delgado, M.D. Harper & Row, Publishers ($7.95). A fighting bull in full charge at a man on foot is abruptly halted by the crooking of the man's finger! The bull stops, turns to one side and seems to lose its deep-bred desire to attack the intruder. On many repetitions the bull accepts men in the ring for minutes without charging at them. This is a thoughtful, up-to-date account of remarkable experiments with electric stimulation of the brain, carried out in cats, monkeys, chimpanzees and a few human patients, as well as in that somewhat romantic experimental animal the fighting bull. The means are direct and simple in concept, but they are subtle, even enigmatic, in detail. A set of fine stainless-steel wires is implanted in the living brain, in a region chosen carefully (but not with microscopic precision) by the experimenter. A pulse of current of a milliampere or so is allowed to flow through the brain for seconds. That pulse can be released by radio command. You can see chimps with connectors on the scalp allowing the choice of 100 different electrodes. In the latest work these inconvenient—but not painful or dangerous—penetrations can be completely concealed under the skin. Two chimps have been fitted with a small transistorized device, needing no batteries, that can remain for life within their skull; the instrument places the flexing of a leg forever under the control of an experimenter. The chimp Paddy, which bears a scalpful of connectors still, was placed in two-way radio link with an on-line analogue computer. The electrical activity of a specific brain region was telemetered from the freely active chimp to the computer. Whenever a specific pattern of waves occurred, the computer recognized it and sent back to Paddy's brain

signals to trigger current pulses in another region of the brain "known to have negative reinforcing properties." In a week the special patterns no longer occurred, and "the chimpanzee was quieter, less attentive, and less motivated during behavioral testing, although able to perform olfactory and visual tasks without errors." The pattern returned two weeks after the link was broken; the experiment had been repeated several times. A woman patient, suffering from severe epileptic seizures accompanied by unpredictable rages and assaults on others, has played a role like Paddy's. The computer was missing; in its place in the loop was Dr. Delgado. He could watch the records of brain activity while the patient was in another room, aimlessly walking around the ward. Features of the brain-wave patterns could be associated with behavior. One deep contact allowed the induction of rages resembling the spontaneous outbursts but starting at the radio command of the physician. A pulse was applied "while [the patient] was playing the guitar and singing with enthusiasm and skill." She threw down the guitar after seven seconds of stimulation and "launched an attack against the wall." In other cases there is a subjective report by the patient; he attributes his changes in behavior to internal desires, never to any specific awareness of the stimulating pulse.

What is one to make of this remarkable, suggestive and somehow ominous complex of skills and half-knowledge? That is the burden of most of the book, which is a clear, straightforward, calm, rather conservative and personal statement of the purposes and implications of such work. The discussion ranges from therapy to society to philosophy to ethics, and even touches modestly on theology. Two points are central: the intervention depends on structures of behavior already in place, which it touches off as a switch turns on a specialized machine. The pulses cannot instruct. It still appears that the classical means of reaching the mind are much richer. Moreover, the art is at present crude: the electrodes are placed with millimeter accuracy but nerve-cell contacts are measured in microns. Only in the most general way do we know what to expect from any electrode. Above all, the human mind is not wholly individual; already it is in large part social. We do not make our language for ourselves. In the same sense the pulses injected can be seen as a crude extension of what man as a social being now knows. How far this intracranial moralizing can proceed we do not yet know. It is difficult to deny Dr. Delgado's major plea for extension of such neurobehavioral work; it is less difficult to foresee that it will not play the widespread role in society some might imagine. It is knowledge of ourselves, not easy control, that will be the fruit of this daring work.

The book is meant for the nonscientific reader. It is a pity that its editors supplied no index, and not a single labeled diagram to give local habitation to the Graeco-Roman anatomical names freely used in the text.

PICTURE ATLAS OF THE ARCTIC, by R. Thorén. Elsevier Publishing Company ($57.50). HUNTERS OF THE NORTHERN ICE, by Richard K. Nelson. The University of Chicago Press ($8.50). The Arctic sea is an icy Mediterranean, studded with islands, its littoral dotted with settlements large and small, its broken waters crossed by voyagers on many errands in strange craft. Two populations of men are at home there: one group consists of the immigrant miners, pilots and radiomen of our own world—men of the American, Canadian, Scandinavian and Soviet states; the second group is made up of the old families, the 60,000 or so Eskimo men, women and children, who have lived on the shore and hunted on the sea ice for a hundred generations.

Captain Thorén is a well-traveled immigrant. An air reconnaissance expert lately retired from the Royal Swedish Navy, he has assembled a remarkable (and expensive) set of about 600 photographs, mostly taken from aloft, that display the Arctic. Here is the North Pole itself in a picture he took a decade ago from four miles up. There are photographs on the ground too; one can see the signposts at Longyearbyen in Spitsbergen, the northernmost of sizable human habitations, where more than 1,000 men overwinter in the coal-mining center of the North. The town was founded by an American, and the signpost points to sunny Honolulu, 10,000 kilometers away. There is Alert on Ellesmere Island, the northernmost of all land stations, and a whole set of photographs of those stations, Russian and American, that drift on great floe rafts, 100 feet thick, a few miles a day right across the Arctic Basin. Huts and helicopters, four-engined Soviet aircraft, radomes and unloading icebreakers can be seen at these stations.

The heavy tractor trains of the U.S. Army working into the Greenland ice cap have their Lapland counterparts in the BM-Volvo amphibious tracked vehicles of the Swedish army. Neither of these useful haulers can match the appeal of the elegant Tupolev model-TU propeller-driven aerosledge, shown speeding with five passengers across the snowy rolling Siberian plains; at 60 miles per hour "its pressure against the surface of the snow is so slight that scarcely any traces are left." Most of the photographs, however, are not of men or their works but of the bleak, beautiful land and the ice-filled seas. There are a few well-presented stereoscopic pairs to show relief on many scales. One fascinating air view shows the volcano Beerenberg on Jan Mayen Island, a seaside Fujiyama with a cleft crater brimful of ice. It last erupted in 1818.

Nelson is an Arctic immigrant too. He is a husky anthropology student still working for his Ph.D. He has lived, learned and hunted with the men of Wainwright, Alaska, an Eskimo town some distance down the coast from Point Barrow. His book is no ethnography of family and song, hearth and legend. He does not even speak the language well. He has here reported at first hand—with insight, learning and penetration—the way these men hunt the shore and the sea ice. On one of Nelson's first hunts a young Eskimo hunter bagged a seal by the subtle techniques of his people, looked at his southern companion and smiled "as he pointed to his head saying, 'You see, Eskimo is a scientist.' "

If we extend science to include its applications, the hunter was right. Exactly the same inquiring spirit, the same close attention, theorizing, empirical testing, modification, training and evolving depth marks Eskimo science and technology as it does that reported by Captain Thorén. The difference is scale. The pilot sees the ice on 1,000-kilometer hops, burning fuel hauled from the Persian Gulf; the Eskimo, feeding himself and his dogs seal meat and oil, sees his land on foot at a scale of 10 meters. He watches the sky closely; he listens for the animals; he feels the black skin of the newly forming ice. He finds his way across the broken ice by the "map" of the ice forms ahead, which he sees reflected in the cloud layer above him. He notices that whenever the auroral arcs are long cohesive bands, they always align themselves east and west. He can change too, and build his technique afresh. The Eskimo hunter today owns a watch and navigates with its aid. In summer the sun is always present, and the watch gives its bearing. He uses the magnetic compass as an ice seismometer; placing the compass on the ice in a set position carefully screened from the

wind, the sea-ice hunter can check the needle every few minutes. If a crack opens somewhere and the ice floe shifts, its rotation shows up at once by a small shift in compass direction, and the hunting party is forewarned that the floe is beginning to break away. The electric light, particularly on the high towers of the Dew line, has become a prime aid to the hunter's navigation. "It would be difficult for today's Eskimos to do without these landmarks."

Much of Eskimo technology, unlike our own in the Arctic, is biology. Nelson reports at length and step by step both how to travel the shifting ice and how to hunt all those various land and sea species that are invisible in the *Picture Atlas* (except for a few reindeer). The Eskimos hunt seal by explicit application of their knowledge of seal behavior. At its air hole under the ice the seal is wary; a man's single breath can frighten it off and send the harpooning hunter home without game. In open water, however, where the modern rifle can reach the quarry, the seal is attracted by a special scratching on the ice to come within range. That is the mode of seal hunt they use in Wainwright nowadays. The technique is here in detail, so that one could become a new hunter himself from this book, written by a man who learned to make the tools and then to hunt as an apprentice to the Eskimo. It is a tight technical introduction to this rich body of Eskimo technology, the kind of specialized ethnography we badly need. With the marvelous films made of Pelly Bay Eskimos in the past decade by Asen Balikci and his collaborators, this book will go far to preserve the way of the Eskimo, a fading legacy of human creativity and insight, "before it is lost forever in the icy graves of the old men."

THE PROTON FLARE PROJECT (THE JULY 1966 EVENT): VOLUME III OF THE ANNALS OF THE IQSY, INTERNATIONAL YEARS OF THE QUIET SUN. A. C. Stickland, General Editor. The M.I.T. Press ($23.50). Science looks out at the world in diverse directions, but it is always man looking. This technical volume, with 60 brief specialized papers and five distinct summary essays, is an account of the rich set of phenomena called a proton flare. The event begins with a fierce local magnetic discharge on the solar surface, with its concomitants of a flare-up of hydrogen-line light in a sunspot group, a characteristic radio burst and even X rays. Within an hour fast electrons hit the high atmosphere near the North Pole of the earth, there

to be observed by their effects on the ionosphere, as detected by radio soundings, and also by direct counting from balloon-borne instruments. Very soon instruments all over the earth from Ellesmere Island to Kerguelen, from Dallas to South Pole Station, record at ground level the fast solar protons, the cosmic ray particles that give this most energetic type of solar storm its name. Four to five hours later no effects remain at ground level, although in the high atmosphere there are still solar particles. No fewer than six satellites took part in recording particles and fields and plasma gradients; three were near the earth, *Imp-3* and *OGO-III* were in distant orbits, *Explorer 33* was out by the moon and the remote *Pioneer 6* was 45 degrees away along the earth's yearly orbit. By the end of that week the event was over, the geophysical weather back to normal.

We do not fully understand cosmic rays and how they originate. The sun is not the source of most of them, but it makes them during events we can watch in detail. It is an opportunity we could not overlook. Moreover, such events fill the innermost solar system with a flux of particles that can penetrate to the marrow of space travelers unprotected by the soft but thick blanket of the earth's atmosphere. Add the whole sequence of effects of the magnetic and ionic and optical kind that the solar particles produce on and near the earth, and you can ascribe to this first connected study, even though it still does not reach the core of the event, a high purpose.

The general reader will learn much not only from the solar event but also from the human one. The IQSY was a postscript to the International Geophysical Year, a few follow-up years chosen so that the events expected in the declining phase of the solar cycle would occur spaced well enough to allow teasing them apart. By the middle of 1965 Professor Z. Švestka, the Czechoslovakian president of the International Astronomical Union Commission 10 (Solar Activity), was writing to his colleagues suggesting a broad international study of solar protons. By May of 1966 Professor P. Simon of the Meudon Observatory in Paris had been named chief coordinator. The plan was to obtain detailed observations of one selected event "from all possible aspects" and to publish the account in one set of coordinated papers ready for the editor by late 1967. "Many scientists kindly agreed... perhaps with a skeptical smile for this naïve schedule." Surprisingly the forecasts worked: the unstable region on the sun, followed since 1963, did burst out within the scheduled summer, and "today the coordinator himself is still astounded that he is able to write so soon the story of this exciting scientific cooperation." *Nihil obstat!* Crimean magnetograms, narrow-line photographs from Bucharest, Washington X-ray satellite records, Tokyo radio-burst data, Coolgoora radio spectra and an account of balloons sent aloft over Lapland continuously one after another for days are only a fraction of the pieces gathered here. Professors Simon and Švestka write the main summary, which is a coherent if still incomplete account, of this discipline: the magnetic meteorology of the sun and of space. Perhaps this book is a hopeful forecast of the future of science on earth. There are four IQSY annals volumes still to appear.

HANDBOOK OF GEOCHEMISTRY: VOLUME I, VOLUME II (PART 1), edited by K. H. Wedepohl. Springer-Verlag ($61.60). This science, the study of "the distribution of the chemical elements and their isotopes throughout the Earth," has from the first been encyclopedic. The big texts are always crammed with data and discussion, at home with the ends of the earth and with the most diverse processes of separation. (Once there was a famous study of atmospheric methane, one plausibly important source of which appears to be bacterial fermentation within the multiple gassy stomachs of cattle and elephants!) It is therefore not unexpected to see a modern handbook appear with many expert authors, in this case predominantly but not exclusively German and American. The burst of new and powerful analytical methods (particularly for isotopes) and the growth in the number of workers in the field take the subject out of the style of the great man's treatise and place it in the domain of social effort, with an executive editor, an international board of editors and some six dozen specialist contributors.

The work is not complete. We have only Part 1 of the key second volume, of which there will someday be three or even four parts totaling some 2,000 pages. It comprises the detailed heart of the work, listing one by one the chemical elements and devoting to each a chapter of appropriate length, treating in a set of 14 standard sections the crystal chemistry, the isotopes, the abundances of minerals, the rocks, the air, the waters, the extraterrestrial sources, the behavior in transport and in chemical processes, the biological properties and so on. So far parts of some 20 chapters have been produced, with the chapters for the most important light elements and the heaviest ones complete. The volume is loose-leaf, and the reader-subscriber will have to insert the missing sections as they appear. Most of the writing was done between 1966 and the middle of 1968; the somewhat inconvenient plan allows the work as a whole to appear much faster than the pace set by the most laggard expert contributor.

There are riches to be found here. It is remarkable to look in the oxygen chapter, where G. D. Garlick compiles the isotope ratios measured in surface water. From South Pole Station to Barbados the graph marches, every rain sample revealing the mean temperature of its place of fall by its content of oxygen 18. No biological use for uranium is known for any organism, yet there is a common association between uranium in sedimentary rocks and organic matter. One fossil fish skeleton from Scotland was as heavy with uranium as with the poorer ores.

Volume I is an introduction to the subject, with articles by a dozen experts, giving a brief history of the science and reviewing the thermodynamics, the crystal chemistry, the general geophysics, the nature of the air and the seas, the statistical treatment of data and the like. The work is everywhere of high quality, yet it does not possess that special richness of the best encyclopedias that guarantees the reader he will not search in vain, whatever he wants.

UNIVERSAL NATURAL HISTORY AND THEORY OF THE HEAVENS, by Immanuel Kant. New introduction by Milton K. Munitz. The University of Michigan Press ($2.45). This is the first paperback version of that work of the young Kant (in 1755 still a private tutor) which contains his prescient vision of the universe of galaxies qualitatively as we see it today: the Milky Way stands before us as an ecliptic of stars, and here and there are tiny spindle-shaped or circular nebulae, being other Milky Ways seen in the distance as we look out into extragalactic space. The translation dates from the 1900 volume of W. Hastie. (It is dedicated to Lord Kelvin.) The chapter on beings on other planets is unfortunately omitted, although the account of the nebular hypothesis for the formation of the solar system is here, as well as the review Kant had read of the work of Thomas Wright of Durham, his predecessor in understanding the nature of the Milky Way.

INDEX OF ADVERTISERS

JANUARY 1970

BIBLIOGRAPHY

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

THE LIMITATION OF STRATEGIC ARMS

DIPLOMATIC AND STRATEGIC IMPACT OF MULTIPLE WARHEAD MISSILES: HEARINGS BEFORE THE SUBCOMMITTEE ON NATIONAL SECURITY POLICY AND SCIENTIFIC DEVELOPMENTS OF THE COMMITTEE ON FOREIGN AFFAIRS HOUSE OF REPRESENTATIVES. NINETY-FIRST CONGRESS, FIRST SESSION. U.S. Government Printing Office, 1969.

STRATEGIC AND FOREIGN POLICY IMPLICATIONS OF ABM SYSTEMS, ANTI-SUBMARINE WARFARE, AND MULTIPLE INDEPENDENTLY TARGETED REENTRY VEHICLES (MIRV): HEARINGS BEFORE THE SUBCOMMITTEE ON INTERNATIONAL ORGANIZATIONS AND DISARMAMENT AFFAIRS OF THE COMMITTEE ON FOREIGN RELATIONS UNITED STATES SENATE, PART 3. NINETY-FIRST CONGRESS, FIRST SESSION. U.S. Government Printing Office, 1969.

LEARNING IN THE AUTONOMIC NERVOUS SYSTEM

INSTRUMENTAL LEARNING OF HEART RATE CHANGES IN CURARIZED RATS: SHAPING, AND SPECIFICITY TO DISCRIMINATIVE STIMULUS. Neal E. Miller and Leo DiCara in *Journal of Comparative & Physiological Psychology,* Vol. 63, No. 1, pages 12–19; February, 1967.

INSTRUMENTAL LEARNING OF VASOMOTOR RESPONSES BY RATS: LEARNING TO RESPOND DIFFERENTIALLY IN THE TWO EARS. Leo V. DiCara and Neal E. Miller in *Science,* Vol. 159, No. 3822, pages 1485–1486; March 29, 1968.

HOMEOSTASIS AND REWARD: T-MAZE LEARNING INDUCED BY MANIPULATING ANTIDIURETIC HORMONE. Neal E. Miller, Leo V. DiCara and George Wolf in *American Journal of Physiology,* Vol. 215, No. 3, pages 684–686; September, 1968.

LEARNING OF VISCERAL AND GLANDULAR RESPONSES. Neal E. Miller in *Science,* Vol. 163, No. 3866, pages 434–445; January 31, 1969.

AERODYNAMIC WHISTLES

THE THEORY OF SOUND. John William Strutt, Baron Rayleigh. Dover Publications, 1945.

ON THE EDGETONE. Alan Powell in *The Journal of the Acoustical Society of America,* Vol. 33, No. 4, pages 395–409; April, 1961.

TONES FROM A CHOKED AXISYMMETRIC JET, I: CELL STRUCTURE, EDDY VELOCITY AND SOURCE LOCATIONS; II: THE SELF EXCITED LOOP AND MODE OF OSCILLATION. M. G. Davies and D. E. S. Oldfield in *Acustica,* Vol. 12, No. 4, pages 257–277; 1962.

SOME EXPERIMENTS CONCERNING THE HOLE AND RING TONE. R. C. Chanaud and Alan Powell in *The Journal of the Acoustical Society of America,* Vol. 37, No. 5, pages 902–911; May, 1965.

THE SHAPES OF ORGANIC MOLECULES

STEREOCHEMISTRY OF CARBON COMPOUNDS. Ernest L. Eliel. McGraw-Hill Book Company, Inc., 1962.

SYMPOSIUM: THREE-DIMENSIONAL CHEMISTRY. *Journal of Chemical Education,* Vol. 41, No. 2, pages 65–85; February, 1964.

CONFORMATIONAL ANALYSIS. Ernest L. Eliel, Norman L. Allinger, Stephen J. Angyal and George A. Morrison. Interscience Publishers, 1965.

CONFORMATION THEORY. Michael Hanack. Academic Press, 1965.

GIGANTOPITHECUS

GIGANTOPITHECUS BLACKI VON KOENIGSWALD, A GIANT FOSSIL HOMINOID FROM THE PLEISTOCENE OF SOUTHERN CHINA. G. H. R. von Koenigswald in *American Museum of Natural History Anthropological Papers,* Vol. 43, Part 4, pages 295–325; 1952.

THE STATUS OF GIGANTOPITHECUS. Raymond A. Dart in *Anthropologischer Anzeiger,* Vol. 24, No. 2/3, pages 139–145; October, 1960.

THE MANDIBLES AND DENTITION OF *GIGANTOPITHECUS*. J.-K. Woo in *Palaeontologia Sinica,* New Series D, Vol. 146, No. 11, pages 1–94; 1962.

GIGANTOPITHECUS (PONGIDAE, HOMINOIDEA): A NEW SPECIES FROM NORTH INDIA. E. L. Simons and S. R. K. Chopra in *Postilla: Peabody Museum Yale University,* No. 138; October 1, 1969.

THE RECOGNITION OF DNA IN BACTERIA

HOST-INDUCED MODIFICATION OF T-EVEN PHAGES DUE TO DEFECTIVE GLUCOSYLATION OF THEIR DNA. Stanley Hattman and Toshio Fukasawa in *Proceedings of the National Academy of Sciences of the United States of America,* Vol. 50, No. 2, pages 297–300; August 15, 1963.

GENERAL VIROLOGY. S. E. Luria and James E. Darnell, Jr. John Wiley & Sons, Inc., 1967.

RESTRICTION OF NONGLUCOSYLATED T-EVEN BACTERIOPHAGE: PROPERTIES OF PERMISSIVE MUTANTS OF *ESCHERICHIA COLI* B AND K12. Helen R. Revel in *Virology,* Vol. 31, No. 4, pages 688–701; April, 1967.

DNA MODIFICATION AND RESTRICTION. Werner Arber and Stuart Linn in *Annual Review of Biochemistry,* Vol. 38, pages 467–500; 1969.

RESTRICTION OF NONGLUCOSYLATED T-EVEN BACTERIOPHAGES BY PROPHAGE P1. Helen R. Revel and C. P. Georgopoulos in *Virology,* Vol. 39, No. 1, pages 1–17; September, 1969.

THE PEOPLE OF YORK: 1538–1812

LIFE AND DEATH IN THE SIXTEENTH CENTURY IN THE CITY OF YORK. Ursula M. Cowgill in *Population Studies,* Vol. 21, No. 1, pages 53–62; July, 1967.

HISTORICAL POPULATION STUDIES. Edited by Stephen R. Graubard in *Dædalus: Journal of the American Academy of Arts and Sciences,* Vol. 97, No. 2, pages 353–681; Spring, 1968.

MODELS OF OCEANIC CIRCULATION

WIND-DRIVEN OCEAN CIRCULATION. Edited by Allan R. Robinson. Blaisdell Publishing Company, 1963.

A LABORATORY MODEL FOR THE GENERAL OCEAN CIRCULATION. D. J. Baker, Jr., and A. R. Robinson in *Philosophical Transactions of the Royal Society of London, Series A,* Vol. 263, in press.

MATHEMATICAL GAMES

THE HISTORY OF THE ABACUS. J. M. Pullan. Frederick A. Praeger, Publishers, 1969.

THE AMATEUR SCIENTIST

THE ORIGIN OF LIFE. Alexandr Ivanovich Oparin. Dover Publications, 1953.

THE ORIGINS OF PREBIOLOGICAL SYSTEMS AND OF THEIR MOLECULAR MATRICES. Edited by Sidney W. Fox. Academic Press, 1965.

Join the most sensible book club ever established!

Save up to 81% on every book in print! No limits on what or when you buy! No commitments to take any number of volumes!

WHAT A VALUE! Now you can buy *any* book on the market...at practically wholesale prices...without involving yourself in a single commitment!

(Why Didn't Somebody Think of This Before?)

IT'S ALMOST UNBELIEVABLE! Here's the ultimate in book clubs. Where the whole system works *for you.* And no one tells you that you MUST do this or CAN'T do that. There are absolutely no restrictions, no "quotas", no monthly postcards to return, no obligations whatsoever!

UNLIMITED SELECTION. You can order *any* book of *any* publisher listed in the Master Catalog of American Books at discounts *guaranteed* up to 81%—right across the board! That includes hard-cover and paperback...fiction and non-fiction...religious works...technical and scientific books...textbooks...art portfolios...anything between two covers that captures your interest!

As a club member you can order from *any* publisher: Random House, Simon & Schuster, Harper & Row, Doubleday, McGraw-Hill, Harvard University Press. And that's just a smattering!

Remember: you select *any* title. But IGNORE THE REGULAR LIST PRICES—because you'll *never again* have to pay anything close to them!

LIFETIME MEMBERSHIP. When you join the American Book Club it's for keeps. Your membership will *never* expire—will *never* have to be renewed. And you don't have to make a single purchase!

Think what this means. For the rest of your life, you can order all the books you want. No yearly purchase quotas. But we're as close as your mail box *when you want us.*

REAL PUBLISHERS' EDITIONS. Perhaps you've wondered: "There *must* be a catch here. They must be putting out cheaper editions, like some other clubs." Not so! Every book you buy through us is *guaranteed* to be the original publisher's edition. We don't give you cheaper paper or smaller type or bindings that stain your hands. You receive the *genuine article*—the original publisher's edition, just as if you had picked it off a bookstore counter!

FREEDOM FROM PRESSURE. Honestly, we don't care how many volumes you buy. Or how few. You can order a carload...or purchase *nothing!*

We'll never bug you with "reminders - that - you - didn't - buy - enough - this - year." We'll never send you cards to fill out and return. And we'll never mail you books other than those you *specifically requested.*

FREE SUPPLEMENT. As a member, you'll receive the regularly up-dated supplement to the Master Catalog of American Books containing *special bargains even beyond the Club's normal discount!*

MONEY-BACK GUARANTEE. We'll take our chances that you'll feel delighted with every book you buy through the American Book Club. And if you aren't—whatever your reason—just mail it back for a *full refund!* (What other club would dare make a promise like that?) Your orders are processed *by computer*—our fastest possible service—so you can enjoy the books you want as soon as possible!

THESE REMARKABLE BENEFITS of membership are yours for the one-time, *lifetime* fee of only $5—equal to your *savings* on the first 2 or 3 discount-priced books you order! Act today. Join the *ultimate* in book clubs for your enjoyment for years and years to come!

FREE IF YOU ACT NOW

MASTER CATALOG OF AMERICAN BOOKS

UNOBTAINABLE OUTSIDE BOOK TRADE EXCEPT FOR MEMBERS OF AMERICAN BOOK CLUB

Huge 350-page Master Catalog lists full 20,000 books in print. Every title at guaranteed discounts of as much as 81%. All categories, all subjects included—hard cover and paperback, fiction and non-fiction, best sellers and classics, even multi-volume reference works, encyclopedias and college texts. NO EXCEPTIONS! Discount always shown side-by-side with regular retail price so you can compare in every case. No commitment to buy any number of volumes. Order any book in print through club direct from warehouse. No exceptions. No middleman. You never pay list price for any book, ever. Request your Master Catalog now.

Keep Catalog FREE even if you decide NOT to be a member!

MAIL COUPON TODAY!

American Book Club 139
Hazleton, Pennsylvania 18201

Yes! Though I'm still blinking in amazement, I want to become a member of the AMERICAN BOOK CLUB and receive the lifetime privilege of ordering any and all books in print for discounts up to 81%. I enclose my onetime membership fee of $5. In return, I will expect the **Master Catalog of American Books** plus a free subscription to its regularly updated supplement BOOKMARKER. I understand there is NO obligation to buy anything **ever,** and you will ship me only those volumes I specifically order. (Small handling and postage charge.) Any books that dissatisfy me for any reason may be returned within 10 days for a 100% cash refund. And if the club itself dissatisfies me I need only let you know within 10 days to receive a full refund of my membership fee. **But the Master Catalog of American Books Will Be Mine to Keep Regardless.**

NAME _____

ADDRESS _____

CITY _____

STATE _____ ZIP _____

STOP SAYING . . .
"I CAN'T AFFORD TO TRAVEL"

8 BOOKS THAT GIVE YOU THE FACTS ON HOW YOU CAN TRAVEL TODAY WITHOUT BEING RICH

AROUND THE WORLD BY FREIGHTER

Where and how to travel by freighter —the lower cost way to travel

FOR no more than you'd spend at a resort, you can take a never-to-be-forgotten cruise to Rio or Buenos Aires. Or through the Canal or to the West Indies or to England, France, the Mediterranean, etc.

And what accommodations you get—large rooms with beds (not bunks), probably a private bath, lots of good food, and plenty of relaxation as you speed from port to port.

Travel Routes Around the World names the freighter lines (700 of them, with sailings from practically every port in the world), tells where they go, what they charge, briefly describes accommodations plus life on your freighter, clothes to take, etc.

To stop saying that travel is expensive, get your copy now. Price $1.50.

BARGAIN PARADISES OF THE WORLD

West Indies, Mexico, Californias Abroad

This is a book on how to double what your money can buy. For that is what spending a few weeks or months, or even retiring, in the world's Bargain Paradises amounts to.

Throughout this big book you learn where to spend a while in the West Indies, South America, the healthful islands of the South Seas, and the marvelous Balearic Islands where two can live like kings for $50 a week.

You read about cities and towns where it's always spring, about "Californias Abroad," about "Four Modern Shangri-Las," about mountain hideaways, tropical islands as colorful as Tahiti but nearer home, about modern cities where you can live for less, about quiet country lanes and surf-washed coastal resorts.

If you've ever wanted to travel but wondered how you could afford it; if you have a little income but wonder how you'd ever be able to retire on that; if you want a life of luxuries on what you'd get only necessities back home, then you want this book. $1.95.

HOW TO TRAVEL WITHOUT BEING RICH

DO YOU know it costs only $179 to travel all the way to Argentina through colorful Mexico, the Andes, Peru, etc., by bus and rail? Or that there are half a dozen round the world routings for around $1000?

If you know the seldom-advertised ways of reaching foreign countries, you don't need fantastic sums of money in order to travel. This book shows you the lower cost, comfortable ways to practically any part of the world. Here are the ship, rail, bus, airplane, and other routings that save you money and open the world to you.

This is the guide that helps you explore the West Indies like an old time resident who knows all the tricks of how to make one dollar do the work of two. Roam around Mexico, South America, Europe, elsewhere? This is the guide that tells you where and how to go at prices you can really afford. $1.95.

OFF-THE-BEATEN PATH

—these are America's own Bargain Paradises

Where to retire or vacation at what look like prewar prices and no one ever heard of nerves or worries.

Off-the-Beaten Path names the really low cost Florida retirement and vacationing towns, the topnotch values in Texas, the Southwest, California, the South and East, Canada and a dozen other areas which the crowds have not yet discovered.

—Fabulous places like that undiscovered region where winters are as warm and sunny as Miami Beach's, yet costs can be ⅔rds less. Or that island that looks like Hawaii yet is 2000 miles nearer. Or France's only remaining outpost in this part of the world . . . or a village more Scottish than Scotland . . . or resort villages without crowds or high prices . . . or island paradises aplenty in the U.S. or Canada . . . or areas with almost a perfect climate. And for good measure you also read about low cost paradises in Hawaii, the Virgin Islands, and Puerto Rico.

A big book, with about 100,000 words and plenty of pictures. Yet it costs only $2.

SPECIAL OFFER: All 4 books above—*Travel Routes Around the World*, *Bargain Paradises of the World*, *How to Travel Without Being Rich*, and *Off-the-Beaten Path*—($7.40 value) for $4.95.

FABULOUS MEXICO—WHERE EVERYTHING COSTS LESS

THE land of retirement and vacation bargains, where you can build a modern home for $6500 and an American retirement income looks like a fortune, and your vacation money can buy double or more what it might back home. Norman Ford shows you vacation and retirement values where you can live like a prince on what you might just get along on in the U.S.A. He pinpoints areas that look like the South Seas, others where it's like June all year round, towns where many other Americans have retired; shows where to find modern, flower-bedecked hotels and inns that charge hardly half of what you'd expect to spend in even such a land of vacation and retirement bargains as Mexico. *Plus a big section on where to start your money earning so much more than in the U.S.A.* $1.50.

AMERICA BY CAR

THIS big book is your insurance of seeing all the 4-star sights in whatever corner of the U.S., Canada, or Mexico you drive to. Whether you're visiting New England or California, Florida or the National Parks, the Great Lakes, the Mississippi, the East, the South, the Southwest, the Indian country, etc., it tells you day by day and road by road the scenic way to go and it always directs you to the important sights along the way and in the cities. In Niagara or Los Angeles, Washington or New Orleans, the Black Hills or Montreal, it takes the guesswork out of travel.

America is so big you can easily overlook or forget important sights or make many a wrong turn. Se get *America by Car*, the book that makes sure you'll see everything of consequence and always travel right. Only $3.50 for this 170,000 word book (as big as 3 ordinary-sized novels).

WHERE WILL YOU GO IN FLORIDA?

Florida needn't be expensive—not if you know just where to go for whatever you seek in Florida. And if there's any man who can give you the facts you want, it's Norman Ford, founder of the world-famous Globe Trotters Club.

His big book, *Norman Ford's Florida*, tells you, first of all, road by road, mile by mile, everything you'll find in Florida, whether you're on vacation or looking over job, business, real estate, or retirement prospects.

Always, he names the hotels, motels, and restaurants where you can stop for the best accommodations and meals at the price you want to pay. For that longer vacation, if you let Norman Ford guide you, you'll find a real "paradise" —just the spot which has everything you want.

Of course, there's much more to this big book. If you want a home in Florida, he tells you just where to head. If you've ever wanted to run a tourist court or own an orange grove, he tells you today's inside story of these popular investments.

If you want to retire on a small income, Norman Ford tells you exactly where you can retire now on the money you've got, whether it's a little or a lot. Because he always tells you where life in Florida is pleasantest on a small income, he can help you to take life easy now.

Whatever you seek in Florida, *Norman Ford's Florida* gives you the facts you need to find exactly what you want. Well over 100,000 words, but it costs only $2.50—only a fraction of the money you'd spend needlessly if you went to Florida blind.

WHERE TO RETIRE ON A SMALL INCOME

This book selects out of the thousands of communities in the U. S. only those places where the climate is right, living costs are less, the surroundings pleasant, and nature and the community get together to guarantee a good time from fishing, boating, gardening, concerts, or the like.

It covers cities, towns, spas, resorts, etc., throughout America—from New England south to Florida, west to California and north to the Pacific Northwest. It includes both Hawaii and the American Virgin Islands.

Some people spend hundreds of dollars trying to get information like this by traveling around the country. Frequently they fail—there is just too much of America to explore. This book saves you from that danger. Yet it costs only $2.

Mail to HARIAN PUBLICATIONS,
82 Ocean Drive
GREENLAWN (Long Island), N. Y. 11740

I have enclosed $..... (cash, check, or money order). Please send me the books I checked below. YOU WILL REFUND MY MONEY IF I AM NOT SATISFIED.

- ☐ **Travel Routes Around the World** (travel by freighter). **$1.50.**
- ☐ **Bargain Paradises of the World. $1.95.**
- ☐ **How to Travel Without Being Rich. $1.95.**
- ☐ **Off-the-Beaten Path. $2.**
- ☐ SPECIAL OFFER #1. All 4 books above for $4.95.
- ☐ **America by Car. $3.50.**
- ☐ **Norman Ford's Florida. $2.50.**
- ☐ **Where to Retire on a Small Income. $2.**
- ☐ **Fabulous Mexico — Where Everything Costs Less. $1.50.**
- ☐ SPECIAL OFFER #2: All 8 books above—$16.90 value—for only $9.95.

Print Name.....

Street Address.....

City.....

State.....Zip Code.....

The new Bird.
Longer, lower, wider.
And unmistakable.

The new Bird.
Powerful Thunderjet V-8.
Power steering, power front disc brakes, power ventilation. New belted radial-ply tires. And a transmission you can shift for yourself or automatically. All standard

The new Bird.
Depend on it. Astrotechnology and a computer-designed ride provide smooth reliable flights.

The new Bird.
2 doors or 4. Sunroof or no.
Buckets or Bench seats. All up to you.

The new Bird.
Born to fly. Built to last.
At your Ford dealer's now.

1970: THUNDERBIRD OF THUNDERBIRDS

For more information about Thunderbird see your Ford Dealer or write: Thunderbird Catalog, Dept. T5, P.O. Box 1503, Dearborn, Michigan 48121