SCIENTIFIC AMERICAN

FUSION ENGINEERING

$2.50

October 1983

CHRYSLER CREATES LASER XE. The sports car

We gave Laser XE world-class performance. In the slalom, Laser beats all entries – from Trans Am to Mustang GT.

We built Laser XE to outperform the competition: Camaro Z28, Trans Am, Mustang GT, Toyota Supra, Mazda RX-7. Laser does it when you equip it with turbo, performance handling package and nitrogen-charged shocks.* Laser does it with front-wheel drive, new dual-path suspension system and quick-ratio power steering. In the slalom Laser finishes No. 1 – even ahead of the legendary Porsche 944.

We turbocharged it. From 0-50, Laser XE leaves Camaro Z28 with its shadow.

Z28 is a powerhouse – but Laser XE is the sophisticated new wave. Its multi-point injection system "spritzes" fuel in at four points. Its water-cooled bearing reduces a critical turbo temperature by 500°F. Its turbo engine boosts h.p. 45% and moves Laser like light.

With 5-speed your time to 50 mph is 5.8 seconds. Z28, Trans Am, Supra and RX-7 are in your remote-controlled side-view mirrors.

We gave it high-performance braking. Laser XE stops where Trans Am doesn't.

We think total performance calls for performance braking. So we gave Laser XE semi-metallic brake pads, power brakes all around and optional wide 15" alloy wheels with Goodyear Eagle GT radial tires. Result: Laser stops quicker than Z28, Trans Am,

Laser beats Porsche in the slalom.

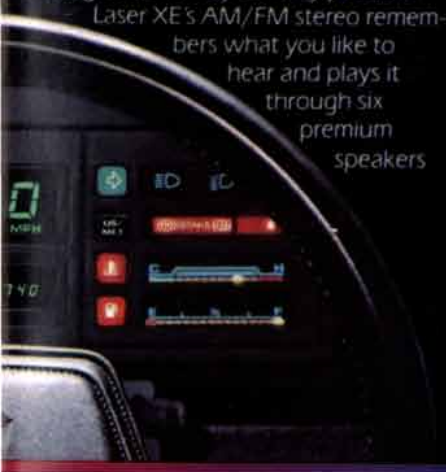
Laser outperforms Trans Am in braking.

Laser is faster than Camaro Z28 from 0-50 mph.

that had to outperform the competition.

Mustang GT, Supra, RX-7. Even Porsche 944 can't beat our world class braking. We even gave it a brain.

This is a car that thinks with you. Laser XE's 21 feature electronic monitor is like your sixth sense of the road. It even talks your language. And Laser XE's navigator computes 11 things you need to know while its color graphic displays help make you a calculating driver. But performing better isn't your only pleasure. Laser XE's AM/FM stereo remembers what you like to hear and plays it through six premium speakers you can choose. And its self-diagnostic system is the nearest thing to an on-board mechanic.



Even your performance seat performs.

It cushions you with pronounced padding and holds you in position on turns with lateral "wings." You pump up pneumatic cushions for thigh and lumbar support, and you can order a six-way power seat. And it's only fitting that you can choose world-class Mark Cross leather for your seats and cockpit.

We gave it our best: a 5 year/50,000 mile Protection Plan.

Chrysler believes a performer has to be more than a winner. It has to be a survivor. We build for that. And back your engine and power train with a 5 year/50,000 mile Protection Plan, with outer-body rust-through protection for the same period.* What competitor gives you that? None. See dealer for details. Buckle up for safety.

35 Est. Hwy.
22 EPA Est. MPG†

Chrysler

Laser. A product of The New Chrysler Technology.

*Based on overall results of USAC Sports Car Certification tests versus 1983 models. Laser XE equipped with optional handling suspension, Turbo package and 15" Road Wheels tires. 5 years or 50,000 miles, whichever comes first. Limited warranty. Deductible required. Excludes wear items. †Use EPA est. mpg for comparison. Actual mileage may vary depending on speed, trip length and weather. Hwy. mileage less.

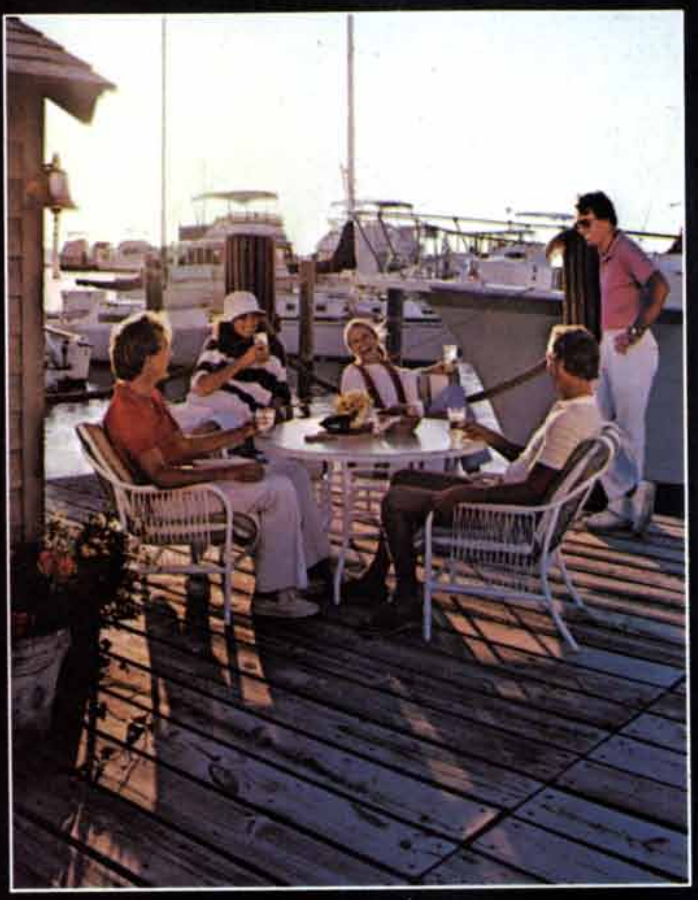
CHRYSLER

LASER

"THE COMPETITION IS GOOD. WE HAD TO BE BETTER."*

Lee A. Iacocca

And Beefeater makes it even better.



BEEFEATER® GIN. The Crown Jewel of England.™

Established 1845 **SCIENTIFIC AMERICAN** October 1983 Volume 249 Number 4

ARTICLES

DEPARTMENTS

SCIENTIFIC AMERICAN (ISSN 0036-8733), PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017.

SCIENTIFIC AMERICAN

CORRESPONDENCE

Offprints of more than 1,000 selected articles from earlier issues of this magazine, listed in an annual catalogue, are available at 75 cents each. Correspondence, orders and requests for the catalogue should be addressed to W. H. Freeman and Company, 4419 West 1980 South, Salt Lake City, UT 84121. Offprints adopted for classroom use may be ordered direct or through a college bookstore. Sets of 10 or more Offprints are collated by the publisher and are delivered as sets to bookstores.

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

Advertising correspondence should be addressed to C. John Kirby, Advertising Director, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, NY 10017.

Subscription correspondence should be addressed to Subscription Manager, SCIENTIFIC AMERICAN, P.O. Box 5969, New York, NY 10017. The date of the last issue on your subscription is shown in the upper right-hand corner of each month's mailing label. For change of address notify us at least four weeks in advance. Please send your old address (if convenient, on a mailing label of a recent issue) as well as the new one.

Name

New Address

Street

City

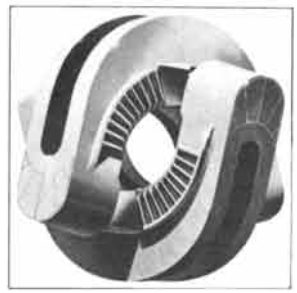
State and ZIP

Old Address

Street

City

State and ZIP



THE COVER

The painting on the cover shows a pair of superconducting magnets in what is called a yin-yang configuration. They form a magnetic mirror, that is, they trap charged particles such as atomic nuclei by reflecting them between peaks of magnetic field strength; thus they symbolize the attempts to confine a plasma (a gas of charged particles) magnetically and then heat it so that thermonuclear fusion is possible (see "The Engineering of Magnetic Fusion Reactors," by Robert W. Conn, page 60). The configuration, which is about eight meters long, was designed and built by the General Dynamics Corporation and the Lawrence Livermore National Laboratory. It was tested at Livermore, where it produced a maximum field strength of some 80,000 gauss. It is currently being incorporated into a larger device at Livermore, a tandem mirror, which requires a yin-yang configuration at each end of a linear sequence of magnets.

THE ILLUSTRATIONS

Cover painting by Ted Lodigensky

Page	Source
27–36	Ilil Arbel
55	Barrie Rokeach
56–59	Ilil Arbel
60	Ian Worpole
62–69	Gabor Kiss
70	F. W. Wiffen, J. O. Steigler and E. E. Bloom, Oak Ridge National Laboratory
71	Gabor Kiss
73	John E. Moody, Edwin L. Turner and J. Richard Gott III, Princeton University
74	S. Djorgovski, University of California at Berkeley
75–77	Walken Graphics
78	Carlos Frenk and Simon White, University of California at Berkeley; Marc Davis, Center for Astrophysics of the Harvard College Observatory and the Smithsonian Astrophysical Observatory
79	Walken Graphics
80	George Efstathiou, University of Cambridge
90–91	Ilil Arbel
92–99	Jerome Kuhl
103	EROS Data Center
104–109	J. Dyke Fledderus
121	B. O. K. Reeves, University of Calgary
122–124	Andrew Tomko
124D–124H	B. O. K. Reeves, University of Calgary
128–129	Patricia J. Wynne
130	Ilil Arbel
135	Patricia J. Wynne
137	William K. Sacco, courtesy of Peabody Muesum of Natural History, Yale University
138–146	Tom Prentiss
150–153	Ilil Arbel
162–168	Michael Goodman

Sleep Sheep

We may have found a way to improve your sleep forever.

New Zealanders discovered that sleeping under sheep's wool induced sleep.

The story we are about to tell you may seem rather incredible. And indeed it is. But if you'll have an open mind, what you will learn may indeed change your life.

There is a new product manufactured in New Zealand that is selling very well. It's called the Woolrest—a bed pad made of thick wool. You simply place it over your mattress and then cover it with your bottom sheet as you normally do when you make your bed.

SLEEP INDUCING

Sheep's wool has always had an outstanding reputation for keeping you warm in winter and cool in summer. That is why wool seat covers are so popular. But wool has another property known by New Zealanders for many years. Namely—wool induces sleep.

In New Zealand, for example, a way to cure insomnia was to cover yourself with a sheepskin rug. For some very unscientific reason, the hypnotic quality of the wool encouraged sleep. Counting sheep was another technique that was often recommended. But it was the development of the Woolrest bed pad that suddenly turned an old wive's tale into fact.

DIFFERENT EXPERIENCE

Sleeping on a Woolrest is a different sleeping experience. Whether you sleep on a hard or soft mattress, the Woolrest apparently radiates a feeling of comfort and relaxation from the wool fibers which mold, massage, and conform to your entire body.

Scientific tests conducted by Dr. Peter Dickson of Ohio State University proved that the Woolrest pad indeed helped induce sleep. Testimonials from people who owned them clearly demonstrated that Woolrest not only induced sleep but also provided great relief for backaches, arthritis, and rheumatism. Its natural fibers tend to alleviate the pain and pressure caused by these illnesses and thus make sleep come easier and deeper.

Frank Thornton, a Seattle Washington dental technician, had trouble sleeping for six years. He purchased a Woolrest pad and has been able to sleep through the entire night practically every night. According to Thornton, "I felt a sensation of buoyancy from the Woolrest. I have read in literature that a person sleeps more restfully with natural fibers surrounding their body." Thornton has already purchased seven Woolrest pads for his entire family.

There are hundreds of other testimonials we could mention from the thousands who have purchased them, but one thing is clear. Using a Woolrest pad you know that the rest of your life will be spent sleeping comfortably, with a minimum amount of sleeplessness. Certainly, there will be nights when it will be difficult to go to sleep. But with the Woolrest those nights will be fewer, shorter and without the tradeoff of taking sleep-inducing drugs.

WARM IN WINTER

In the winter the Woolrest holds your body heat and thus keeps you warmer. You'd expect that. But in summer it keeps you cooler through a process of moisture absorption by absorbing up to one-third of its weight in moisture to keep your body cool and dry.

Will the Woolrest work for you? We're willing to prove it with no risk on your part. Order one for a 45-day sleep test. When you receive it, closely examine the surface. Feel the thick pure woven pile of natural New Zealand wool. Place it on your bed and then cover the pad with your regular bottom bed sheet—either fitted or plain.

JUST A FEW DAYS

That night go to sleep on it. But don't judge the effectiveness until you've slept on it for at least a full month. You should actually notice the difference in just a few days, but after a month you'll turn from being skeptical like we were, to a real enthusiastic believer. If not, we'll understand. After all it may not work for everybody. Just return it within the 45-day sleep trial and you'll receive a prompt and courteous refund including the $4 delivery charge. The Woolrest washes easily in your washing machine and has a limited five-year warranty. Complete instructions come with each pad. Sleep on a Woolrest and experience what we mean at no risk or obligation. Order one, today.

To order, credit card holders call toll free and ask for product by number below or send check plus $4 delivery for each pad ordered.

Twin Size (0025F)	**$129**
Full Size (0026F)	**179**
Queen Size (0027F)	**209**
King Size (0028F)	**269**

The New Zealand wool used exclusively in the Woolrest could be a major reason for its effectiveness. Here's why.

Most sheep are raised in countries where temperature extremes cause their wool fibers to become brittle, rigid and often cracked at the ends. In Australia sheep are often raised in the dusty outback where temperature and rainfall can vary greatly.

In New Zealand however, the sheep enjoy a year-round temperate climate and graze in lush green pastures. Their wool fibers are thick and vibrant with good shape retention .

NEW ZEALAND WOOL

The Woolrest uses only the best New Zealand wool. The fibers are actually woven onto a pure wool blanket base and thoroughly washed and tufted.

We have mentioned the importance of New Zealand wool for good reason. Just as there are several grades of sheepskin seat covers, we suspect eventually there will be several grades of wool bed pads. None will ever compare to the wool used in the Woolrest.

JS&A

One JS&A Plaza
Northbrook, Illinois 60062

CALL TOLL FREE 800 323-6400

IL residents add 6% sales tax. ©JS&A Group, Inc.,1983

LETTERS

Sirs:

In "The Slowing of Urbanization in the U.S." [SCIENTIFIC AMERICAN, July] Larry Long and Diana DeAre write: "The term Megalopolis was coined by Jean Gottman of the University of Oxford in a book of the same name published in 1961." I don't think so. Gottman may have been the first to apply it to the East Coast corridor between Boston and Richmond, but he was certainly not the first to employ it to categorize the emerging supercities (in population and area) of the late 20th century.

In *The Decline of the West,* Oswald Spengler (at least in the translation of Charles Francis Atkinson) uses the word (in both its nominal and adjectival forms) and discusses its significance at some length and depth (Vol. I, Chapter 1, and Vol. II, Chapter 4).

Of some interest is the fact that there was a city named Megalopolis in ancient Greece. It was in the Peloponnesus a few miles northwest of Sparta. It can be found on any good map of ancient Greece and was mentioned by many of the classical authors. Because Megalopolis was not remarkable for its size, it would be interesting to know how it got its name.

RORY FORAN

Glen Burnie, Md.

Sirs:

In "The Salmonid Fishes as a Natural Livestock" [SCIENTIFIC AMERICAN, July], Lauren R. Donaldson and Timothy Joyner have given a thorough account of advances in the nutrition and breeding of salmon. This report of their contribution to our need for food from the sea is indeed significant.

The authors graciously acknowledge our discovery of home-stream olfactory imprinting in salmon, but the article they cite ["The Homing Salmon," by Arthur D. Hasler and James A. Larsen; SCIENTIFIC AMERICAN, August, 1955] was written when that discovery was still a hypothesis. It was not until 1976 that our group conducted the rigorous studies using the synthetic odors morpholine and phenethyl alcohol as imprinters on salmon introduced into Lake Michigan that the hypothesis was proved. (See "Imprinting to Chemical Cues: The Basis for Home Stream Selection in Salmon," by Allan T. Scholz, Ross M. Horrall, Jon C. Cooper and Arthur D. Hasler in *Science,* Vol. 192, No. 4245, pages 1247–1249, June 18, 1976, and "Olfactory Imprinting and Homing in Salmon," by Arthur D. Hasler, Allan T. Scholz and Ross M. Horrall in *American Scientist,* Vol. 66, No. 3, pages 347–355, May–June, 1978.)

Donaldson and Joyner find it pointless to imprint salmon with synthetic chemicals. It is this technique, however, that has improved the harvest of salmon in Lake Michigan. On the Wisconsin side there are no streams in which salmon can reproduce, hence salmon must be artificially reared in local hatcheries. In some cases the young hatchery salmon can be stocked in smolting ponds next to a stream where natural imprinting can occur. It is often advantageous, however, to imprint the salmon artificially in a hatchery and then stock them directly into the lake. When these salmon mature, they have no home stream, only a "memory" of the "home" hatchery. They can therefore be decoyed to the best and most convenient harvest sites by scenting the inlets of selected streams with imprinting chemicals. An example is morpholine, which was added to the hatchery water during the salmon's smolting period.

ARTHUR D. HASLER

ROSS M. HORRALL

ROBERT A. RAGOTZKIE

University of Wisconsin
Madison

Sirs:

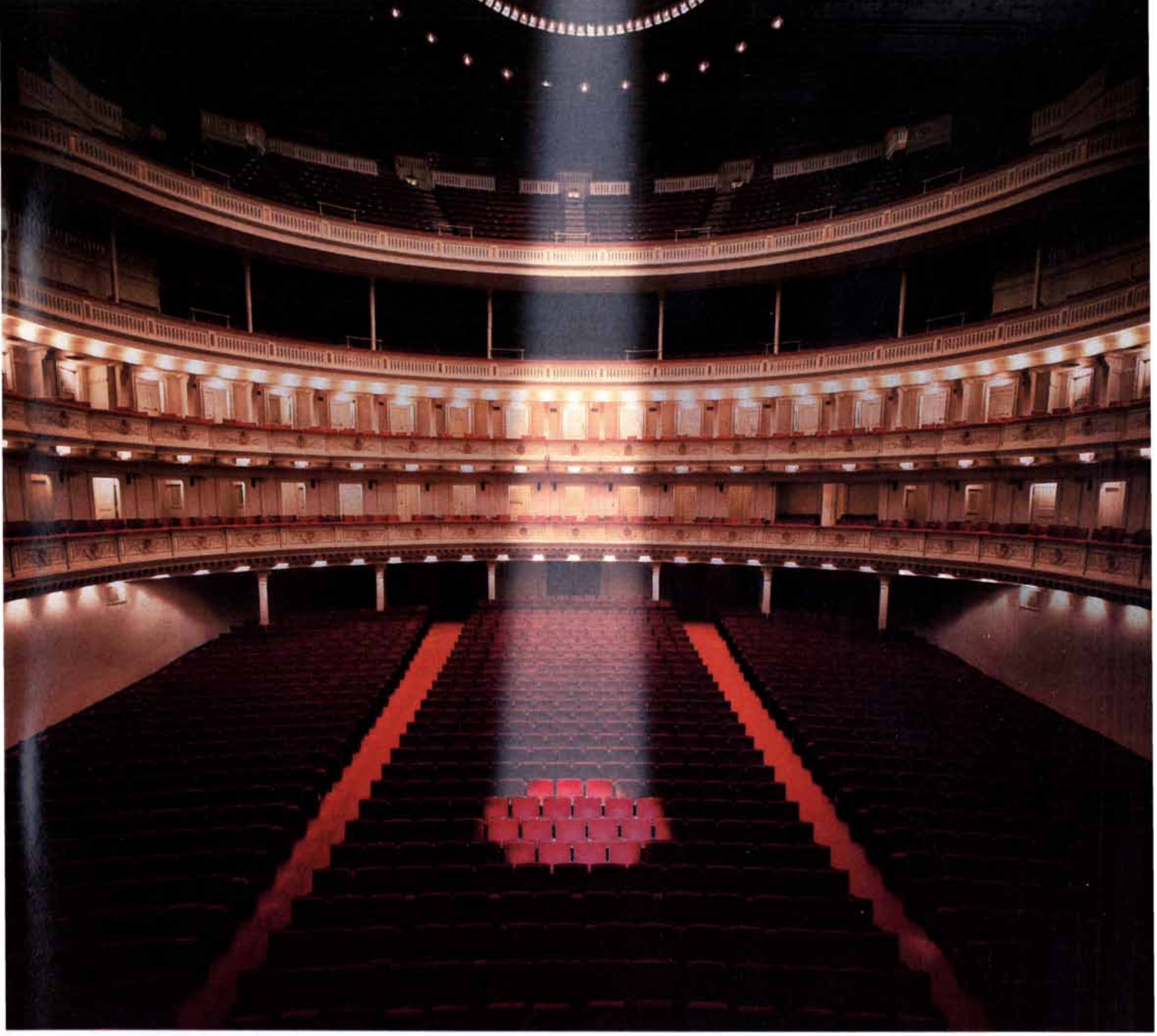
Albert J. Blodgett, Jr.'s, "Microelectronic Packaging" [SCIENTIFIC AMERICAN, July] was an excellent introduction to the subject. In focusing on IBM's water-cooled thermal-conduction module, however, he overlooked the more advanced air-cooled packaging used in Amdahl Corporation's 580 series of large computers.

Each Amdahl chip is bonded to a chip carrier whose upper surface has a metal stud with numerous circular cooling fins, which transfer the chip's heat to the airstream. Up to 121 logic and memory chips are mounted on a ceramic multichip carrier (MCC) similar to the substrate for IBM's TCM. The entire central processing unit of a fully configured 580 consists of a stack of nine MCC's connected by printed circuit boards. It occupies 5.6 cubic feet.

Compared with a water-cooled design, air-cooled packaging reduces system complexity, manufacturing costs, power consumption and floor space needed, while increasing reliability and ease of maintenance. The 580's advanced packaging is also one reason it has a better price/performance ratio than the 3081.

GARY HLADIK

Saratoga, Calif.



Sony creates seventh row, center. Forever.

INTRODUCING THE SONY COMPACT DISC PLAYER.

You are looking at an invention so extraordinary that High Fidelity magazine has hailed it as "the most fundamental change in audio technology in more than eighty years."

A piece of audio equipment that permits you to hear something you've never heard before: perfection.

Sony is pleased to raise the curtain on the world's first digital audio compact disc player. The CDP-101.

THE END OF HI-INFIDELITY.

The CDP-101 uses a laser beam to play compact discs that hold far more musical information than conventional records ever could. The result: fidelity and depth of sound that no conventional turntable could ever deliver.

This highest of fidelity remains faithful too. Because the digital discs are read by laser beam, there is absolutely no physical wear. Nor is there any distortion from such annoyances as dust, fingerprints or even scratches. The laser simply sees through them.

Equally ingenious, an infrared remote control lets you select tracks without budging from your armchair.

While an ever-expanding library of compact discs lets you listen to your favorite artists as though you, and your armchair, were centered in the spotlight above.

Maybe most important, the CDP-101 is fully compatible with the conventional equipment you may own.

We suggest you hear the Sony Compact Disc Player soon. For a sound you can't believe, from the audio innovator you assuredly can.

SONY®
THE ONE AND ONLY

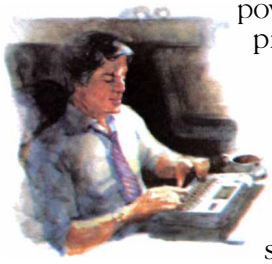
Killer pigmy,

INTRODUCING A TOTAL COMPUTER SYSTEM NO LARGER THAN THIS MAGAZINE.

You're looking at a miracle. A creation of technology that you can actually use.

The amazing Epson Notebook Computer.®

Go ahead – put your hands on that full-sized keyboard. You now control a *complete* computer system. A system that includes a liquid crystal display screen, a micro cassette document and program storage unit, a 50-hour rechargeable internal power supply, and a dot matrix printer. All for *less* than $800.



Nothing else can equal it. Not the 30-pound "transportables" that are like lugging sewing machines around, and certainly not those so-called "portables" that try to skimp by with no printer, no provision for document storage, and a maddeningly short battery life.

The Epson Notebook Computer has everything you need to get down to work. Exquisitely crafted into a sleek and silent package that you can take anywhere and use anywhere.

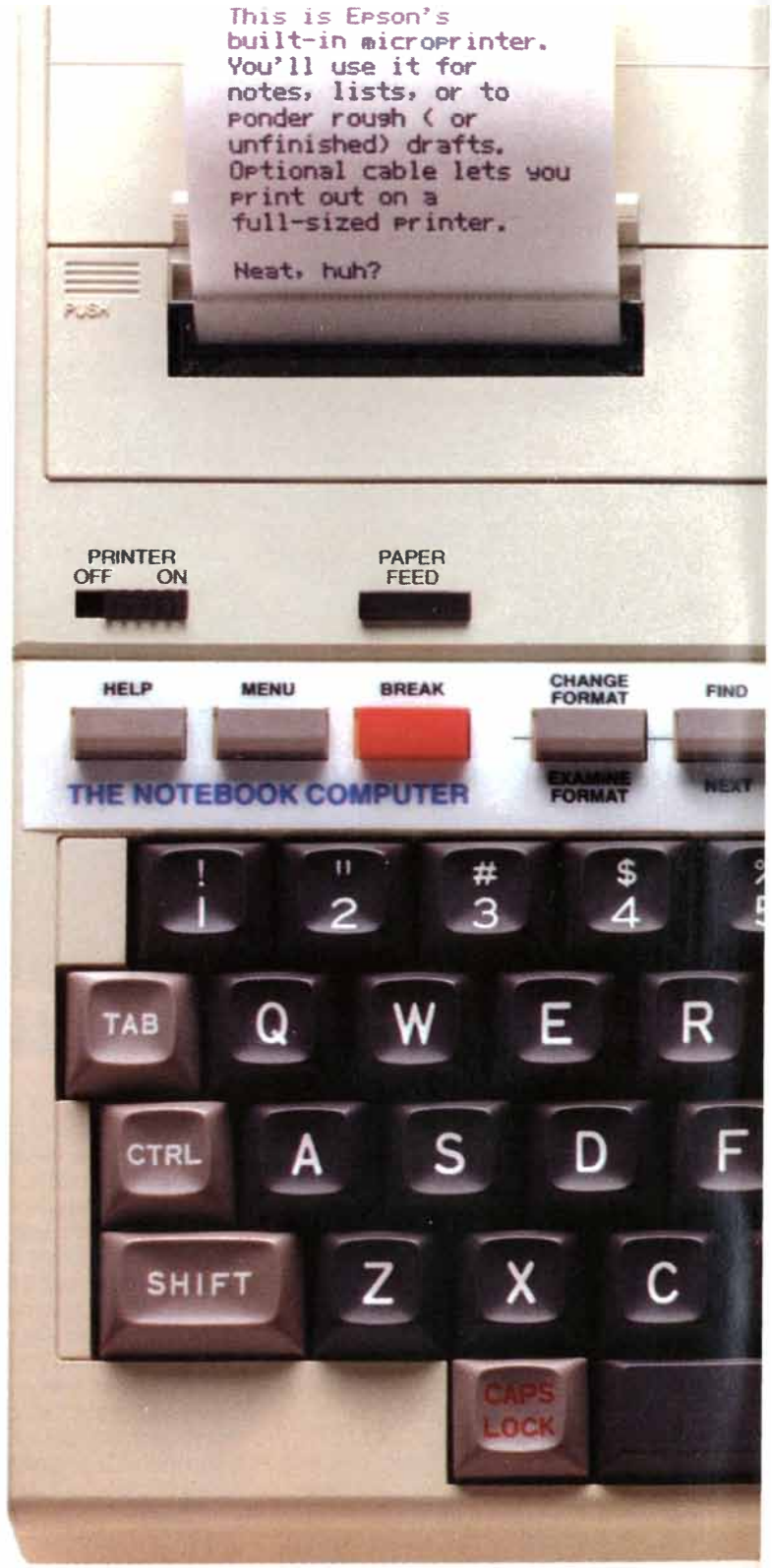
It weighs less than four pounds. Has a surface area the size of a sheet of typing paper. And it contains a whopping 16K of random memory (optionally expandable to 32K, if you need it).

You can program the Notebook Computer in a built-in, extended version of Microsoft® BASIC. An internal word processing program called SkiWriter® will have you turning out letters, notes, memos, or full reports after just fifteen minutes of reading the simple instructions.

Available software ranges from personal productivity programs to education and entertainment. We even offer a telephone modem and software that allows you to instantly transmit information to a full-sized computer.

To put your hands on a *real* Epson Notebook Computer, call toll-free (800) 421-5426, or (213) 539-9140 in California for the name of your nearest Epson dealer.

But be warned. Few who touch the "killer pigmy" go away empty-handed.



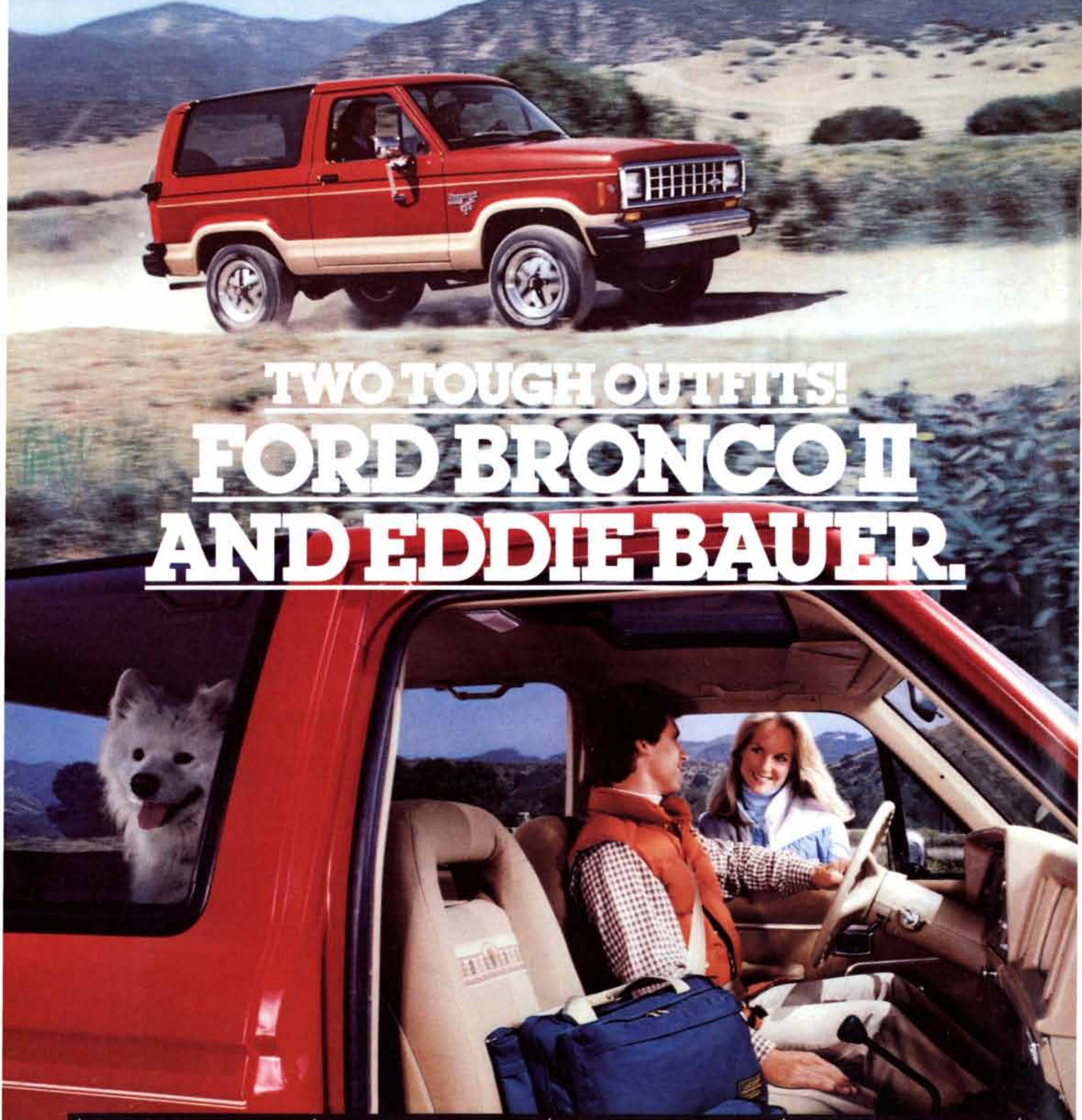
EPSON

STATE OF THE ART... SIMPLICITY.

actual size:

EPSON NOTEBOOK COMPUTER

Microsoft is a trademark of Microsoft Corp. SkiWriter is a trademark of SkiSoft Inc.



TWO TOUGH OUTFITS!
FORD BRONCO II AND EDDIE BAUER.

SPECIAL EDDIE BAUER BRONCO II

Two names known for toughness get together –in Ford's special Eddie Bauer Bronco II.

Like all Bronco's, Bronco II is field-tested ...built Ford tough, with husky frame and Twin-Traction-Beam suspension. Eddie Bauer survival gear has been field-tested too...right to the top of Mount Everest!

The Eddie Bauer Bronco II is outfitted for all outdoors–with unique interior and exterior trim plus an optional flip-away spare tire carrier. Free Eddie Bauer top quality gear bag and map folder included, plus scheduled maintenance and a limited warranty for 24 months/24,000 miles, whichever comes first, excludes tires, fluids, accidents or abuse.

Trimmer Bronco II is fun to drive, easy to park and maneuver... with a V-6 engine standard. Seats 4 in comfort, with split fold-down rear seats for extra cargo.

Get it together–Buckle up!

Eddie Bauer Bronco II –it's a brand-new kick in survival gear!

Bronco II

Ford

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1933: "The Tennessee Valley Authority Act of 1933 has granted President Roosevelt the power to appoint a body of three members to develop the natural resources of the Tennessee River basin, with special reference to the improvement of navigation, which would be linked to flood control; reforestation, which would embrace improvement of the unemployment situation; utilization of marginal lands, which have been overworked for agricultural purposes, and finally the development of great blocks of power for the further industrialization of the entire Tennessee River Valley area. Admitting that this would be a gigantic Federal experiment on a scale never heretofore undertaken, the President has suggested the possibility of carrying the idea further into other regions if the Tennessee River basin project indicated that it would succeed. The area under the jurisdiction of the Tennessee Valley Authority covers most of central and western Tennessee, extends widely over northern Alabama, includes portions of North Carolina, South Carolina and Georgia, and touches small portions of Virginia, West Virginia, Kentucky and Mississippi."

"There is a very satisfactory theory of what happens in a nova—except for the greatest question of all. What causes the tremendous initial outburst? A noteworthy suggestion has been made by E. A. Milne, namely that the main inner part of a star may become unstable as regards its internal equilibrium and suddenly collapse to a state of much greater density and smaller diameter. It is possible that in such an event practically the whole of the enormous amount of gravitational energy liberated by the contraction might be stored up in one form or another in a collapsed mass, leaving but a relatively small amount to be got rid of by radiation. The new and smaller core, however, would at first be exceedingly hot. The rapid progress of nuclear physics makes it reasonable to hope that, before many years have passed, we may know enough to say whether such suggestions are to be accepted."

"The Pennsylvania Railroad is engaged in what is one of the greatest, if not the greatest, single electrification projects ever undertaken in this country or any other. It consists in the electrification of 1,082 miles of railroad track, serving the great cities of the Eastern Seaboard from New York to Washington and extending westward to the Susquehanna River in the heart of Pennsylvania. It is expected that 816,000,000 kilowatt-hours per year will be required for the operation of trains when the project is completed. The project's magnitude and its possibilities are great enough to stir the imagination of the most prosaic."

"It is being asserted widely that science has at last abandoned its early materialistic taint, swinging strongly toward religion and mysticism. The furor started small in a corner of physical science. It was discovered a few years ago that things as small as electrons do not individually obey the law of cause and effect. This phenomenon is known as the principle of indeterminacy, or the principle of uncertainty, and its discovery came about when the German physicist Werner Heisenberg showed that it is impossible to ascertain both the position and speed of an electron; we can ascertain the one or the other singly, but not both. Evidently, then, the behavior of an electron is indeterminable. Right here a number of thinkers made false deductions and, as A. S. Eddington put it, 'science went off the gold standard.' What these thinkers failed to grasp was that mere indeterminability does not in itself establish indeterminacy. A thing may be indeterminable but not indeterminate. Nature knows what she is doing, and does it, even when we cannot find out. It did not take the mystics long to discover the principle of uncertainty. If we could no longer predict, at least in theory, the entire future of the universe, given the position and velocity of every particle in it, then perhaps there was freedom in it after all. The return of science to some sort of modern mysticism would be essentially a slip in man's hard-won progress away from one of his most ancient bad habits—that of ascribing to the supernatural whatever he did not yet understand."

OCTOBER, 1883: "The Straits of Sunda, separating the islands of Java and Sumatra, form one of the main gateways used by the vast trade that navigates the China Sea. Half-way through the strait, equidistant from the two shores, was a group of three islands, the largest of which was Krakatoa, four and a half miles long and three miles broad, its volcanic summit reaching to a height of 2,623 ft. above the sea level, about 10 times higher than the surrounding sea was deep. The tremendous volcanic eruption, with the accompanying earthquake and inundation of the coasts, on Sunday, the 26th of August, has wrought a fearful change. As far as our present information goes, it appears that the whole island of Krakatoa, consisting of about 8,000 million cubic yards of material, has fallen in and disappeared below the sea."

"Apart from oxygen and nitrogen there is but one other substance in dry air that we are at present warranted in regarding as being a necessary and constant component, namely carbonic acid or carbon dioxide (CO_2). Small as its proportion in the air is, its relation to animal and vegetable life on the earth has long been recognized. The gas is liberated in abundance by the action of heat on limestone and other carbonates, and also by the spontaneous decomposition of solutions of bicarbonate of lime. The abundant deposits of limestone in the crust of the earth form, therefore, an inexhaustible source of the gas under certain conditions, and their abundance points probably to a period in the earth's history when a much higher proportion of carbonic acid was present in the air. While all the evidence goes to show that carbonic acid is now an almost invariable constituent of the air, it is one that requires least change in the physical conditions under which the earth exists to effect a change in its proportion. Minute as the proportion is, the delicacy of its relation to animal and vegetable life on the earth makes the maintenance of the apparently unstable equilibrium a matter of serious concern to mankind."

"Professor Albert S. Bickmore describes his methods of imparting instruction in natural history by ocular demonstration, 'believing that the sense of sight is the royal avenue to the mind.' A large part of the objects that it was desired to display were either too small or too large to be taken to the lecture hall, and at the same time too important to be omitted. To overcome this difficulty the most complete stereopticon to be found was purchased; and as it was discovered that photographic transparencies of the desired subjects could not be obtained in anything like a systematic series, an assistant skilled in this branch of photography made negatives and slides from the specimens on exhibition in the public halls of the Museum of Natural History in New York, supplemented by copies of the best illustrations in standard works on natural history. There have been made some 800 negatives, in addition to a large number purchased from every available source. Such slides, although giving more satisfactory results when used in connection with the lime light, will be distinctly visible by from 50 to 75 persons when a lamp burning kerosene oil is used."

THE AUTHORS

PHILIP L. MARTIN ("Labor-intensive Agriculture") is associate professor of agricultural economics at the University of California at Davis. His interest in the subject of temporary alien workers originated when he was a Fulbright fellow in Germany in 1973 and 1974. He returned to the U.S. to obtain his Ph.D. in economics and agricultural economics from the University of Wisconsin in 1975. In 1978 and 1979 he was a Brookings fellow and also served as consultant on economics to the Select Commission on Immigration and Refugee Policy. He has been a member of several other commissions that were attempting to make policy on temporary workers both in Europe and in the U.S. Martin's chief interest is in the future of labor-intensive agriculture in postindustrial societies.

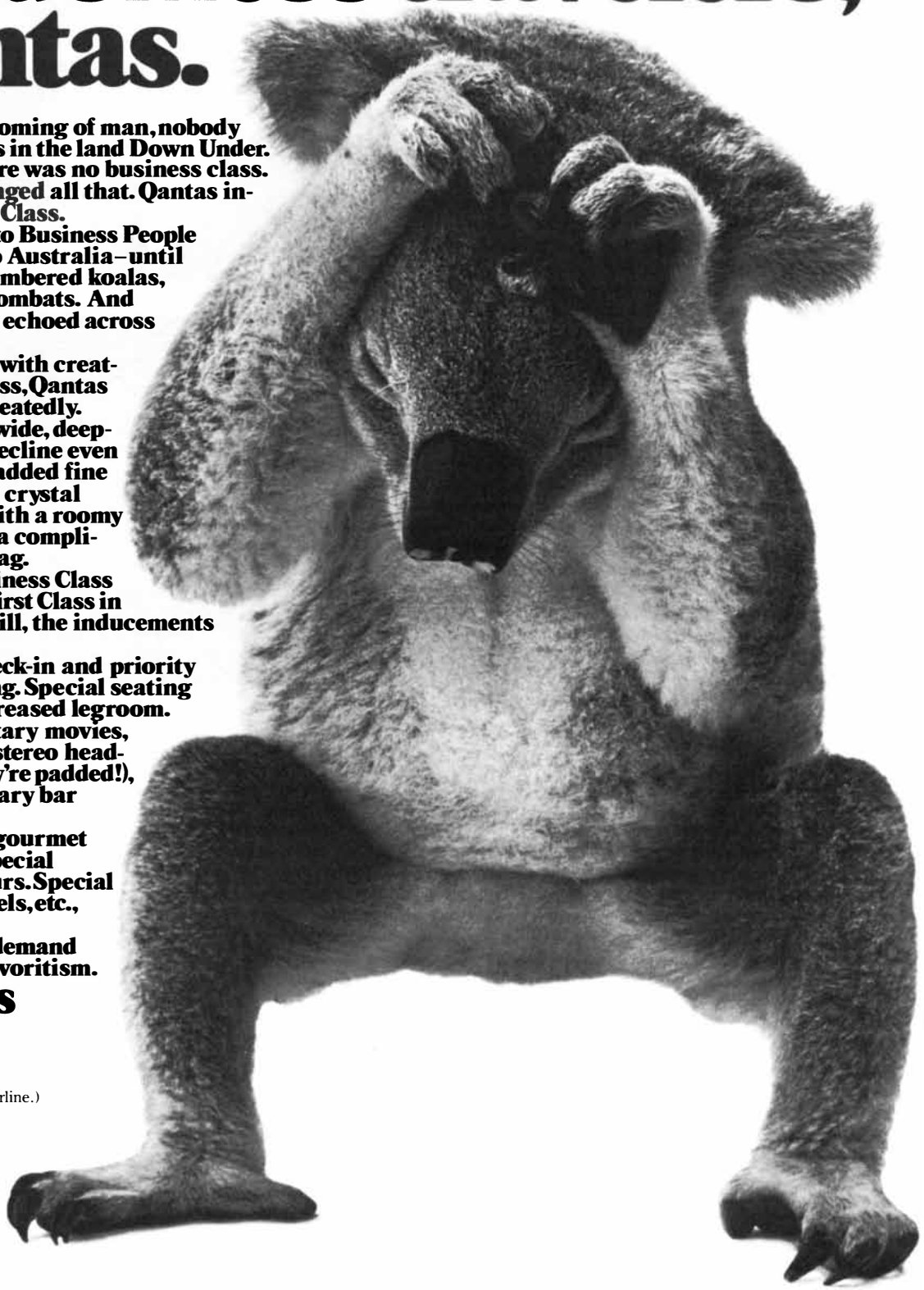
ROBERT W. CONN ("The Engineering of Magnetic Fusion Reactors") is professor of engineering and applied science at the University of California at Los Angeles. He got his B.S. at the Pratt Institute before going on to obtain his M.S. and his Ph.D. in engineering science from the California Institute of Technology. After getting his advanced degrees he spent a year at the Joint European Nuclear Research Center at Ispra in Italy and then joined the staff of the Brookhaven National Laboratory. In 1970 he joined the faculty at the University of Wisconsin at Madison and in 1974 he became director of the Fusion Research Program at Wisconsin, a job he held until moving to U.C.L.A. in 1980. Conn is codirector of the Center for Plasma Physics and Fusion Engineering there.

JOSEPH SILK, ALEXANDER S. SZALAY and YAKOV B. ZEL'DOVICH ("The Large-Scale Structure of the Universe") are astrophysicists who work at widely separated institutions. Silk is professor of astronomy at the University of California at Berkeley. His Ph.D. in astrophysics is from Harvard University. He has been at Berkeley since 1970, but he spent the past academic year (1982–83) as a visiting scholar at the Institut d'Astrophysique in Paris. He is the author of *The Big Bang* (W. H. Freeman and Company, 1980) and coauthor with John Barrow of *The Left Hand of Creation,* which is to be published by Basic Books later this year. Szalay is assistant professor of physics at Eötvös University in Budapest. He obtained his Ph.D. in astrophysics in 1975 from the same institution. After periods of postdoctoral study at Berkeley, the University of Chicago and Moscow University, he returned to Eötvös University in 1980. Szalay writes that his interest in cosmology was inspired by Zel'dovich, who is professor of astrophysics at Moscow University and director of the theoretical group at the Institute of Physical Problems in Moscow. Zel'dovich is a member of the Soviet Academy of Sciences and a foreign member of both the Royal Society in Britain and the National Academy of Sciences in the U.S.

JAMES E. DARNELL, JR. ("The Processing of RNA"), is Vincent Astor Professor at the Rockefeller University. He attended the University of Mississippi as an undergraduate, getting his B.A. in 1951. He obtained his M.D. at the Washington University School of Medicine in 1955. In 1956 he joined the staff of the Laboratory of Cell Biology at the National Institutes of Health. In that laboratory Harry Eagle had for the first time succeeded in culturing human cells outside the body. Together with Eagle, Darnell utilized the cultured human cells to do some of the first modern biochemical studies of the growth of viruses in their host cells. In 1961 Darnell moved to the Massachusetts Institute of Technology, and in 1964 he joined the faculty of the Albert Einstein College of Medicine in New York. He moved to Columbia University in 1968 and to Rockefeller in 1974.

ILANA STEINHORN and JOEL R. GAT ("The Dead Sea") are respectively an employee of Israel Limnological and Oceanographic Research, Ltd., and head of the isotope department at the Weizmann Institute of Science. Steinhorn, a native of Israel, received her B.S. in physics and mathematics (1972) and her M.S. in atmospheric sciences (1974) from the Hebrew University of Jerusalem. Her Ph.D. (1981) is from the Weizmann Institute. She writes: "My interest in the Dead Sea arose during my studies toward the Ph.D. degree. Because it was becoming apparent that the long-term stratification of the Dead Sea was weakening, the emphasis of my research was changed from a theoretical approach to one of intensive field measurements. These were set up quickly so as to document the changes in the structure of the Dead Sea water column that lead to its complete overturn." Gat was born in Germany and emigrated to the area then known as Palestine in 1936. He attended Hebrew University as an undergraduate and went on to obtain his M.S. in physical chemistry there in 1949. His Ph.D. in physical chemistry was awarded by the Weizmann Institute in 1956. After working for several years at the Israeli Atomic Energy Commission he

Enough already. No more inducements to business travelers, Qantas.



Before the coming of man, nobody had any business in the land Down Under. So, naturally, there was no business class.

Qantas changed all that. Qantas invented Business Class.

It gave rise to Business People who poured into Australia–until briefcases outnumbered koalas, wallabies and wombats. And word processors echoed across The Outback.

Not content with creating Business Class, Qantas improved it. Repeatedly. Now their extra-wide, deep-reclining seats recline even further. They've added fine china, linen and crystal service. Along with a roomy coat closet. And a complimentary flight bag.

Qantas Business Class now resembles First Class in other airlines. Still, the inducements continue:

Priority check-in and priority baggage handling. Special seating section with increased legroom.

Complimentary movies, complimentary stereo headphones (now they're padded!), and complimentary bar service.

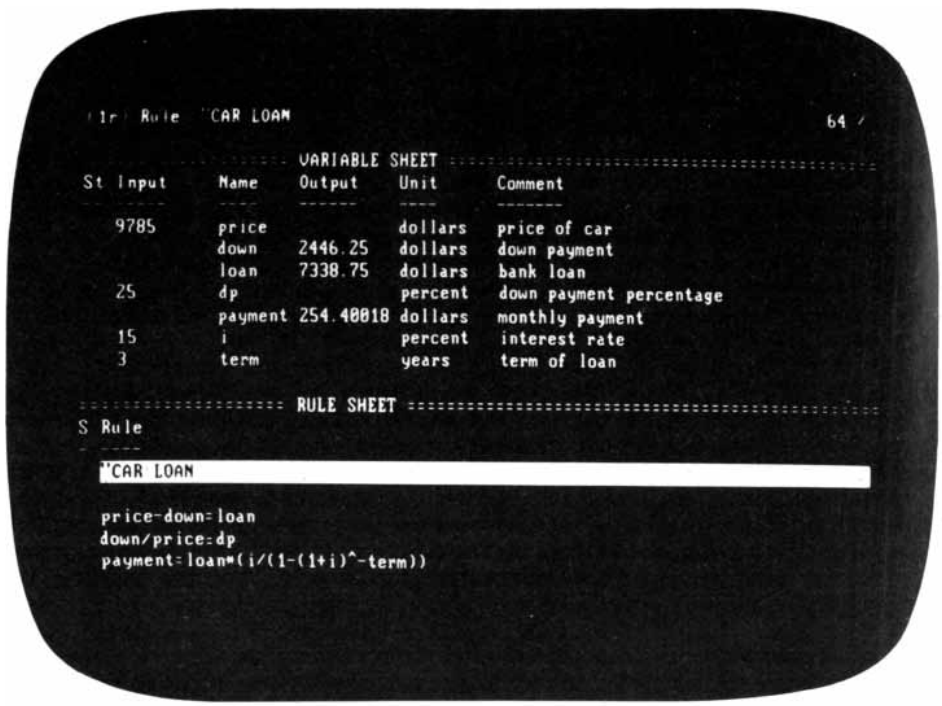
A choice of gourmet menu entrées, special wines and liqueurs. Special privileges at hotels, etc., etc., etc.

Qantas, we demand an end to such favoritism.

Koalas Against Qantas.

(The Australian Airline.)

TK!SO
EXPLA



TK!Solver does for equations what word processing did for words. The first thing you should know about the TK!Solver™ program is that it is not a spreadsheet. Instead, it does something completely unheard of (until now)—it turns your personal computer into a voracious equation processor.

The next thing you should know is that if the TK!Solver program can't make life with your personal computer easier (and pay for itself), even if you use it only 15 minutes a week, you are a very rare person.

And finally, you should know exactly what equation processing is, and how it works. If you keep reading this, you will.

Equation processing with TK!Solver, or problem solving made easy. The best way to understand what the TK!Solver program *is*, is to understand what it *does*. The following simple example is designed to do just that. If you're still a little in the dark after reading it, stop in at your local computer store for a very enlightening hands-on demonstration.

Begin by setting up your problem. The TK!Solver program lets you do it quickly, easily, and naturally. For example, a car costs $9785. What would be the monthly payment on a three-year loan if the down payment is 25% and the interest rate is 15%?

STEP 1. Formulate the necessary equations to solve your problem and enter them on the "Rule Sheet" simply by typing them in (as in the screen photo). For example: "price−down = loan."

STEP 2. Enter your known values the same way on the "Variable Sheet." For example: "9785" for price. You may also enter units and comments, if you want.*

STEP 3. Type the action command ("!" on your keyboard) to solve the problem.

STEP 4. TK!Solver displays the answer: the monthly payment is $254.40.

Backsolving, the heart of TK!Solver. Now that you've defined the problem and solved it, TK!Solver's unique backsolving ability also lets you think "backwards" to solve for any variable, regardless of its position in the equation. For example, if you can only afford a monthly payment of $200, you can re-solve the problem in terms of that constraint. The TK!Solver program will solve the problem, displaying your choice of a higher down payment, a longer loan term, or a lesser interest rate. This unique backsolving capability forms the basis of TK!Solver's remarkably flexible problem-solving ability.

DLVER™
AINED:

Also, as you can see from the example on the screen, TK!Solver deals not only with single variables, but with entire equations and sets of simultaneous equations. It also deals with much more complicated problems than this one. How complicated? That's up to you. What kinds of problems? That's up to you, too, but popular applications include finance, engineering, science, design, and education.

Other extremely useful and interesting things TK!Solver does. Aside from its basic problem-solving abilities, the TK!Solver program performs a number of pretty fancy tricks. Like: *Iterative Solving;* in which TK!Solver performs successive approximations of an answer when confronted with equations that cannot be solved directly, (like exp (x) = 2 – x • y and sin (x • y) = 3 – x – y). Like: *List Solving;* in which TK!Solver attacks complete lists of input values and solves them all, allowing you to examine numerous alternative solutions, and pick the one you like best. Like: *Tables and Graphs;* using the values you produced with the List Solver, the TK!Solver program will automatically produce tables and graphs of your data. You can look at your formatted output on the screen or send it to your printer with a single keystroke. And like: *Automatic Unit Conversion;* in which TK!Solver lets you formulate problems in one unit of measurement, and display answers in another. Very convenient what with all this talk about going metric.

The TK!Solver program also provides a wide variety of specialized business and mathematical functions like trig and log and net present value.

Then, there's TK!Solver's on-screen Help facility that provides information on commands and features any time you want it. Just type "?" and a topic name.

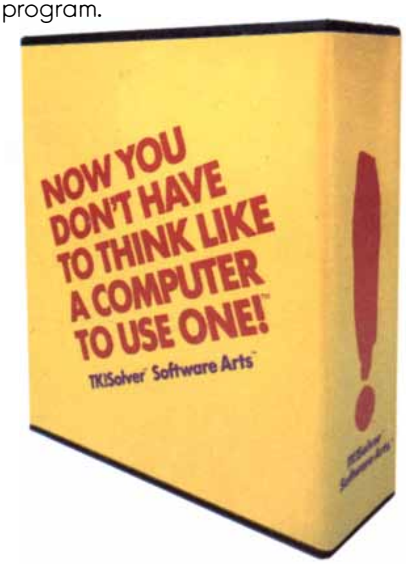
And of course the TK!Solver program combines all these features in one *integrated program.*

TK!SolverPacks make problem-solving a picnic. TK!SolverPack™ application packages are specially developed by experts in specific fields. Each package contains a diskette with about a dozen models that include the necessary equations, values, and tables for solving a particular problem. The models are usable as-is or you can easily modify them.

TK!SolverPack application packages available from Software Arts include Financial Management, Mechanical Engineering, Building Design and Construction, and Introductory Science. Additional TK!SolverPacks are on the way from Software Arts, McGraw-Hill,™ and others.

We know you're out there. No matter who you are, or what you do, if it involves using equations, the TK!Solver program is an indispensable tool for you.

So, visit your local computer store today, and see TK!Solver in action. You'll be amazed at how much faster and more effectively you'll be able to work when you discover the power of equation processing with the TK!Solver program.

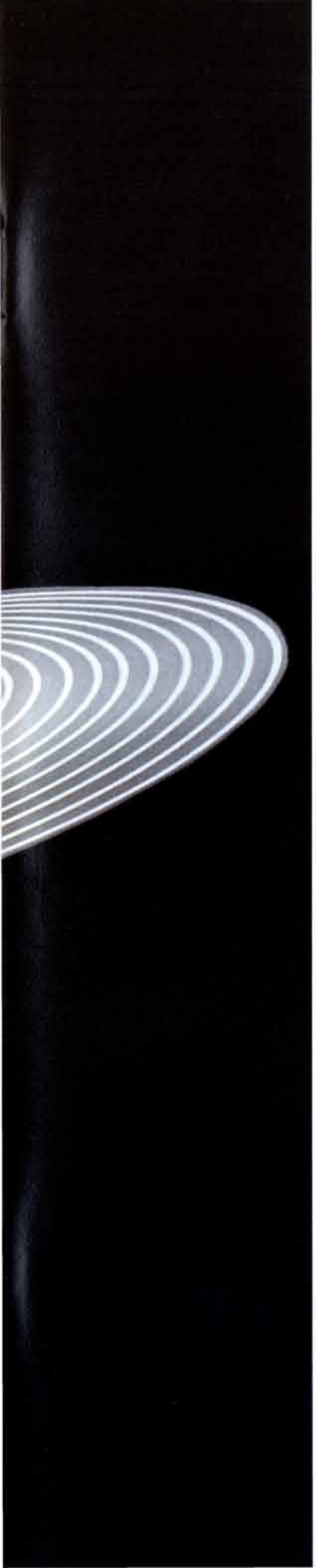


Software Arts™
The inventors of VisiCalc®

27 Mica Lane, Wellesley, Massachusetts 02181
617/237-4000

*You can easily define appropriate unit conversions on the unit sheet.

P/N 100-092 P 8/83



Who on earth will install enough lightguide fiber to circle the earth 10 times?

Western Electric, an AT&T company.

In just five years, Western Electric has already created and installed enough lightguide fiber to circle the earth. That's 25,000 miles of fiber in 60 lightwave communications routes.

Those totals should increase at least tenfold by the year 2000, as Western Electric continues to install lightwave systems to transmit the high-speed voice and data services of the Information Age.

Far more efficient and economical than copper cable, lightwave communications speeds your messages over 90 million light pulses per second through hair-thin glass fibers. A single lightguide cable can carry 240,000 telephone calls at once.

Right now Western Electric is installing the world's largest lightwave system in the busy Northeast Corridor. Another will transmit the entire 1984 Los Angeles Summer Olympics to ABC television studios.

And our research and development arm, Bell Labs, is working on a transatlantic lightwave cable that will triple calling capacity and enhance transmission quality.

These systems are forerunners of a continually expanding lightwave network that one day will literally circle the earth, bringing everyone exciting new information services.

Western Electric, an AT&T company. Applying the technologies of lightwave, microelectronics, and software to make the dream of the Information Age a reality.

AT&T

returned to the Weizmann as a faculty member in 1959.

B. O. K. REEVES ("Six Millenniums of Buffalo Kills") is associate professor of archaeology at the University of Calgary. He is a native of southern Alberta who was graduated from the University of Alberta with a B.S. in geology in 1961. He got a second undergraduate degree (a B.A.) two years later at the University of Alberta at Calgary before going on to obtain his M.A. (1967) in archaeology and his Ph.D. in the same subject (1971) at the University of Calgary. He writes: "My studies have been somewhat eclectic although geographically focused, dealing with archaeological sites ranging from those of early man to the period of World War II, including fur trading posts, missions, whiskey posts, and mine towns."

PETER WARD ("The Extinction of the Ammonites") is associate professor of geology at the University of California at Davis. He received his bachelor's and master's degrees from the University of Washington and completed his Ph.D. in 1976 at McMaster University. He taught earth history and paleobiology at Ohio State University from 1976 to 1978 before moving to Davis. He writes: "I am currently working on the chambered nautilus in New Caledonia, Fiji and Palau, using electronic methods to track the animals over several days and nights. The study of the living nautilus gives valuable information about the uses of the chambered shell and, more important, about the constraints imposed by the shell in the life cycle of the shelled cephalopods."

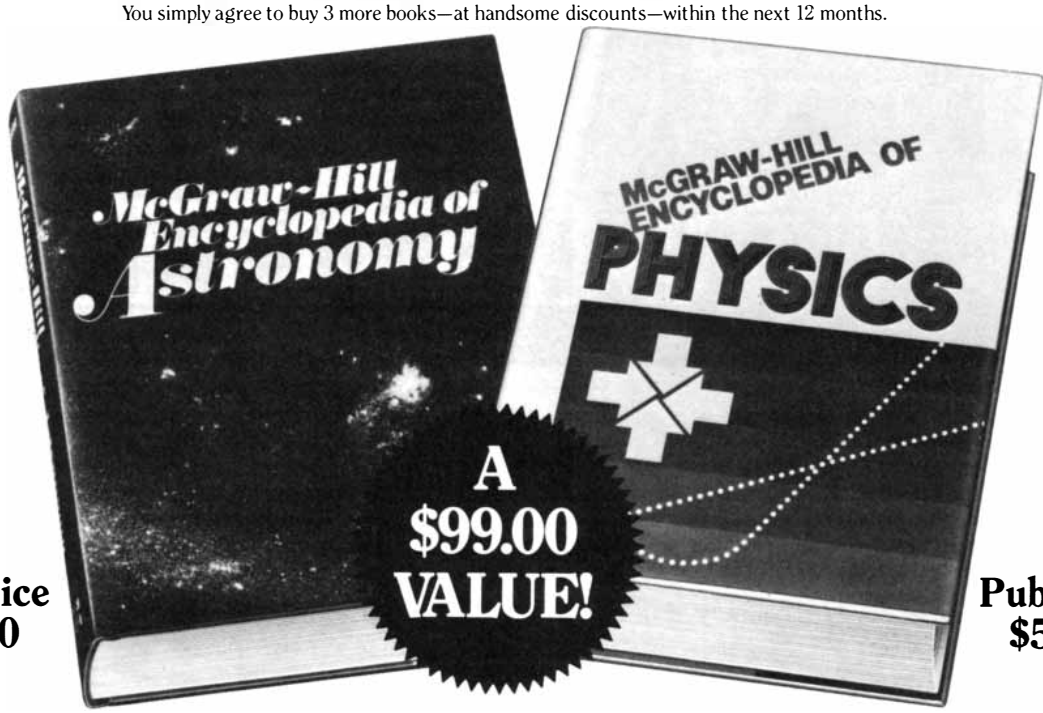
HERBERT F. YORK ("Bilateral Negotiations and the Arms Race") is professor of physics and director of the program in science, technology and public affairs at the University of California at San Diego. He got two degrees from the University of Rochester: an A.B. (1942) and an M.S. in physics (1943). His Ph.D. in physics was awarded in 1949 by the University of California at Berkeley. During World War II he worked for the Manhattan Engineer District (the "Manhattan Project") at the Y-12 plant in Oak Ridge, Tenn. In 1952 he helped found the Lawrence Livermore Laboratory of the University of California; later he served as its director. In 1958 he left to become the first Director of Defense Research and Engineering for the Federal Government, a job he was given by President Eisenhower. In 1961 he returned to the academic world as chancellor of the University of California at San Diego; he resigned in 1964 to become professor of physics. He has served as adviser to the Federal Government on arms and arms control in many different capacities.

An exhaustive compendium covering all aspects of physics and astronomy.

Take the 2-Volume LIBRARY OF PHYSICAL SCIENCES for only $3.95

as your introductory selection to one of Macmillan's two science book clubs—
The Astronomy Book Club *or* **the Library of Science.**

You simply agree to buy 3 more books—at handsome discounts—within the next 12 months.



Pub. Price $44.50

Pub. Price $54.50

The McGraw-Hill Encyclopedia of Astronomy contains 230 articles providing coverage of everything from constellations, and the gravitational lens to Einstein shift, and the instruments used in ultraviolet, radio and X-ray astronomy. Nearly 400 photographs, charts, graphs and drawings—including 13 pages in full color—illustrate and illuminate the articles.

The Astronomy Book Club is a very special club operated exclusively for astronomy enthusiasts. Whether you are interested in unusual astronomical happenings or just in being able to understand the night sky, whether you are an astronomer by profession or by interest, we're sure you'll find membership in the Astronomy Book Club beneficial.

Over 25,000 astronomy enthusiasts already are members of our Club. Recent offerings have ranged from popular explanations of deep-sky phenomena to authoritative references for serious sky watchers to important theoretical works on the frontiers of astrophysical research.

Eminent authorities such as Carl Sagan, Robert Jastrow, George Abell and John Gribbin appear frequently. The Club is devoted to making the finest books available, conveniently and inexpensively.

A SAMPLING OF THE INFORMATION YOU'LL FIND IN THESE VOLUMES:

Keeping you abreast of the latest advances in physics and astronomy, the Library of Physical Sciences provides a wealth of information on these closely related and rapidly developing fields. These two companion volumes contain a total of 990 articles by over 500 of the world's leading scientists. The articles originally appeared in the 15-volume *McGraw-Hill Encyclopedia of Science and Technology* (Fifth Edition, 1982).

These outstanding references provide easy access to material. Most articles contain a complete, current bibliography. Cross-references guide the reader to related topics. Finally, both volumes contain a detailed index.

MEMBERSHIP BENEFITS: In addition to getting the LIBRARY OF PHYSICAL SCIENCES for only $3.95 when you join, you keep saving substantially on the books you buy. Also, you will immediately become eligible to participate in our Bonus Book Plan, with savings of up to 70% off the publishers' prices. At 3–4 week intervals (16 times a year) you will receive the Book Club News, describing the coming Main Selection and Alternate Selections, together with a dated reply card. If you want the Main Selection, do nothing and it will be sent to you automatically. If you prefer another selection, or no book at all, simply indicate your choice on the card, and return it by the date specified. You will have at least 10 days to decide. If, because of late mail delivery of the News, you should receive a book you do not want, we guarantee return postage.

The McGraw-Hill Encyclopedia of Physics covers all areas of classical and modern physics as well as related topics in mathematics which play an important role in physical science. The 763 alphabetically arranged articles discuss experimental and theoretical aspects of acoustics, atomic and molecular physics, particle physics, fluid mechanics, heat and thermodynamics, low-temperature physics, nuclear physics, and more. You'll also find over 1000 tables, graphs, photographs and other illustrations.

The Library of Science is the oldest and most respected scientific book club in the country.

Convenient and enjoyable, The Library of Science puts you in touch with the major science developments, theories, and applications of our day. Books by Stephen Jay Gould, Karl Popper, and Steven Weinberg. Regularly made available to you in the Library of Science NEWS.

You'll save time selecting books that span an exciting variety of subjects from climatology to creativity, Einstein to evolving continents, with handsome discounts on virtually every book you purchase.

If reply card has been removed, please write:
Macmillan Science Book Clubs—Dept. ___-AZ3, Riverside, N.J. 08075 to obtain membership information and application.

10 QUESTIONS TO ASK YOURSELF BEFORE YOU BUY A BUSINESS COMPUTER.

The toughest thing about investing in the best computer is finding which computer is best for you. Because computers can be just as different as the people they work for.

That's why we've devised a list of 10 basic, unbiased questions to help simplify the choice of which computer will get along with you.

1 HOW MUCH SHOULD I SPEND?

As little as possible, and still get a fully functioning computer.

That would not include machines you see advertised for under $1,000. They're mainly designed for home entertainment and balancing your checkbook in full color.

For a serious business system, with all the capabilities you need, you can spend as little as $1,600, including software. Or as much as $5,000. And up.

Of course this gives you a choice of more than 500 different makes and models. So rather than devote the next 5 years of your life trying 500 different computers, a good short list would include computers from IBM, Kaypro, Apple and Tandy—the leading brands.

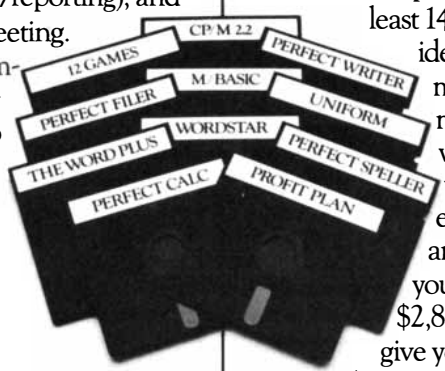
2 WHAT CAPABILITIES DO I NEED?

While businesses can be very different, their computer needs usually aren't.

We've found that 95% of all business needs can be fulfilled by a computer with three basic capabilities. Word Processing/Spelling, Data Base Management (filing/reporting), and Financial Spreadsheeting.

If the same computer has a popular 'operating system,' so much the better.

It will have thousands of other programs available to fill more specialized needs.



3 HOW MUCH HARDWARE DO I NEED TO GET STARTED?

Beyond the basic computer, you need a monitor and at least one disk drive, the device that stores information. For word processing or data base management, you will need a computer with 2 drives. Such powerful programs require the storage capacity of their own disk drive.

A second drive also eases copying data from one disk to the other.

4 HOW MUCH MEMORY WILL I NEED?

For most business purposes, a machine with a built-in memory (RAM) of 64K, about 42 typed pages.

Since you'll need a disk drive to store data, its capacity should be at least 140K. Of course, the idea is to get the most memory for the money. For example, when you compare the hardware of equivalent systems, an IBM PC will give you 320K for about $2,800. A Kaypro II will give you 400K for about $1,595. And an Apple IIe will give you 286K for about $2,400. So once again, the choice depends upon your needs.

5 DO I NEED AN 8-BIT OR 16-BIT SYSTEM?

A 16-bit system costs more, gives you a little more speed, and can run longer programs. Unfortunately, only a handful of programs

take advantage of 16-bit capacity.

75% of all microcomputers sold today are of the 8-bit variety, indicative of their ability to satisfy the needs of most businesses.

6 WILL I NEED A PRINTER?

Most people do, sooner or later. It's a fast, efficient way of getting information from your computer screen to other people. For letters, for reports, for balance sheets and for records. That's why it's important to make sure the computer you want has a built-in printer connection. Otherwise when you go to buy a printer, you'll also find yourself paying for an interface.

7 HOW MUCH TRAINING WILL I NEED TO USE MY COMPUTER?

You won't have to learn to write programs to use your computer. Somebody's already done that for you. You will have to learn how your machine operates, which may take a few hours.

And you'll learn how to run programs. The time that it takes depends on their complexity. The ideal way to save time is having a family of programs that share the same commands. Each program in the series will take less time to learn.

8 WHERE CAN I GO FOR GOOD SOLID ADVICE?

Do the same thing you would do if you were shopping for a stereo or an expensive camera. Ask an enthusiast. A computer buff. You probably know one. If not, call a consultant. In the long run, he or she could save you a lot of money by directing you to the right combination of hardware and software. And by advising you whether to buy a computer now or wait for prices to come down further.

It is true that the price of serious business computers is drifting down an average of 10-12% a year. The average system costing $3,000 today may cost $2,700 next year. Yet, you could lose thousands of dollars of increased productivity, waiting to save $300.

SPECIFICATIONS

Microprocessor
Z-80
Operating System
CP/M 2.2
User Memory
64K
Disk Drives:
2 drives, 400K, unformatted
Interfaces
1 Serial
1 Parallel
Keyboard
Detached, 63-key with numeric keypad
Software included:
Perfect Writer word processing
Perfect Speller
Perfect Filer
Perfect Calc spreadsheet
Wordstar word processing
The Word Plus
Profit Plan spreadsheet
M-Basic
12 Games
Uniform—allows computer to 'read' and 'write' TRS-80, Osborne, Xerox disks
Dimensions
Height: 8 inches
Width: 18 inches
Depth: 15½ inches
Weight: 26 lbs. (portable)

9 WHY IS THERE SUCH A GREAT DIFFERENCE IN THE PRICE OF COMPUTERS?

Some differences are based on capabilities. Business computers capable of playing joystick games cost more than ones that stick to business. And, as we mentioned before, 16-bit computers cost more than 8-bit systems.

A more important difference is the way computers are manufactured and sold. Most start with the basic keyboard and microprocessor, for a basic price.

You then pay more for a monitor. More for disk drives. More for communication interfaces. More for software. All optional extras that can run up the price two or three times.

However, at Kaypro we don't consider monitors, disk drives and software to be optional extras. So we make and sell completely integrated systems with all the hardware you need. All the software you need. All for $1,595.

Of course, a lot of other computer companies feel you should pay extra for everything you get.

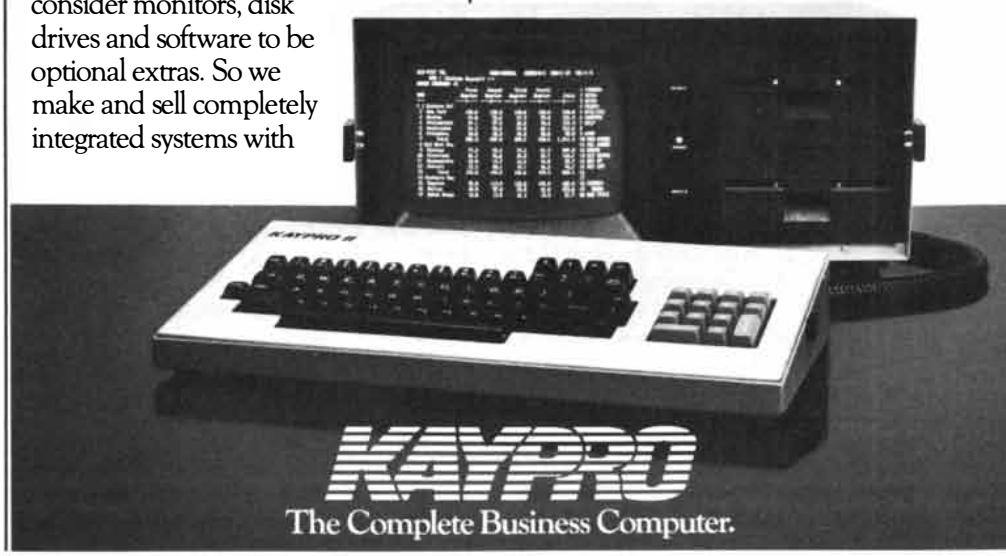
10 WHICH IS THE SMARTEST COMPUTER FOR ME TO BUY?

All things considered, we'd consider it a Kaypro. And since this is a Kaypro ad, you wouldn't think we'd suggest anything else. But fortunately for us, our computer gives us a lot to be biased about. Off the shelf, it gives you everything you want for 95% of your business needs. Plus the ability to run 3,000 more programs. It's the complete business computer.

What do you get complete? 64K RAM, Z-80 microprocessor. CP/M, the most widely used business software operating systems. A 9", easy-to-read, green monitor. Two disk drives (400K capacity). Interfaces for both a printer and communications. A detachable keyboard, with a numeric keypad. And one of the leading computers in the $1,000 to $5,000 price range.

A Kaypro may not be the best computer for everyone. But for $1,595 complete, it gives you the best solution to serious business problems.

CALL 800-447-4700 FOR THE DEALER NEAREST YOU.



COMPUTER RECREATIONS

Introducing a department concerned with the pleasures of computation

by Brian Hayes

Let us calculate.
—GOTTFRIED WILHELM VON LEIBNIZ

Some of the livelier games played with a microcomputer now come equipped with a function designated TBIC. The letters stand for "The boss is coming," and when the key assigned to the function is pressed, the battlefield on the glass screen immediately goes silent and dark. Here, it seems, are the two poles of the public response to the recent proliferation of inexpensive computers. On the one hand the computer is an engine of business, a capitalist tool; on the other it is a medium for entertainments so frivolous that they must be hidden from view, like comic books.

I do not mean to belittle either the practical applications of computers in business and industry or the genre of computer games whose principal aim is to test the player's reflexes. Utilitarian computing is unquestionably important. As for the video games, their construction may well be among the highest expressions of the programmer's art. It should be observed, however, that neither of these uses of the computer engages very deeply the question of what a computer is and what it can do.

There is a vast territory between business programming and video games, between VisiCalc and Space Invaders. The territory includes the applications of the computer in all the arts and sciences, and perhaps most obviously in mathematics. It includes the use of the computer to simulate aspects of the natural world and of human societies. Furthermore, it includes many pursuits that properly speaking are not "uses" of the computer at all but rather serve to focus attention on the computer itself and on the nature of mechanized computation. It is this realm between stern practicality and mere diversion that "Computer Recreations" will undertake to explore. Contributions from readers are welcome. Given that thinking remains a good deal harder than computing, those without access to computing machinery should be at only a slight disadvantage.

Even the tools of the businessman can sometimes be applied to problems in the theory and practice of computing. Here I shall consider some questions raised by novel applications of the programs called electronic spreadsheets.

A paper spreadsheet is a large page ruled into many columns and rows. It might be employed for analyzing the budget of a company. Each department could be given a column and each category of income or expense a row. Totals and percentages for each department and each category could be entered in additional columns and rows.

The electronic spreadsheet reproduces this structure on the screen of a cathode-ray tube, but with a few notable differences. On paper a given cell (defined as the intersection of a column and a row) can hold either a label, such as the name of a department, or a number. In an electronic spreadsheet a cell can also be assigned a mathematical formula. Thus the cell at the end of a row might hold a formula that calls for summing the values entered into all the other cells in the row. What is displayed on the screen is the number that results from evaluating the formula, in this case the total, but the underlying content of the cell is the formula itself rather than the number. If one of the other entries in the row is changed, the total is recalculated automatically.

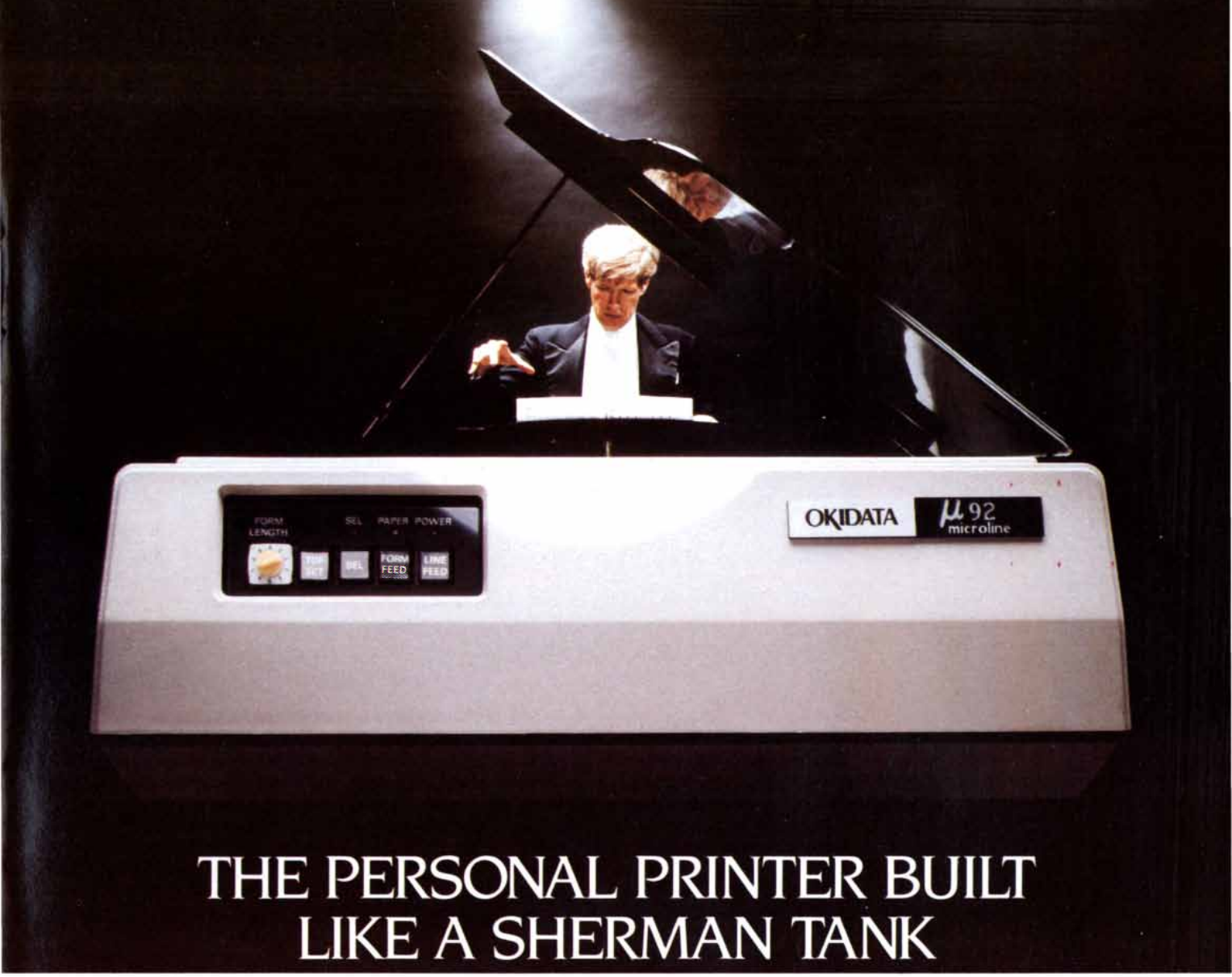
The first of the electronic-spreadsheet programs was VisiCalc, developed in 1978 by Daniel Bricklin, who was then a student at the Harvard University School of Business, Robert Frankston and Dan Fylstra. It is said to have sold more copies than any other computer program. Dozens of other programs operating on similar principles have been introduced since then, and VisiCalc itself has been revised several times. Most of the experiments described here were done with two later spreadsheet programs: 1–2–3, conceived by Mitchell Kapor and Jonathan Sachs of the Lotus Development Corporation of Cambridge, Mass., and Multiplan, a product of the Microsoft Corporation of Bellevue, Wash. In most cases other spreadsheet programs would serve as well.

Although the electronic spreadsheet was designed for financial analysis, it is capable of much more. It is a two-dimensional matrix of cells where the value of each cell can be made to depend on any other cell or group of cells. It is surprising how much of the mathematical structure of the world can be coaxed into such a format. Indeed, it turns out that the spreadsheet represents a quite general context for describing mathematical and logical relations.

A simple example can give a better grasp of how a spreadsheet is manipulated and suggest what its potential is. Each cell is specified by its coordinates in a grid; in most of the programs the columns are identified by letter and the rows by number, starting at the upper left. Suppose cells A1 and A2 are each assigned a numeric value of 1. In cell A3 a formula is then entered: the value at position A3 is set equal to the sum of the value in the cell immediately above it and the value in the cell above that one. In other words, A3 is equal to the contents of A2 plus the contents of A1, and it displays the value 2.

What has been accomplished so far is trivial: it is a highly elaborate scheme for expressing the relation $1 + 1 = 2$. It is now possible, however, to copy the formula in cell A3 into many other cells. (The exact procedure for making copies varies from one program to another, but all the programs include such a facility.) Suppose the formula in A3 is copied into cells A4 through A10. Each of those cells will then hold a value equal to the sum of the values in the two cells above it. Note that the formulas are all identical, but because they are applied to different values the results are not. The numbers displayed, reading from top to bottom, are 1, 1, 2, 3, 5, 8, 13, 21, 34 and 55.

There are many ways of generating the Fibonacci series with a computer, and most of them make far more efficient use of the machine's resources than this one does. There is something quite distinctive, however, about the spreadsheet strategy: it is nonalgorithmic. In almost all programming languages a task or the solution to a problem is defined in terms of an algorithm, that is, a sequence of explicit instructions to be executed one after another. An algorithm is like a recipe: it might begin, "First mix flour, yeast and water, then let rise and finally bake." Doing the same operations in another sequence would have a quite different result. The spreadsheet does not have this characteristic temporal ordering. What goes into the cells is not a sequence of steps that leads from the problem to the solution but a static structure that attempts



THE PERSONAL PRINTER BUILT LIKE A SHERMAN TANK

PERFORMS LIKE A CONCERT GRAND.

Why We Get Encores. Okidata takes center stage with a cast of printers that can't be outperformed. All eight dot matrix printers offer you more features for your money than you can find anywhere else. Pick your tempo: data processing at speeds from 80 to an exceptional 350 cps; to stress a point, enhanced and emphasized printing at up to 100 cps; outstanding letter quality printing at speeds three times faster than most daisywheels — up to 85 cps. Add a full range of graphics capabilities, downline loadable character sets for creating personalized typefaces and symbols, and your print repertoire is virtually unlimited.

We Play On and On. Our virtuosos feature rugged steel frames, laser-welded parts, and our long-life, non-ballistic print head warranted for up to one full year. With this tank-toughness you'd expect Okidata to have the lowest warranty claim rate in the industry. And we do: less than ½%.

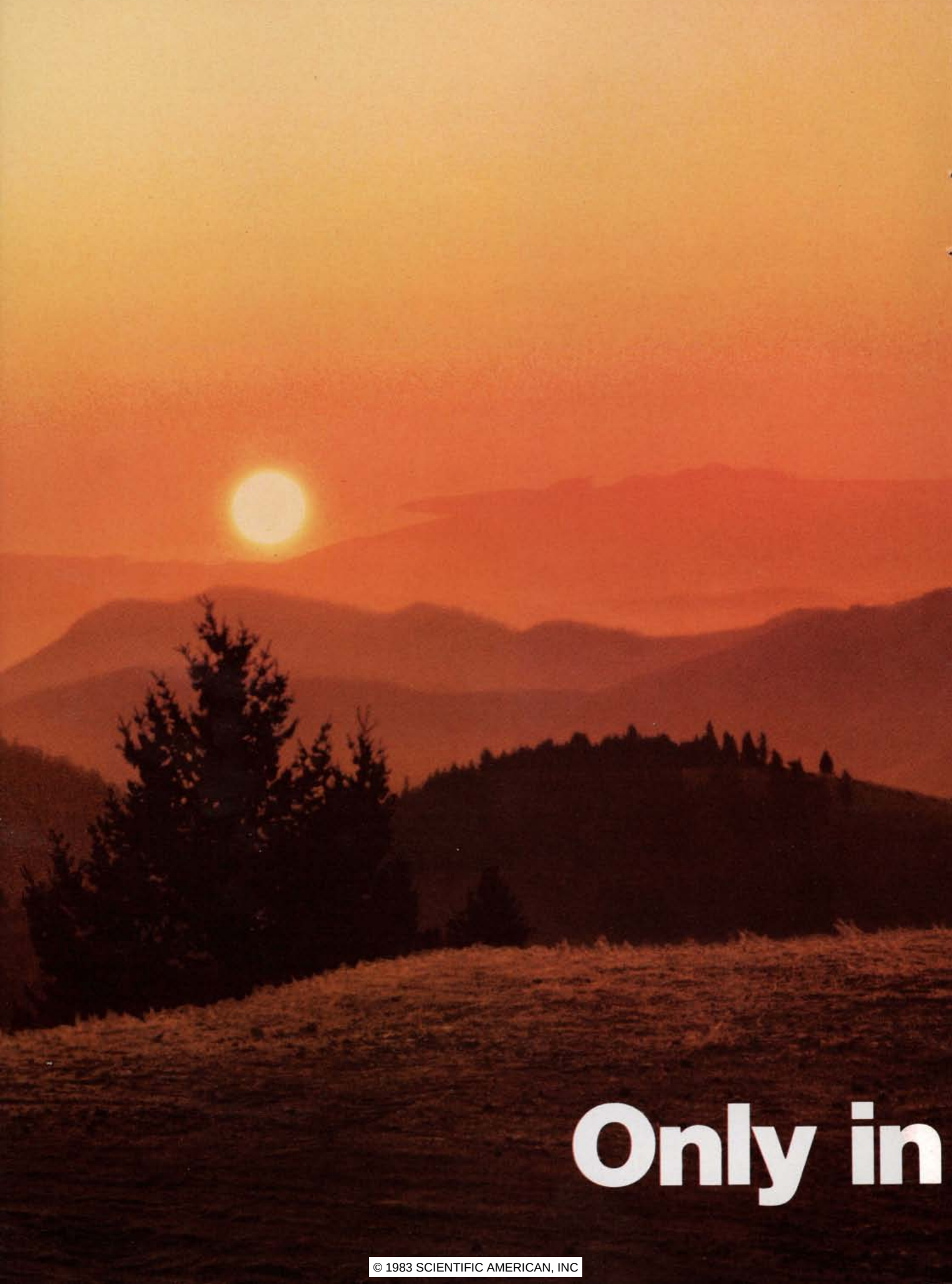
In Tune with All Major Computers. We've designed each of these finely tuned instruments to be harmonious with all the major names in personal computers. And to give you more than you'd get from the major computer name printers. After all, we specialize in printers. The computer folks specialize in computers. (That's why MOST buy their printers from somebody else).

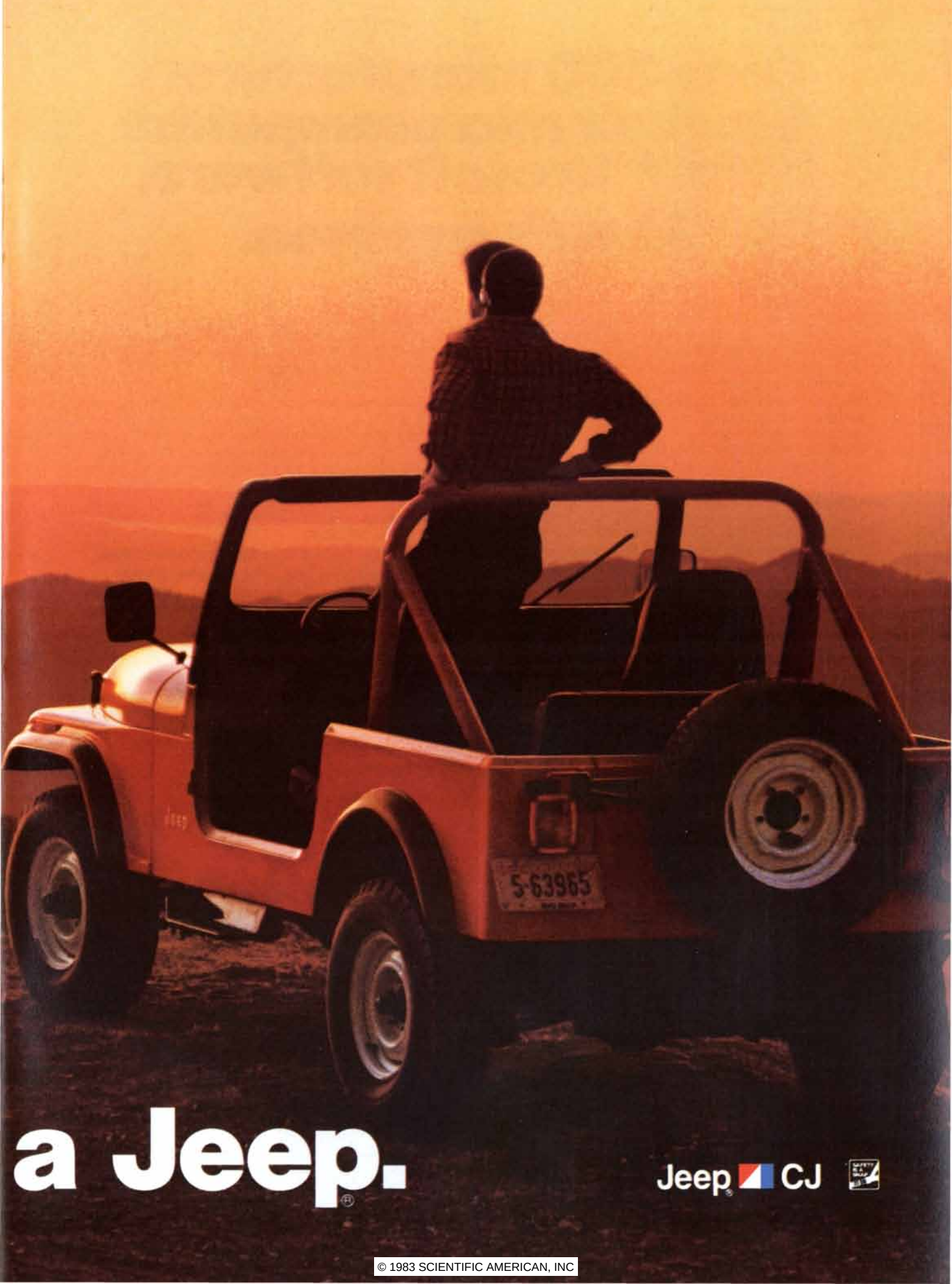
Larger Selection. Smaller Prices. Because we make more printers than anybody else, we can give you just the right one to fit your specific needs. Not to mention your budget. Suggested retail prices range from $449 to $2995. Call 1-800-OKIDATA (in NJ, 609-235-2600) for the dealer nearest you. Both you and your computer will enjoy the performance.

OKIDATA

Mt.Laurel, NJ 08054

A subsidiary of Oki Electric Industry Company Ltd.





Over 300 manufacturers sell their microcomputers with Microsoft software.

There's a reason.

Powerful simplicity. That's the concept behind every software program we write. Powerful programs that let you spend more time thinking about the problem...and less time thinking about the computer. That concept has earned us the confidence of over 300 microcomputer manufacturers. Starting with the very first microcomputer you could buy. And today, Microsoft® languages, operating systems and applications software are running on well over a million microcomputers. Worldwide.

Made for each other. Manufacturers literally build their computers around Microsoft software. That's no exaggeration. In fact, Microsoft frequently participates in the initial design and development of microcomputers. That's a major reason why Microsoft software runs so well on the majority of the world's 8- and 16-bit systems.

User-oriented. Microsoft is the only software supplier to offer a full range of compatible operating systems, languages, utilities and applications programs. If you're not a computer expert, here's what that means to you: Better programs. Programs that are not only more powerful, but easier to learn and use.

Better tools. We can't buy your trust. We have to earn it. With better products. Tools you can easily use to solve complex problems. We started with the first BASIC for the first microcomputer. Today, we offer a broad range of proven tools for microcomputers. Including SoftCard™ and IBM® RAMCard,™ products that materially increase the capabilities of Apple® and IBM PC computers. Plus, business and management software such as Multiplan,™ the powerful electronic worksheet you can learn to use in just a few hours. Better tools. Because they're designed specifically for your computer.

Ask your Microsoft dealer. Most microcomputer manufacturers offer their systems with some Microsoft software, but you'll undoubtedly want more. Programs and languages that solve your specific problems. Programs for your industry, business or home. Programs that do more, yet ask less. Ask your computer software dealer for a demonstration. You'll see why more than 300 microcomputer manufacturers offer their systems with Microsoft software. The reason is powerful simplicity.

BETTER TOOLS FOR MICROCOMPUTERS

MICROSOFT™

MICROSOFT CORPORATION
10700 NORTHUP WAY
BELLEVUE, WASHINGTON 98004

to encompass the entire procedure all at once. It is a description rather than a recipe: it states that bread consists of flour, yeast and water that have been mixed, allowed to rise and baked.

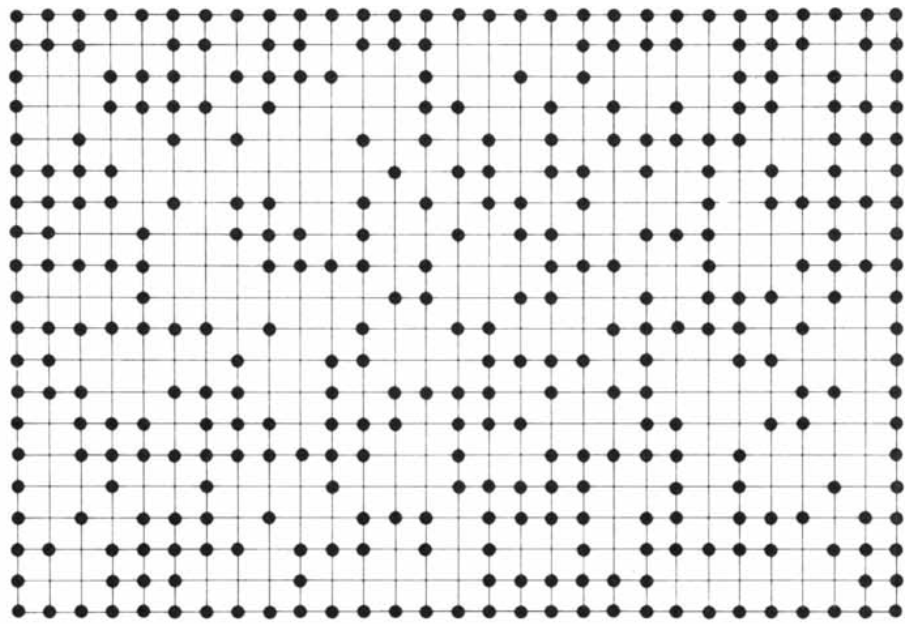
The distinction between an algorithm and a static description can be made clearer by another example. Consider the procedure for multiplying two matrixes of numbers when each matrix has three columns and three rows. The standard algorithm begins with instructions to multiply each element in the first column of the first matrix by each element in the first row of the second matrix, to add the three results and to store the sum as the first element of the product matrix. The same instructions are then repeated for the other eight combinations of rows and columns. The statement of the problem in a spreadsheet takes another form, and it can exploit the structural similarity of a mathematical matrix and an array of cells. Instead of writing a sequence of instructions, one simply defines the product matrix setting each cell equal to a formula that represents the appropriate combination of columns and rows. When the formulas have been entered, they are evaluated "all at once" and the entire product matrix appears.

At a deeper level, of course, a computer running under the direction of a spreadsheet program is indeed executing an algorithm. A computer that has only one central processing unit can do only one thing at a time, and so the cells are necessarily evaluated in some sequence. The user of the program, however, ordinarily has no need to take the sequence into account, and indeed he is often unaware of it. Thus the user need not think in terms of algorithms.

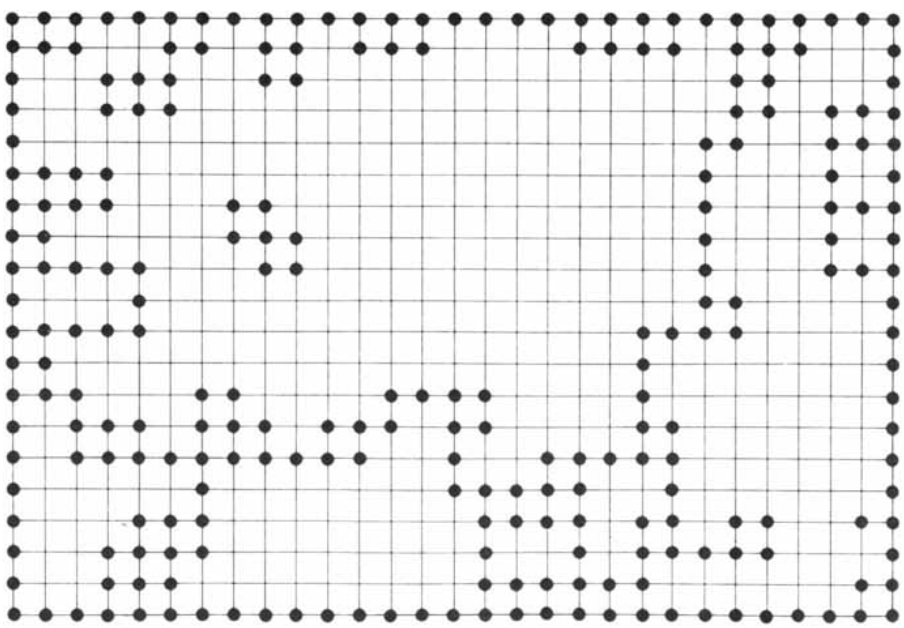
It is certainly not my intention to suggest that the nonalgorithmic mode of thought is somehow better than the algorithmic one. Some people may well prefer it, but that is largely a matter of taste. When a procedure becomes very complex, there is much to recommend the algorithm, which is more readily broken down into manageable pieces. Solving the problem all at once calls for understanding it all at once. It does seem likely, however, that there are certain problems or classes of problems that lend themselves naturally to a nonalgorithmic formulation.

One field where the spreadsheet's two-dimensional rectilinear array provides an appropriate medium is in constructing systems of cellular automata. The study of such systems was initiated in the 1950's by John von Neumann and Stanislaw Ulam, whose main concern at the time was with self-reproducing patterns. The rules they set themselves called for a "uniform cellular space" in which each cell represents an automaton, or machine, that has only a finite number of possible states. The space is uniform in the sense that the laws governing the state of the automata are the same for all the cells. A further constraint is that the state of a cell can be influenced only by its own history and by its close neighbors.

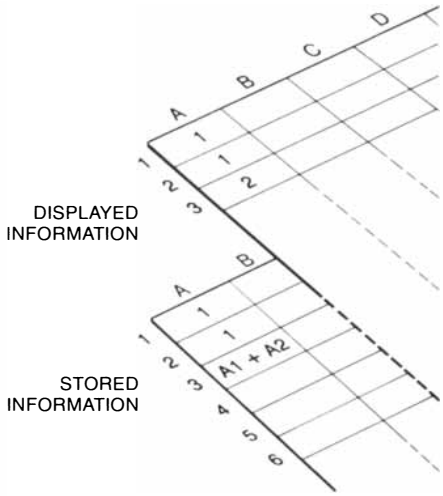
The conditions defining a system of cellular automata can readily be met by a spreadsheet program. In principle the number of states available to a cell is extremely large (perhaps 10^{100}), but it is clearly finite, and it can be reduced to a small number if that seems best; for example, a cell can be assigned a formula that can yield only two possible values, such as 0 and 1. The requirement of uniformity adds an interesting constraint. It implies that every cell in which a formula has been written must hold precisely the same formula. (There is more than one way of deciding whether two formulas are the same. Suppose a formula in cell A1 refers to cell B1, immediately below it. A formula in A2 might be considered identical if it also refers to B1, where the "absolute address" is the same, or if it refers to B2, where the geometric relation is preserved. The latter interpretation is generally more useful and seems more in keeping with von Neumann's and Ulam's ideas, but either scheme is acceptable if it is applied consistently. The spreadsheet routines for copying the contents of cells provide an easy operational test of uniformity. An array of cells can be considered uniform if a formula can be entered into one of



A lattice generated by a spreadsheet program simulates percolation



"Thinning" the lattice makes continuous paths easier to recognize



Structure of an electronic spreadsheet

them and then copied by the program into all the others.)

Von Neumann was able to prove that a self-replicating configuration of cells does exist. He did it the hard way, by showing there is a universal constructor that can create any pattern and therefore must be able to create its own pattern. The proof calls for some 200,000 cells having 29 possible states. As far as I know, the pattern has never actually been constructed, either manually or with the aid of a computer. Conceivably it might be within the capabilities of the larger spreadsheet programs.

A far simpler system capable of self-replication was devised in 1960 by Edward Fredkin of the Massachusetts Institute of Technology. Each cell has just two possible states, living and dead, which can be represented by the numbers 1 and 0. The state a cell will occupy in the next generation is determined by the present state of its four orthogonally adjacent neighbors, that is, the four cells immediately to the north, east, south and west. If the number of living neighbors is even (0, 2 or 4), the cell dies or remains dead. A cell with an odd number of living neighbors (1 or 3) lives.

It is a straightforward matter to express this rule in a spreadsheet formula, particularly with programs that include a function for modular arithmetic. In the case of cell B2 the formula is (B1 + C2 + B3 + A2) modulo 2. The effect of the formula is to add the values in the four neighboring cells, divide by 2 and retain only the remainder, which is necessarily either 0 or 1. It then remains only to copy the formula (in such a way that cell references preserve the same geometric relations) into all the cells throughout a region of the spreadsheet. Actually there is one further subtlety in the construction of the system: two copies of the cellular space are needed. One copy represents the present generation and one preserves the state of the preceding generation. The present state of a cell is based on the number of neighbors it had in the earlier generation.

When the spreadsheet is set up according to Fredkin's rules and an initial pattern is supplied, each cycle of recalculation yields a new pattern. After a few cycles four copies of the original configuration appear. Later the copies themselves are copied four times, so that the initial pattern has been reproduced 16 times. The number of cycles needed for reproduction depends on the complexity of the initial pattern; in the simplest case (a single live cell) the four offspring appear immediately.

Watching the progress of a growing colony can be fascinating. Fourfold symmetry is maintained at all times, and some of the patterns have a striking, stellate form. There is a rhythm to the process: the perimeter of the occupied area expands continuously, but the interior periodically becomes filled with a dense thicket of cells and then empties again.

Surely the best-known system of cellular automata is the game of life, invented by John Horton Conway of the University of Cambridge and introduced to the world at large in 1970 by Martin Gardner in his *Scientific American* column "Mathematical Games." The game, like its own pullulating automata, has by now spread to virtually every kind of computer system and programming language. There is a good reason: the game rewards the attention given it, whether the attention takes the form of casual spectatorship or close analysis.

In Conway's game of life the rules are defined not to ensure the replication of a pattern but rather to maximize variety or minimize predictability. Each cell again has two possible states, but the surrounding neighborhood is made up of the eight nearest cells, including the diagonally adjacent ones. If a cell is living, it will continue to live in the next generation only if it has either two or three living neighbors. With fewer neighbors it is said to die of loneliness and with more it dies of overcrowding. For a nonliving cell a birth is possible only if there are exactly three living neighbors.

An algorithmic specification of this procedure tends to be highly repetitious. It calls for examining a given cell, counting its neighbors, deciding whether the cell is to live or die, then going on to the next cell and the next until all of them have been checked. The repetition is generally embodied in the program structure called a loop, which is executed once for each cell. When the game of life is encoded in a spreadsheet, the repetition is still there, but it is spatial rather than temporal: the same formula is entered into each cell in a large array.

ITT announces the biggest advance in television since color.

Your everyday television set is about to become computer-like.

And it will be doing some very un-television-like things.

It's all due to the item you see here—a sophisticated set of eight semiconductor chips developed by the people of ITT.

These tiny chips will replace some 350 parts in today's television set.

Using the latest in digital technology ("digital" being the language of computers), they will be able to provide astonishingly clear pictures (clearer than anything *any* TV had before). As well as superb, new sound quality.

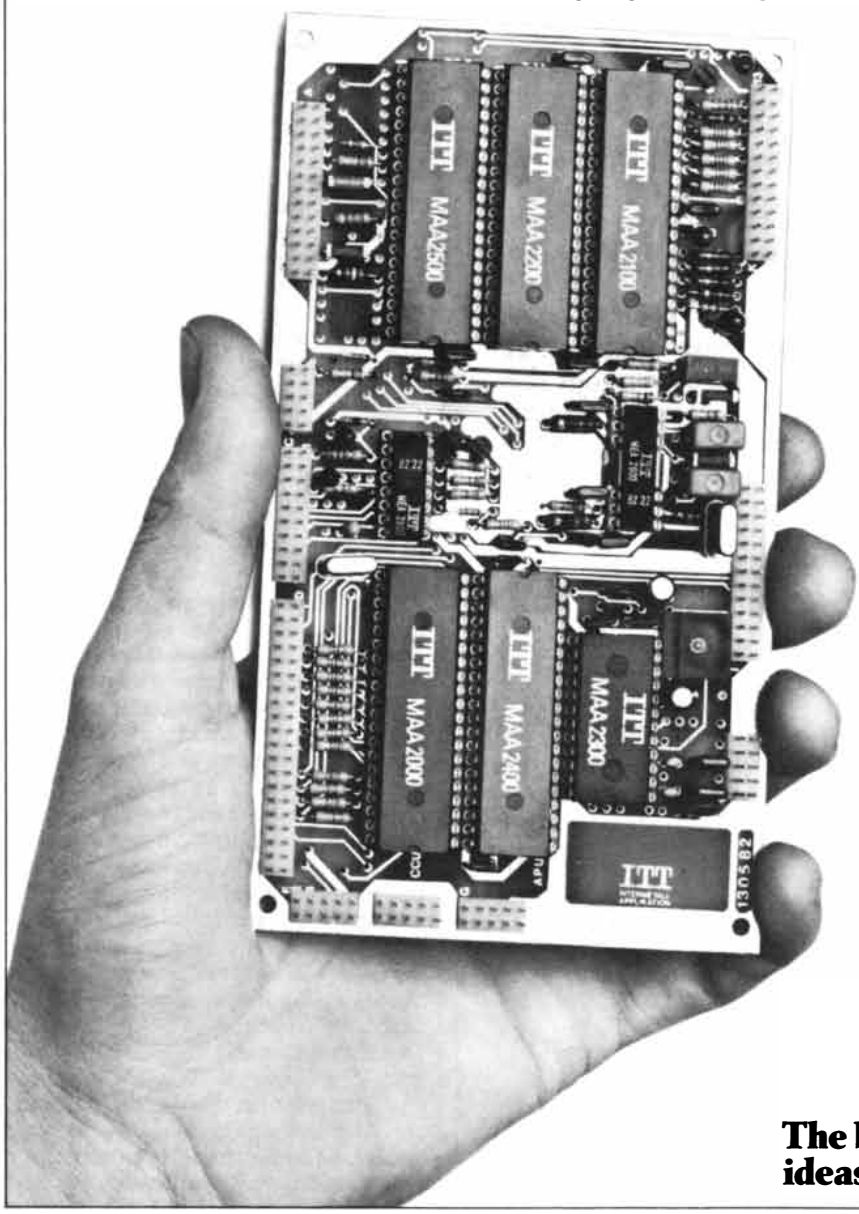
You'll also be able to have two channels on your TV screen at once. Finding out how your stock did on one channel, for example, while you watch the late news on another.

With this new kind of TV, it will be easy to shop at home. You'll just punch up your purchase on a keyboard, selecting from a catalog on the TV screen.

Your TV set will even become part of a home security network—allowing you to have surveillance over your whole property at the touch of a finger.

ITT is making these chips available to various television manufacturers, who will be marketing their own "digital" TV sets very soon.

It's a television worth watching for.



The best ideas are the ideas that help people. ITT

There are many ways of writing a formula to evaluate the state of a cell in the game of life. The best I have seen (meaning the one that runs the fastest) was devised by Ezra Gottheil of Lotus. The basic procedure is to multiply the value in the cell under examination by 9, yielding a result of either 0 or 9, then add the values in the eight surrounding cells. That result is looked up in a small table that gives the new state of the cell for all possible values of the sum (namely those between 0 and 17).

Ideally the game of life would be played on a cellular matrix of infinite extent. One of the fascinations of the game is that certain small initial patterns grow into magnificent symmetrical blooms after just a few generations; other patterns emit compact projectiles that glide off into the indefinite distance. The evolution of the pattern is changed whenever an organism falls off the edge of the world. An infinite matrix is impossible under any circumstances, and when one is working with a spreadsheet, the practical limits are indeed rather small. They are set by the capacity of the program itself, by the memory capacity of the computer and by one's own patience. (The time needed for creating a new generation is roughly proportional to the number of cells included.) One strategy for creating an array that has no boundaries even though its area is finite is to define the cells along opposite edges as being adjacent; the effect is to change the topology of the spreadsheet. Joining two edges in this way creates a cylinder or, if the sheet is twisted, a Möbius band. Joining all four edges in pairs forms a torus.

The Ising model is a simulated physical system that superficially resembles some cellular automata, although its interpretation is quite different. The model, which was introduced in the 1920's by the German physicists Wilhelm Lenz and Ernest Ising, can represent a number of physical phenomena, but it is most commonly applied to the description of ferromagnetic materials. Each site in a lattice represents the spin angular momentum, and hence the magnetic moment, of an atom. Each spin has a fixed magnitude, but the spin axis can point either up or down. When all the spins point in the same direction, the material is fully magnetized; when the spins are random, the magnetization is zero.

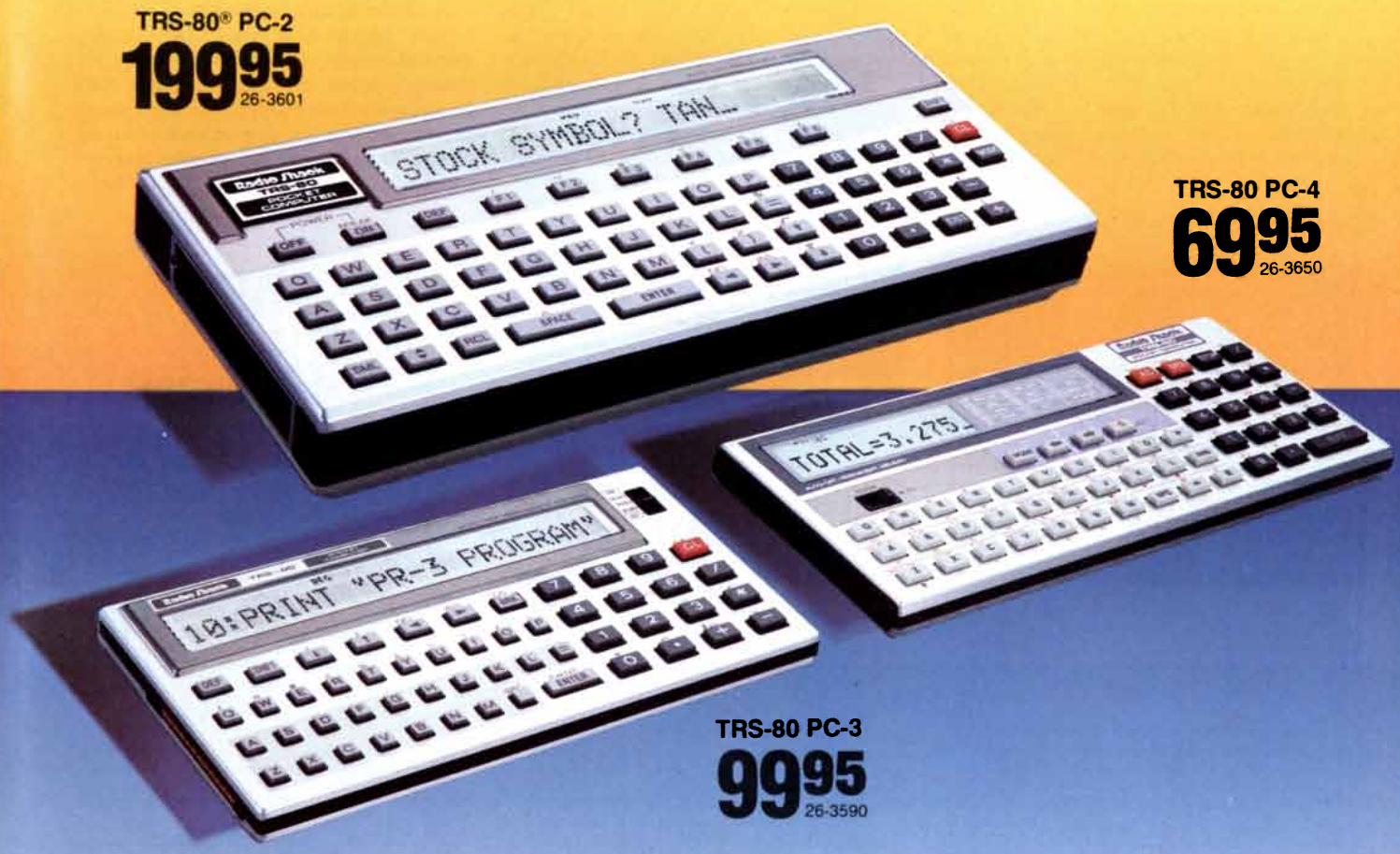
A spreadsheet realization of the Ising model is somewhat more complicated than one for Fredkin's replicating automata or Conway's game of life. The state of a given spin is again influenced by the nearest-neighbor cells, in this case the four orthogonal ones. In the Ising model, however, there is an element of randomness, which represents the effect of nonzero temperature. If a cell's neigh-

Radio Shack's Pocket Computers —Have One To Go!

TRS-80® PC-2
199.95
26-3601

TRS-80 PC-4
69.95
26-3650

TRS-80 PC-3
99.95
26-3590



TRS-80 PC-2. A hand-held computer with power and speed that rivals many desktop micros, yet measures just $1^{1}/_{16} \times 7^{11}/_{16} \times 3^{3}/_{8}$". Ideal for engineers, business people, scientists— anyone with tough problems to solve on the go! Programmable in Extended Pocket BASIC. Fully-addressable 7 × 156 dot-matrix LCD for graphics, plus upper and lower case characters. Expandable 2640-byte memory. Add the PC-2 Printer/Plotter/Dual Cassette Interface (26-3605, $219.95) to create spectacular four-color charts and graphs or to use our library of ready-to-run software.

TRS-80 PC-3. Perfect for students. The PC-3 is easily programmable in Pocket BASIC, and features 16 arithmetic and 8 string functions, 1.4K memory, 24-character display, two-digit exponents, multiple statements, arrays and more. $^{3}/_{8} \times 5^{5}/_{16} \times 2^{3}/_{4}$". Add our Printer/Cassette Interface (26-3591, $119.95) and choose from our large library of programs.

TRS-80 PC-4. Our lowest-priced pocket computer ever! Keep up to ten short programs in memory and enter BASIC commands with just two keystrokes. Features expandable 544-character memory and 12-character display (scrolls to 62 characters). Just $^{3}/_{8} \times 6^{1}/_{2} \times 2^{3}/_{4}$". Expand with the Cassette Interface (26-3651, $39.95) and Printer (26-3652, $79.95).

TRS-80 Computers Are Available Nationwide. Drop by any Radio Shack Computer Center, participating store or dealer and pick up your own TRS-80 Pocket Computer today.

Radio Shack®
The biggest name in little computers®
A DIVISION OF TANDY CORPORATION

☐ **Send me your free TRS-80 Computer Catalog today!**

Mail To: Radio Shack, Dept. 84-A-701
300 One Tandy Center, Fort Worth, Texas 76102

NAME _____

ADDRESS _____

CITY _____ STATE _____ ZIP _____

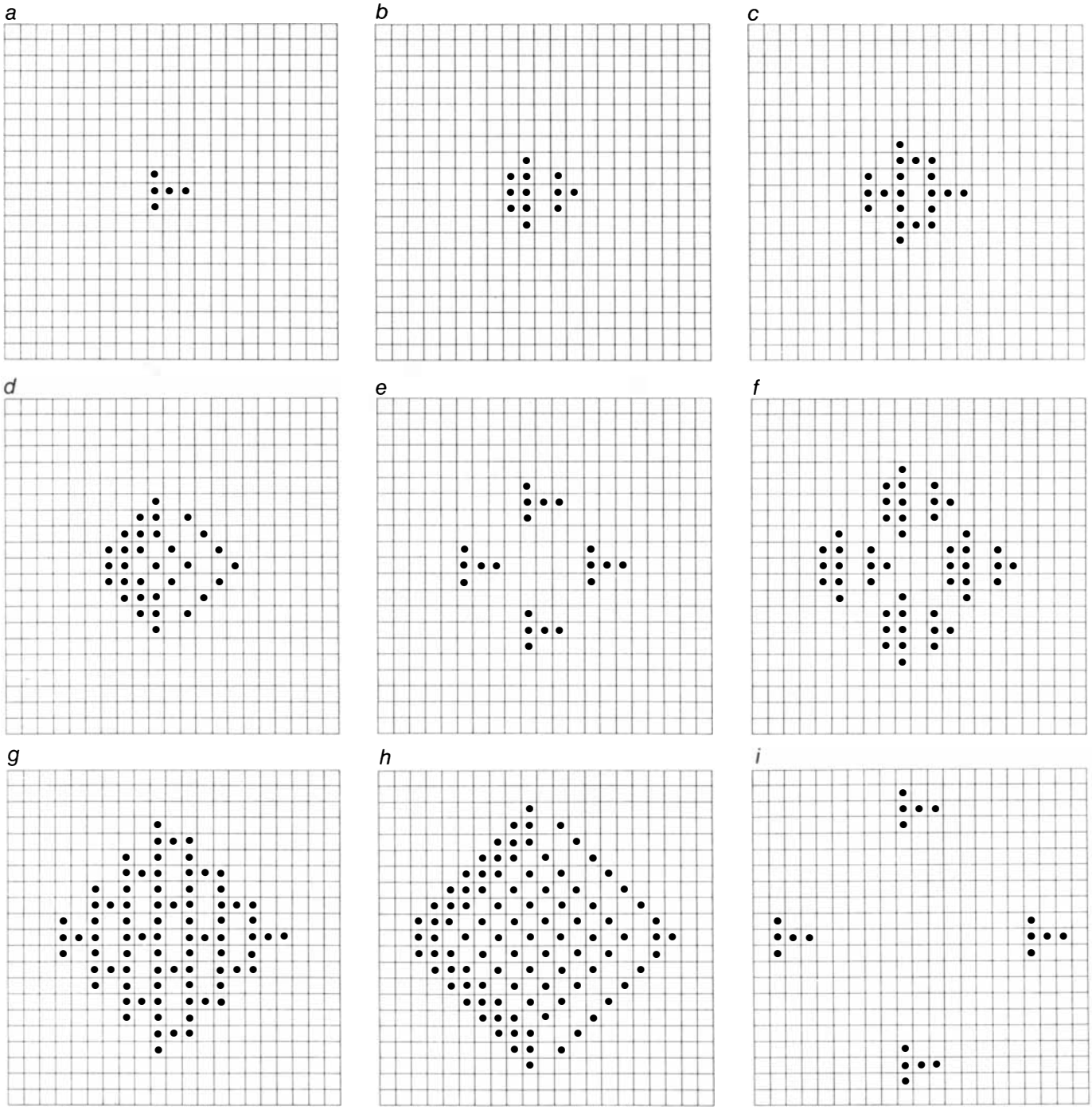
TELEPHONE _____

Prices apply at participating Radio Shack stores and dealers.

bors are all pointing up, the cell also has a tendency to point up, but it is not certain to do so; the probability is inversely proportional to the temperature.

A few experiments I have undertaken with a spreadsheet Ising model have yielded mixed results. The expected properties of the two-dimensional model have been known exactly since 1944, when Lars Onsager of Yale University solved the system analytically (rather than by numerical simulation). As the temperature is lowered through a threshold value (the Curie temperature) the spins should begin to fluctuate wildly and then should become fully magnetized. I have not seen such a phase transition, but I am not really surprised. The Ising model makes outrageous demands on computational resources. Getting accurate results requires a large lattice and a consideration of all possible configurations of the spins, which can take many hours even with an efficient program and a high-speed processor. At the Institute for Theoretical Physics of the University of California at Santa Barbara a special-purpose Ising-model computer has been built that calculates 25 million spins per second. The corresponding figure for the spreadsheet version of the model is about 25.

Even though the interesting events near the Curie temperature cannot be observed, the spreadsheet Ising model does seem to embody some other properties of magnetic materials. At high temperature the array of spins is without apparent pattern, as one would expect. At low temperature the magnetization of the lattice is obvious. Large, irregular blocks of aligned spins develop spontaneously, and blocks of opposite polarity seem to contend along their boundaries. One surprise (at least it surprised me) was the appearance of an antiferromagnetic phase, in which every other spin points in the opposite direc-



System of cellular automata devised by Edward Fredkin in which any pattern reproduces itself

Enter the J&B "It Whispers" Photo Contest.

We're looking for the photograph that whispers J&B best. Capture that scene, and J&B will cover all expenses for a once-in-a-lifetime trip to Scotland. Plus, for the best of the rest, we've got 160 other fabulous prizes.

Grand Prize

Ten-day, nine-night trip for two to Scotland, including round trip air transportation, hotel accommodations, meals, car rental, visit to J&B distillery, sightseeing, plus $2,500 spending money.

10 First Prizes

Nikon F3 Camera with 50mm F1.8 Nikkor Lens. 35mm Camera features automatic exposure control, compact and light design with built-in body grip. Uses Nikon Bayonette Mounting system which assures fast and accurate mounting.

50 Second Prizes

Nimslo 3-Dimensional Camera Outfit. Fully automatic, uses popular brands of 35mm color print film. View finder and information display. Small compact styling and light-weight construction.

100 Third Prizes

Vivitar Instant Slide Printer. Makes Polaroid Instant 3¼" x 4¼" print from any 35mm slide. It features automatic exposure control, a variable composition selector and a built-in electronic flash.

How to Enter

Use the coupon on this page or see your participating liquor store for an entry blank. Take a picture of the scene you think whispers J&B, and send it in. Be sure to follow the rules below. Incomplete entries will be invalid.

Official Rules— No Purchase Necessary

1. To enter, submit a black-and-white or color photograph (2¼" x 2¼" to 8" x 10") of a scene that you feel "whispers." Slides and transparencies are not accepted.
2. Handprint your name, address, and zip code on the official entry form or a plain piece of paper. Glue or tape it to the back of your photo entry. Do not write on photo. Include cardboard backing to protect picture in mail. Include with your entry the answer to the following question: What do the initials "J&B" on a bottle of J&B Rare Scotch stand for? Your entry will not be eligible for judging unless this question is answered. The information needed to answer this question may be found by looking at the label of any bottle of J&B Rare Scotch. You may obtain a free label facsimile by writing to: J&B Label, P.O. Box 3244, Syosset, NY 11775.
3. Enter as often as you wish, but each entry must be mailed separately to: J&B Third Annual "It whispers" Photo Contest, P.O. Box 3258, Syosset, NY 11775. Entries must be received by December 31, 1983. No responsibility is assumed for lost, misdirected or late mail.
4. Entries will be judged on the basis of originality (0 to 30 points), relevance to the theme (0 to 40 points), composition (0 to 20 points), photographic technique (0 to 10 points). Winners will be selected under the supervision of National Judging Institute, Inc., an independent judging organization whose decisions are final on all matters relating to this contest. All prizes will be awarded and winners notified by mail. Prizes are not transferable or exchangeable. Only one prize to an individual or family.
5. All entries become the property of The Paddington Corporation with all rights, including the right to edit, publish and use any photo without further consideration of payment to the contestant. No correspondence about entries will be entered into, nor will photos be acknowledged or returned.
6. Before receiving a prize, each entrant must warrant his age, that the photograph was taken by himself, that he is an amateur photographer, and that he has full rights to the photograph and that it has won no previous award or competition.
7. The contest is open to U.S. residents, except employees and their families of The Paddington Corporation, its affiliates, advertising and sales promotion agencies, liquor wholesalers and retailers, and professional photographers. Void where prohibited. All federal, state and local regulations apply. Taxes on prizes, if any, are the responsibility of the individual winners.
8. Entrants must be of legal drinking age in the state of their residence as of September 1, 1983. For a list of major winners, send a stamped, self-addressed envelope to: J&B Third Annual "It whispers" Photo Contest Winners, P.O. Box 3269, Syosset, NY 11775. Winners list will be available as of March 15, 1984.

Official Entry Form

Mail your completed entry & photograph to: J&B 3rd Annual "It Whispers" Photo Contest, P.O. Box 3258, Syosset, NY 11775

Name_____

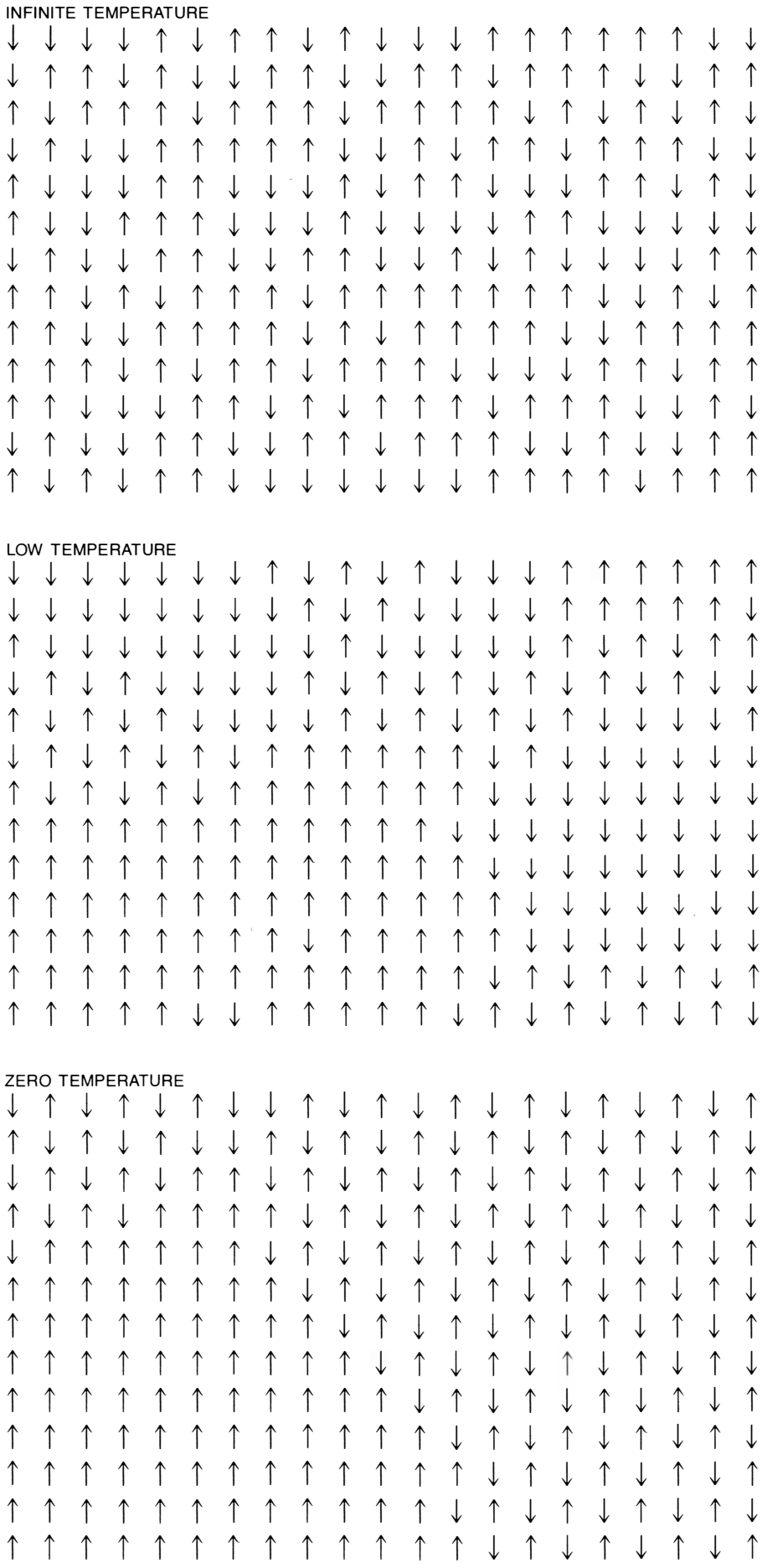
Address_____

City_____ State____ Zip_____

The initials on the label of a bottle of J&B Rare Scotch stand for: _____

Void where prohibited. No purchase necessary. SAM

86 Proof Blended Scotch Whisky. © 1983 The Paddington Corp., NY



A spreadsheet version of the two-dimensional Ising model of ferromagnetism

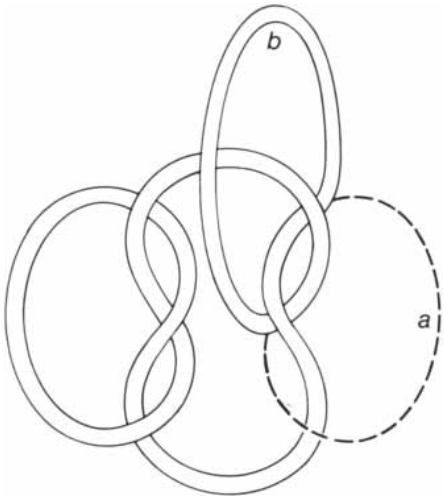
tion. At a temperature of absolute zero the antiferromagnetic phase seemed to be the stablest configuration, but this may reflect a deficiency or an error in my implementation of the model.

Other physical systems can also be conveniently dealt with on a rectilinear lattice. One phenomenon that interests me is percolation, which describes not only the brewing of coffee but also the structure of some polymers, the conductivity of alloys, the efficiency of telephone networks and the propagation of forest fires and infectious diseases. In one simple percolation model the cells of a lattice might represent possible sites of copper atoms in an insulating matrix. As a first approximation, the probability that a site is occupied is proportional to the bulk concentration of copper. The quantity of interest is the probability of forming an unbroken chain of copper atoms across some domain of the lattice; it is this probability that determines the conductivity of the material.

A percolation model in a spreadsheet again demands some form of random function. The easiest approach employs a uniform cellular space, where all the sites have the same probability of being occupied, and they are all independent of one another. The result is a random array of filled and vacant cells. It is then necessary to determine whether or not there is a continuous path across the space. A proper solution would be to mount a systematic search of each potential path, but it is not clear to me how that can be done without resorting to algorithmic methods. A cruder but still helpful technique is to thin out the underbrush by including in the formula for each cell a function that eliminates any atom with fewer than two neighbors. Because any atom that forms part of a chain must have at least two neighbors, the chain is not affected by this procedure, but many dead ends and isolated clusters wither away with each recalculation of the spreadsheet.

A spreadsheet program is surely not the ideal medium in which to represent any of these mathematical or physical models. For serious work each of them would have to be embodied in its own special-purpose program. In the case of the game of life I have compared various spreadsheet versions with a program (an algorithm!) written in the native language of a microprocessor. For arrays of the same size the machine-language program is almost 100 times faster than the fastest spreadsheet. The reason is not hard to find: even though a cell can never have a value other than 0 or 1, the spreadsheet program calculates the value to 15 decimal places.

If the spreadsheet cannot claim efficiency, however, it has the compensating virtue of versatility. Writing a machine-language program for playing the



Proof that a square knot is alternating

game of life is more than an evening's entertainment. Moreover, the program can do nothing else, whereas the simple matrix of linked cells in a spreadsheet constitutes a problem-solving device of impressive generality. There is much more, beyond the ideas sketched above, that is clearly within the capabilities of the programs. It appears that any series of numbers in which the terms are defined by algebraic or trigonometric functions can be generated. A prime-number sieve can be constructed out of one short formula, repeated some hundreds of times. A physical field can be represented by allowing the address of each cell to serve as its coordinates in two-dimensional space. As the sales brochure invariably says: "The only limit is your own imagination."

Is it true? Can a matrix of interdependent formulas without an algorithmic structure be made to compute anything that is computable? Is the mechanism not merely general but universal? In the case of an infinite matrix the question has been settled. Conway has proved that the cellular world of the game of life has sufficient resources for the construction of a Turing machine, the conceptual model of a universal computer. Since an infinite spreadsheet could be employed to play the game of life, it could also be employed to create the Turing machine.

Such a result is certainly worth knowing, but even if the requirement of infinite area could be relaxed, the demonstration would be of no practical significance. Life is too short, and the game of life too long. There is a less formal approach to measuring the scope of the spreadsheet programs that I find more promising. It is the hit-or-miss method of applying the programs to various problems and exercises from the stock of old favorites in computer science. The interesting test cases are likely to be the ones with a highly efficient algorithmic solution. One example is the Tower of Hanoi puzzle, in which several rings are stacked in order of decreasing size on one of three pegs; the aim is to move the rings one at a time, without ever allowing a larger ring to rest on a smaller one, until they are stacked in the same order on another peg. The standard solution employs a recursive algorithm, one that states the final stage in the procedure explicitly and then calls on itself to define the earlier stages.

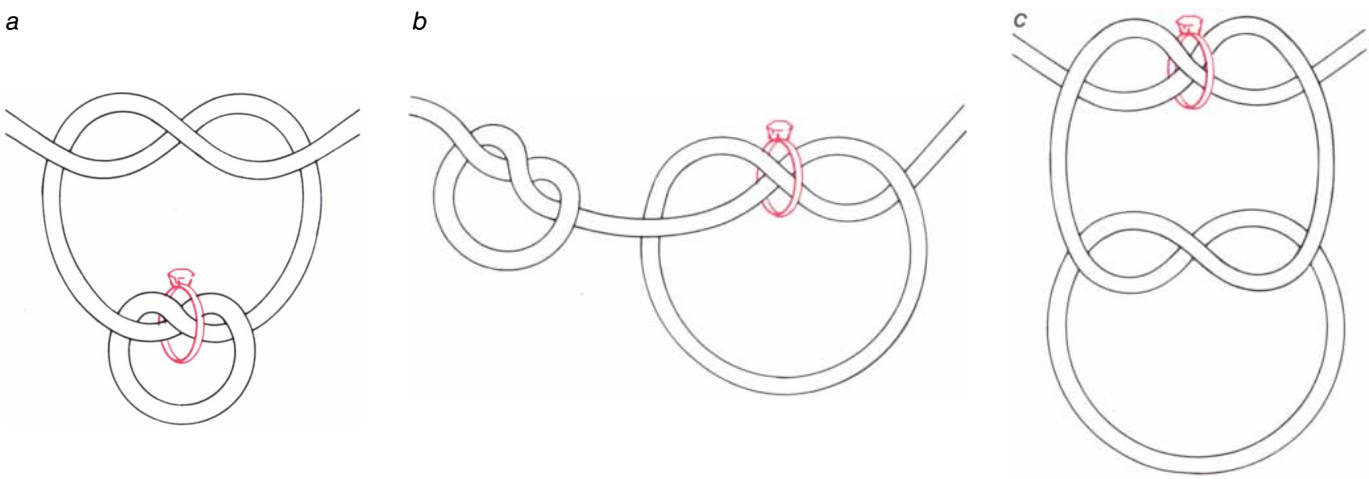
Can the Tower of Hanoi be solved by completely nonalgorithmic methods? Can it be done with a spreadsheet? Exhibiting such a solution would certainly not be a proof that a spreadsheet can do anything an algorithm can, but it would considerably enlarge the spreadsheet's range of action. Note that there is a trivial method of solution that must be declared out of bounds. One can solve the problem by hand, noting the configuration of the disks at each stage, and then write a series of formulas specifying the transitions from one configuration to the next. It is characteristic of such forced methods that with any slight change in the initial conditions, such as the addition of another disk, one must essentially start over. A robust solution would be able to handle any size stack without change or perhaps with a change only in the dimensions of an array. Note also that at least one spreadsheet program, Lotus 1–2–3, includes a simple algorithmic language; clearly all recourse to this facility must also be ruled out.

Another interesting case is the eight-queens problem, where the task is to place eight queens on a standard chessboard so that no queen is attacked by any other. Here the format of the problem—the finite array of squares—is tantalizing. There is certainly no difficulty representing a chessboard with a spreadsheet program. It is also easy to write a formula that reports whether a cell is currently attacked by a queen elsewhere on the board. (The formula merely checks for a nonzero value along all columns, rows and diagonals for a distance of eight cells.) If this were all one needed to solve the problem, however, it would not have attracted the attention of Carl Friedrich Gauss, who investigated it in 1850 but did not solve it. It seems each cell needs information not only on the current configuration of the board but also on the record of configurations that have already been tried. The difficulty of supplying this information in a static representation of the problem suggests that algorithms have a secure future.

The two knot problems posed last month by Martin Gardner are answered as follows:

The top illustration on this page shows how a square knot can be changed to an alternating knot of six crossings. Simply flip dotted arc *a* over to make arc *b*.

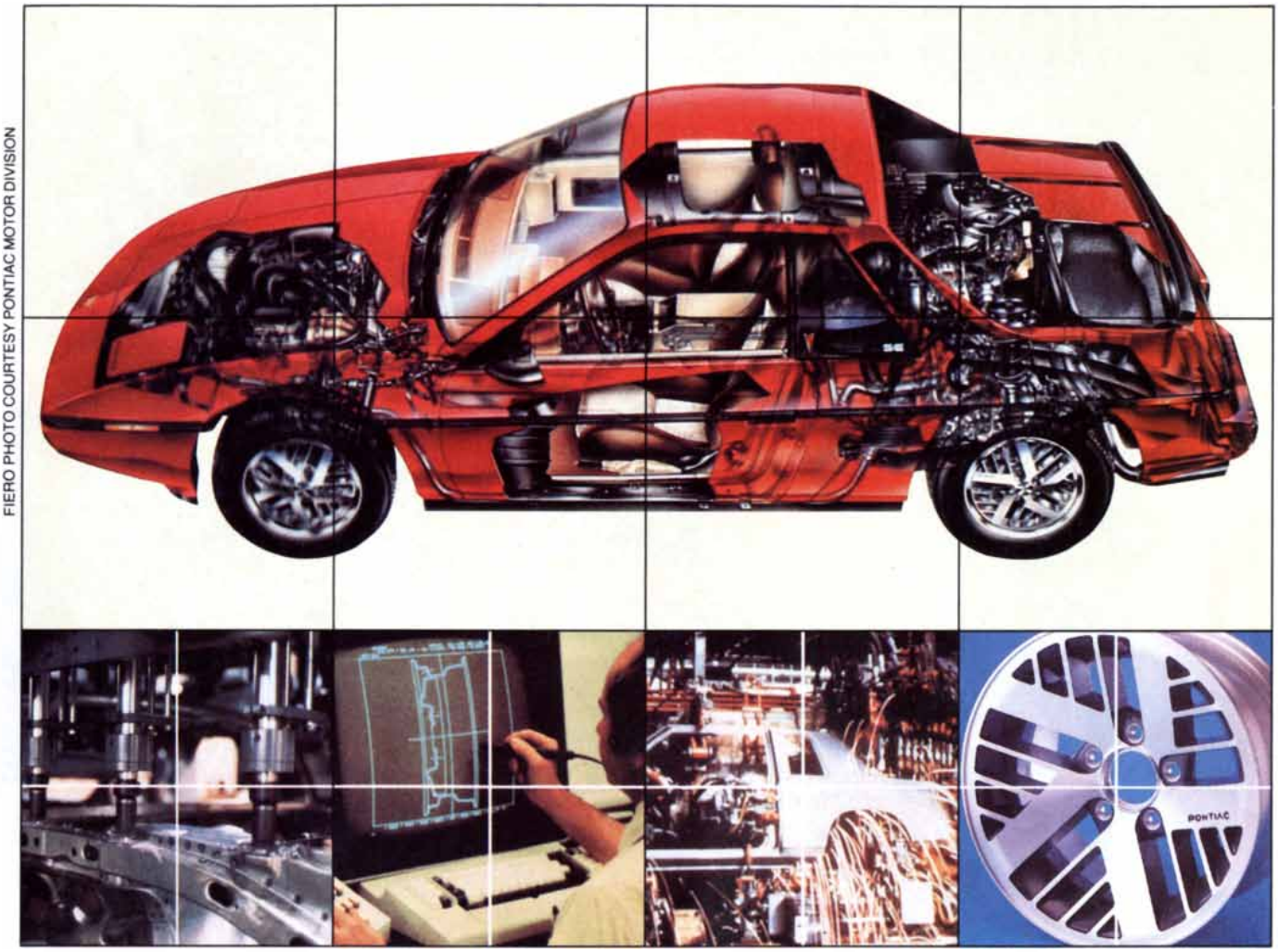
The illustration below shows one way to solve the ring-and-granny-knot puzzle. First make the lower knot small, then slide it (carrying the ring with it) up and through the higher knot (*a*). Open it. Two trefoil knots are now side by side (*b*). Make the ringless knot small, then slide it through and down the other knot. Open it up and you have finished (*c*).



Solution to the ring-and-granny-knot puzzle

PARTNERS IN QUALITY

DETROIT AND ITS AMERICAN SUPPLIERS

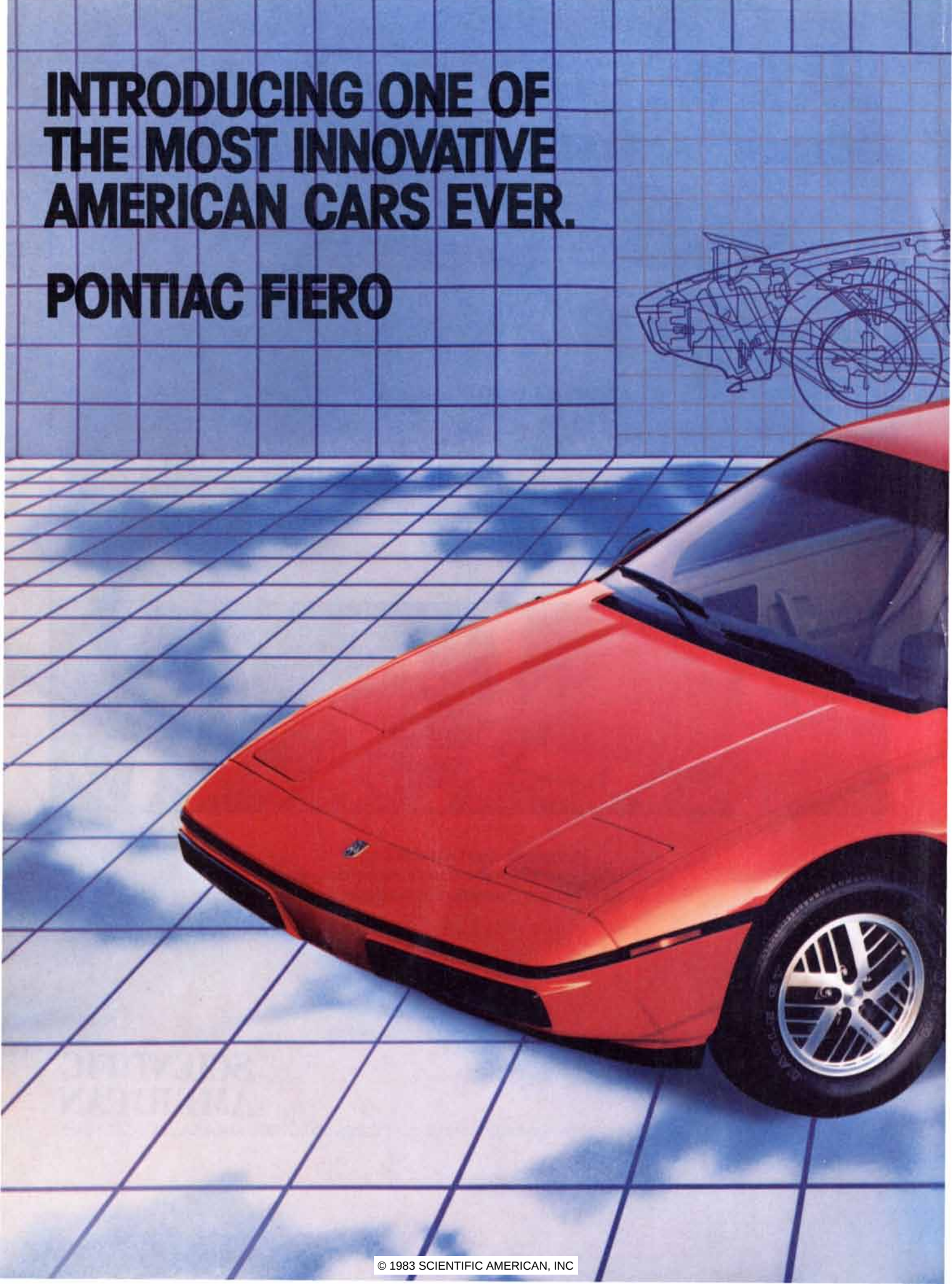


FIERO PHOTO COURTESY PONTIAC MOTOR DIVISION

This special report was prepared by
Jim Plegue of *Automotive News* in association with
Development Counsellors International, Ltd.

SCIENTIFIC AMERICAN

ADVANCED TECHNOLOGY CENTERS USA ADVERTISING SUPPLEMENT/SCIENTIFIC AMERICAN/OCTOBER 1983



Fiero can be described as an economy* car. It can also be considered a practical and durable car. And, by its technical specifications alone, Fiero can be legitimately called a sports car. The beauty of Fiero is that it's all of these cars. Best of all, Fiero is one of Pontiac's best examples of what driving is all about: pure unabridged fun!

Fiero is America's first two-seat, mid-engined production car. Fiero features fully-independent suspension, rack and pinion steering and power four-wheel disc brakes, all standard. Fiero is powered by a responsive 2.5 liter 4-cylinder engine with electronic fuel injection.

Fiero is designed to cope with the realities of driving in the real world: Its Enduraflex™ panels will never rust, the front fenders "give" on minor impacts, all panels are "ding" resistant, and Fiero's clearcoat paint wears a gloss that rivals the world's most pampered show cars.

Fiero! Not only a proud new American car unlike anything else in the world, but a dazzling display of Pontiac innovation in action!

*Pontiac Fiero Sport Coupe with available automatic transmission offers an EPA EST MPG of 27 and a highway estimate of 40. Use estimated MPG for comparisons. Your mileage may differ depending on speed, distance, weather. Actual highway mileage lower. Some Pontiacs re equipped with engines produced by other GM divisions, subsidiaries or affiliated companies worldwide. See your Pontiac dealer for details.

GM

PONTIAC WE BUILD EXCITEMENT

Detroit is a mechanism for the manufacture of automobiles. In the early Seventies the mechanism worked smoothly in an environment of low energy costs, modest government regulation and relatively low labor costs. It made products which American car buyers believed of great value—greater than anything produced by a mechanism operating from abroad.

Then the environment changed, and the mechanism ran rough. Suddenly OPEC upped the cost of crude oil by what would become a factor of five. The United Auto Workers obtained greater wage-benefit increases just as sales and profits peaked. The Federal government added minimum Corporate Average Fuel Economy regulations to its safety and pollution-control standards. And Japan, Inc. introduced a line of low-cost, high mileage autos, products of a "mechanism" that had been revolutionizing itself even as Detroit's mechanism was showing signs of strain.

But Detroit—the auto manufacturers, suppliers, workers, and support infrastructure in finance, insurance, state government—is a rugged and resourceful super-industry, willing and able to do what it saw must be done. Detroit was determined to become America's leading advanced-technology industry. The new environment required it: cars had to be made to emission-control, safety, and fuel-efficiency standards largely set by outsiders. These changes would, in effect, "retool" the nation.

Detroit's network of suppliers, and suppliers-to-suppliers, reaches throughout the continent, with assembly plants in Kentucky and California, glass, rubber, and steel makers in Pennsylvania and New Hampshire, chemical resources in Connecticut and Delaware, all developing, manufacturing, transporting and installing some portion of a vehicle. New ideas from Michigan would, and must, require reindustrialization in hundreds of cities. The automakers planned and decided. The turnaround began almost at once.

IN SEARCH OF QUALITY

The original Detroit mechanism was based on the assembly-line: many cars were made at a minimum cost-per-car. Quality was external—not absent, but not integral to the mechanism. Thus, in the late Seventies the mechanism began producing vehicles similar to Japanese models, and at similar cost, but of inferior quality. Every calculation showed that increasing quality to acceptable levels would increase costs to unacceptable levels. The mechanism wasn't working, and no one was repairing it.

Then, in 1980, an NBC-TV documentary entitled "If Japan Can ... Why Can't We?" was seen by William Hoglund, general manager of GM's Pontiac Motor Division, and some of his key associates. The program, and the processes it suggested, had substantial impact at Ford and Chrysler as well as GM. It displayed nothing which hadn't already been put forward regarding integration of productivity and quality. But its timing, and its audience, were just right.

Ironically, the Japanese mechanism was working well due to the work of an American, Dr. W. Edwards Deming, who had established a reputation in this country for his work in statistical sampling. He had been asked by a Japanese science group to address them on the subject of application of his methods to certain Japanese quality-control problems. According to Deming, achieving higher quality would improve productivity by reducing rework and defect-replacement. The Japanese adopted several Deming concepts, and Deming came very much to the notice of management in Detroit. Deming was hired as a consultant to Pontiac, to Ford, and to other industry producers and suppliers. As Pontiac general manager Hoglund said in *Fortune,* "His message shook the foundations of our approach to quality." John Manugian, executive director of product assurance at Ford/North America, met with Deming often, and Ford's production lines reflect many of the Deming methods.

THE DEMING METHOD: QUALITY TECHNOLOGY

At Pontiac, Deming detailed his 14-point special program for the virtual reconstruction of American car manufacture:

1) Create constancy of purpose toward improvement of product and service, with a plan to become competitive and to stay in business. Decide whom top management is responsible to.

2) Adopt the new philosophy. We can no longer live with commonly accepted levels of delays, mistakes, defective materials and workmanship.

3) Require statistical evidence that quality is built-in. Eliminate need for mass inspection.

4) End the practice of awarding business solely on the basis of price. Eliminate suppliers that cannot qualify with statistical evidence.

5) Find problems. Management must work continually on the system (design, incoming materials, machinery).

6) Institute modern on-the-job training.

7) Institute modern worker supervision. The responsibility of foremen must be *quality.* Improvement of quality will automatically improve productivity. Management must act on reports from foremen concerning barriers such as inherited defects or machinery not maintained.

8) Drive out fear, so that all may work effectively.

9) Break down barriers between departments. People in research, design, sales and production must work as a team.

10) Eliminate numerical goals and slogans for the work force, which demand new levels of productivity without providing new methods.

11) Eliminate numerical quotas.

12) Remove barriers between the hourly worker and his pride of workmanship.

13) Institute education and retraining.

14) Create a top management structure which will push every day on the first thirteen points.

For many in Detroit, the thought of implementing the Deming principles came as a shock. They were too much against the grain of "business as usual." Said Clayton Williams, manufacturing superintendent at Pontiac's Engine Plant No. 18, "At first, I didn't know what to think because the things he was saying like, 'Don't accept any defects,' were so radical compared with the way we had been running the plant. We lived with defects every day. To me it was something we couldn't do. But after being to seminars and sessions where he would speak, after the third or fourth time it occurred to me that what he was saying was attainable and could be done.

"I really believe and support those 14 points 100 percent. They work."

Several of Deming's points concern implementation of Statistical Process Controls (SPC). These work as follows: at each "process" of production, samples are measured for variation within each batch of parts, and then each batch is measured against design specifications. If samples are within predefined tolerances, production continues. If not, the production line stops, and the cause is determined.

Utilizing SPC to define acceptable

quality at each individual process in the production path allows any problem to be rectified quickly. Ideally, it does so all the way through the supplier chain, because if SPC is to work, it must monitor the course from raw material to the finished part.

In the plant itself, SPC has yielded good results. Pontiac manufacturing superintendent Williams cited an example of a worker charged with boring holes in engine camshaft gears. Improper work—and tolerance here is just a few thousandths of a centimeter—means the gear will be loose on the camshaft; the engine will be destroyed in use.

Before the implementation of statistical process controls, explains Williams, "the employee would come to work, turn on his machine and check one part. If it was within spec, he'd turn the machine on and let it run for, say, two or three hours. If the part wasn't within print specification, he'd make an adjustment to the machine and run one more part. If that was okay he'd let the machine run for the rest of his shift."

Under SPC, the same worker would check three camshaft gears per hour, instead of one per shift. And if any one of those gears was outside tolerance levels, he was required to adjust the machine and check three more until the machine would properly produce three.

"SPC showed the employee that he would unknowingly have been making bad parts," says Williams, "because the first part was good, but the second and third were off spec. The three-piece check gives us a confidence level of, say, 95 to 99 percent that all parts measured within that hour are good."

In its first full year of implementation, SPC reduced the number of engines found defective due to cam-gear problems from 38 to six. Through the first half of the 1983 model year the number of failures was *zero.* Pontiac was succeeding: process by process, part by part, high quality was becoming not a goal but a reality.

The evidence mounted. Material Complaint Notices (MCNs)—complaints by Pontiac inspectors against suppliers shipping defective parts—showed an overall 15.8% defect rate for the 1982 model year. Through the first half of the '83 year, the identified rate was just 1.6%. Meanwhile, as defects dwindled, productivity skyrocketed—just as Deming had predicted. Says Pontiac's Williams, "Total productivity improvement averaged 25.6 percent in the 1982 model year. We expect another thirteen percent this year and another seven percent in 1984. If you add it, you're talking about a fifty percent improvement within a span of two to three years." A Ford Motor Company spokesman documented similar defect-rate improvement.

PARTNERSHIP FOR QUALITY

Improvements are attributable to more than SPC alone. Pontiac has implemented a series of new practices based on Deming's ideas, several aimed at improving the supplier/manufacturer relationship. Pontiac and other manufacturers have worked to create what Pontiac calls "an up-front partnership" with all of its key suppliers, based on a spirit of teamwork and cooperation.

Early sourcing, or "pre-sourcing", is one new practice. "Early sourcing" means a supplier is selected before a part has been committed to anything but a preliminary sketch, usually based on a computer-assisted design. High quality, not cost, is the primary criterion. Inputs from all affected staff areas help buyers make informed decisions. Early sourcing also allows the suppliers' R&D people to become involved in the design of a part to ensure that it is compatible with manufacturing processes.

Sourcing families of parts improves quality and streamlines contacts with suppliers. For example, headlamp doors and hood for Pontiac's new 2-seat mid-engine sports car were sourced with a single supplier because the "fit" of these parts is critical. It was thought that a single supplier could better control a group of close-fitting body panels for Fiero than a number of suppliers working independently. For the same reason, several body panels and covers, fenders, and doors were sourced together.

Single sourcing is just what it implies: selection of a single source to supply total production of a part. Historically, manufacturers selected several sources to keep costs low through competition, and through fear of over-dependence on one company. Deming allayed the latter concern with an analogy: two symphony orchestras play the same piece of music with equal fidelity to the notes on the page, but the performances differ because sheet music dictates only so much. Neither orchestra plays the music incorrectly, but results will be different all the same. An engineering "blueprint" is an automotive supplier's sheet music: give two suppliers identical blueprints and chances are that without either supplier deviating from specifications, the parts will be subtly different. As Pontiac director of materials management Donald Pais explained, "Once you develop a source who can meet your quality expectations, what would be the driving reason to go to a second source and duplicate the same effort on the same part?"

At the outset of the Fiero program, top Pontiac management met with top management from key suppliers under an *early contact* procedure. This let suppliers know in advance what would be expected of them. In these early meetings, Pontiac managers stressed the importance of quality in the finished car and its individual parts, and presented an overview of engineering design, manufacturing processes and expectations for service, quality, and delivery.

Pontiac then implemented "one-on-one" meetings between suppliers and buyers, including design and reliability engineers. Discussions of such concerns as identification of critical tolerances were aided by the greater specificity of the Deming methods. If close tolerances were unnecessary, every job became easier. Fred Seng, Pontiac's manager of supplier quality activities on the Fiero project, observed, "We found out—it amazed us—that we were actually asking our suppliers to make parts to certain tolerances that really weren't required. A hood that is, say, a mil and three-quarters wider than what the engineer originally designed really does make a good-looking car. We really don't have to sort that out, inspect for it and throw it away. The drawing says it's not quality because it's oversize, but the car says it's a quality part, and that's really the Bible. The car and its function and its looks really has to be the Bible." To date, nearly 100 "one-on-one" meetings have occurred.

A third stage of Pontiac's effort to improve the supplier-manufacturer partnership included the Fiero Supplier Seminar held in November 1982. 250 suppliers heard management and union officials stress quality and teamwork. At the Seminar, Fiero suppliers saw how their respective parts were assembled on a finished model. And in a developing fourth stage of its "partnership" program, Pontiac seeks to establish daily contact among purchasing agent, assembly plant, and supplier, including regular meetings and tours of facilities.

Comments materials management director Pais, "Typically the process had been to have a single part come in

from a supplier. It was laid out, given dimensional checks—and approval.

"We've changed, in that the product development team stays right with the source on a given part number, right through every design change. It's a different type of approval process, a very significant departure from the way we did business."

The new partnership between Detroit and its suppliers is wide-ranging. At Ford, for example, classes are regularly held for suppliers having difficulty with statistical process controls. "We try to bring them back up to speed," says Jim Olson, a manager in Ford's Detroit region. "We're reluctant to drop a supplier that falls below the mark until we've had a chance to work with him."

Elio P. Lori is plant operations manager for Ford's Engine Division. He cites a personal example: "Best efforts—trying hard—doesn't do it. We had to drop one supplier for consistent poor quality. He then installed SPC and convinced us he had relearned his company's process better than he ever knew it before, and we took him back."

Cost-savings have come about through adoption of Japanese "kanban" or *just in time* (JIT) inventory controls. This process streamlines production by reducing inventories from boxcar quantities to minimum quantities necessary to maintain assembly schedules. Donald Abelson, Pontiac's general superintendent-manufacturing engineering, describes the effect of JIT: "We took several major commodities—engines and sheet metal parts from our plants—and we have them delivered on a daily basis. Some suppliers like Lear Siegler (maker of Fiero seats) will be delivering three times a day. JIT translates into less 'bank' here at the plant, less inventory, which also says that you're going to turn over materials faster."

Traditionally, a supplier would manufacture and ship several months' worth of parts in advance. If a running change were made to the design of a part (as is common), the revised part could not be incorporated until after the existing supply of now-obsolete parts was exhausted. Today, daily shipments by suppliers means that a design change made on Tuesday might be in the car by the weekend.

COST OF QUALITY

Those at Pontiac involved with pricing have confidence that SPC and other Deming principles are working as planned. As Pontiac's Seng explains, "What you've really got to understand is that the cost of quality really is the expense of doing things wrong. If you consider all facets of part/supplier/product development under this team approach, you're going to save money because you're going to avoid making mistakes—and the mistakes are where your money goes."

Tom Charlton is primary purchasing agent for the Fiero program. About seventy percent of Fiero parts (on a cost basis) are being pre- and single-sourced, and it's Charlton's job to work with suppliers to achieve acceptable cost levels without undermining quality goals. Has his job become more difficult?

"Much more so," Charlton states. "In all areas. Because you're spending more time negotiating with suppliers over price and engineering changes. But we still feel it's the right way to do things. We've got to get away from price-buying, where you're always buying from the low bidder, because you're not necessarily getting your best value."

The actual cost per part, from the supplier to the manufacturer, may be higher under the new program than it would have been under older, cost-based methods. But such costs are offset by the superior quality of parts coming in and lower defect and scrap rates, not to mention Deming's all-important "less rework." Pontiac staff reliability engineer Donald Delaney predicts that after six months of operation, just the reduction in scrap rates may actually prompt cost decreases.

THE SUPPLY SIDE

Like a few other suppliers, U.S. Steel has been applying statistical process controls to its manufacturing operations for a few years. Bill Hughes, general manager of sheet products for the nation's largest steelmaker, says "We've definitely seen a change, a new openness between ourselves and Detroit. We are now given access to information that the auto companies considered much too confidential to release just a few years ago.

"That openness has allowed our own statistical process controls system, which was instituted in a very long, painstaking operation, to bring results. We're now enjoying some of the fruits of our investment."

Hughes points out that elements of the Deming method must be applied with care. "JIT is an example," he says. "If all it does is switch large quantities of material from a Detroit plant to a supplier warehouse, nothing's gained and the consumer pays. But an efficient flow of materials, accomplished through accurate forecasting and accurate scheduling, reduces costs. And that's when everybody truly wins."

Libbey-Owens-Ford is sole supplier of laminated and tempered glass for Fiero and is a major glass supplier for all of GM. Tom Walbridge, vice president of automotive OEM (original equipment manufacture), describes the L-O-F relationship: "On Fiero, we worked long in advance to help design the glass parts. In any car design you've got to work as much as four years ahead with the manufacturer's engineering staff, to ensure high optical quality.

"Statistical process controls aren't new," Walbridge adds. "We've all been using them more or less for a number of years. But SPC is being used more by *this* company, on *this* car, than it ever has been before."

For the future, Walbridge says, "We're getting into closer working relationships aimed at minimizing inventory on our customer's floor, and even more formalized programs of applied statistical process controls."

Dana Corporation utilizes an innovative approach to inventory-handling management. Don Decker, public relations director, explains: "We've built a network of small "satellite" assembly centers, all near vehicle manufacturing facilities. This is Dana's version of *kanban* . . . we're able to supply customer plants within 24 hours." Dana's own suppliers have begun using documentation of statistical process controls in lieu of inspections of incoming parts, and Dana provides such data to its customers—Caterpillar Tractor, for one—making receiving inspections unnecessary. Dana's people take pride in the recognition they've earned (including Ford's "Q1" supplier-quality award) as a result of their work.

"I like to think we were quality-conscious long before it became the thing to be," concludes Decker. "But we've put even more emphasis on it in the last couple of years."

Firestone's Tom Reese, vice president in charge of original equipment sales, says the firm is using statistical process controls in cooperation with auto manufacturers every day. Firestone is principal supplier of Fiero all-season radial tires, which it will deliver on a *kanban* schedule. "We're on the leading edge as far as just-in-time delivery goes," Reese notes, adding

Mobay technology auto•mated for the '80s

Interior

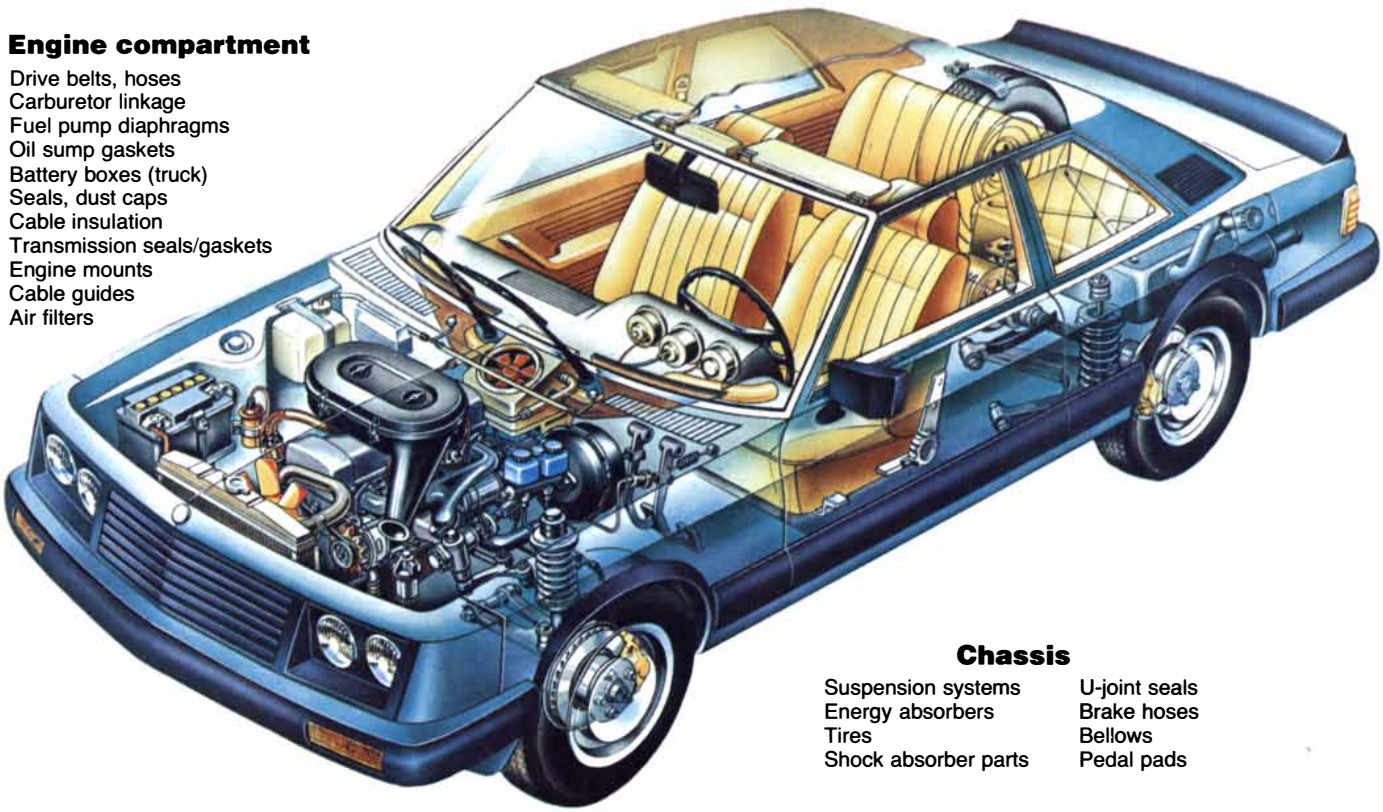
Header panels
Door panels
Seat buckle covers
Visors
Mirror parts
Instrument panels
Electrical parts
Seating
Fabric fibers
Dyes and pigments
Carpet backing
Arm rests
Headliners
Insulation
Crash pads
Head rests

Exterior

Headlamp retainers
Light lenses/reflectors
Fender extensions
Glazing parts
Grille panels
Bumpers
Body trim
Weather stripping
Fenders
Trunk lids
Chip-resistant coatings
Front/rear fascias
Spoilers, flares
Door striker sleeves
Filler panels
Cast wheels
Windshield adhesive
Hoods
Energy management systems

Engine compartment

Drive belts, hoses
Carburetor linkage
Fuel pump diaphragms
Oil sump gaskets
Battery boxes (truck)
Seals, dust caps
Cable insulation
Transmission seals/gaskets
Engine mounts
Cable guides
Air filters



Chassis

Suspension systems
Energy absorbers
Tires
Shock absorber parts
U-joint seals
Brake hoses
Bellows
Pedal pads

These are typical application areas for materials and technology from Mobay divisions*

A new kind of auto is evolving in Detroit's design centers, and Mobay is in the midst of its development. Mobay products contribute to the lighter weight, improved fuel efficiency, easier riding characteristics, better handling and comfort that are the hallmarks of today's automobiles. If you'd like to know more about the technology that has helped to make these improvements possible, please get in touch with G. W. Haines; Bill coordinates Mobay's activities in the automotive field. Phone 412-777-2407, or write.

*Some of the above applications are based on research developments by our parent company in Germany.

Technical Partner to American Industry

MOBAY

Mobay Chemical Corporation
Pittsburgh, PA 15205

Rockwell International know-how: It goes into components used by every major car and truck manufacturer. It's in everything we do.

Every major U.S. manufacturer of passenger cars and trucks relies on the technically advanced, cost-effective components of Rockwell International—everything from axles, brakes and drivelines for heavy-duty trucks to coil springs and sunroofs for passenger cars.

Only a company with the know-how to combine technology with outstanding engineering and management skills can successfully meet the unprecedented challenges of the increasingly competitive

world automotive market. That know-how goes into our automotive business and into everything we do at Rockwell.

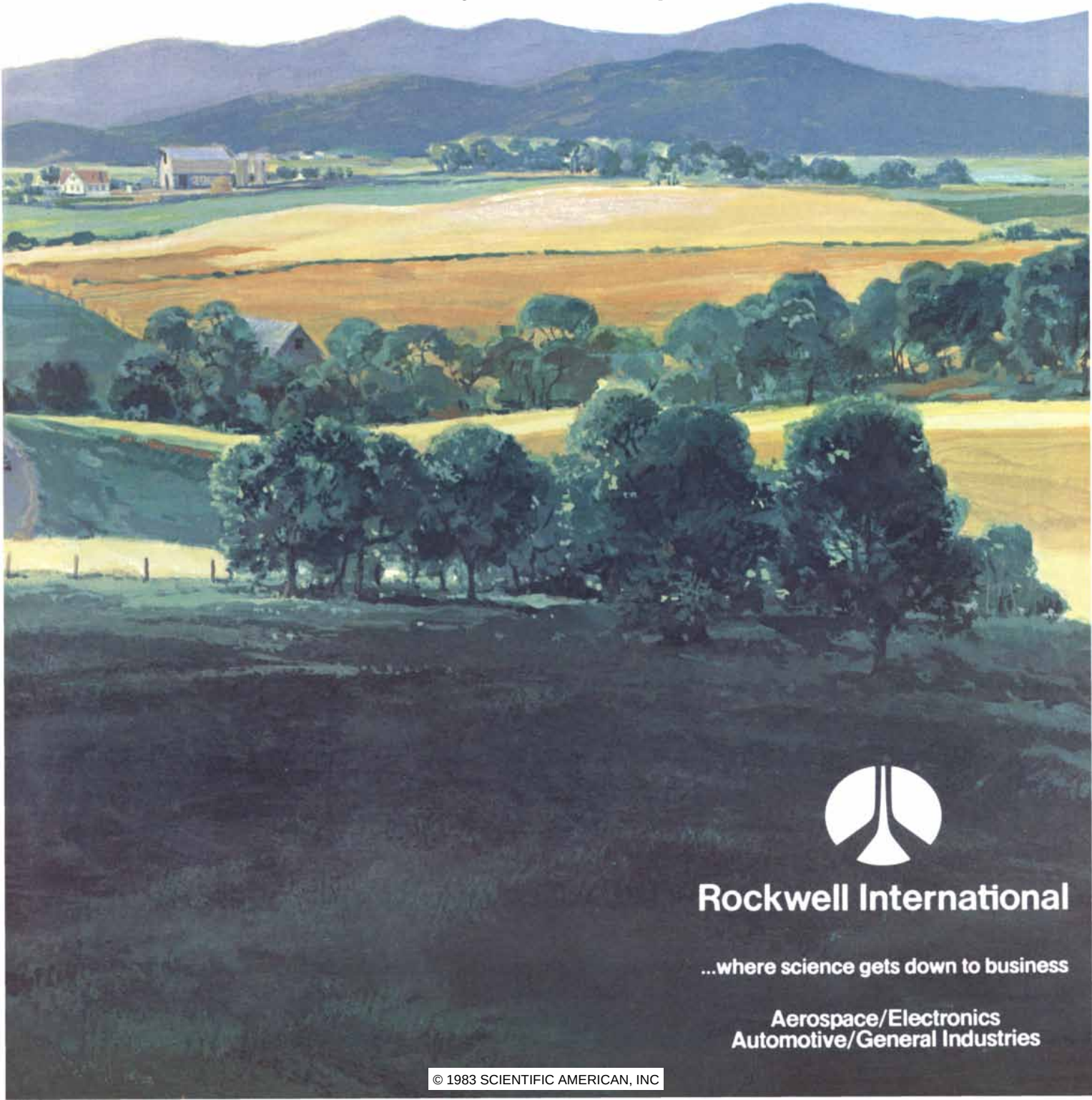
In aerospace: where we are building the NAVSTAR satellites and are helping develop precision navigation receivers for the Department of Defense's Global Positioning System.

In electronics: where we are a major supplier of digital and analog microwave systems to the telecommunications industry. In our semi-conductor business, we are the world's largest supplier of high-speed integral modems that transmit digital information over telephone lines.

In general industries: where we're using electronics and computer-based controls to improve the performance of basic industrial machinery such as drill presses, air-tools and sewing machines to ensure high quality and improved productivity for the woodworking, automotive assembly and apparel industries.

We're a $7.4 billion company where science gets down to business in four diverse areas. And that diversity has helped us achieve seven consecutive years of record earnings and impressive growth.

If you are interested in any of the products of Rockwell International or want to learn more about us, write: Rockwell International, Department 815S-28, 600 Grant Street, Pittsburgh, Pennsylvania 15219.



Rockwell International

...where science gets down to business

Aerospace/Electronics
Automotive/General Industries

BIRTH OF A FIERO

When Pontiac product planners went before General Motors corporate decision-makers in the fall of 1978, they had an idea and a market in mind. Market research showed that, by 1990, a third of the nation would be between 25 and 44 years of age. It was thought to create a small, highly fuel-efficient, highly styled two-seat "commuter" car just for them. (The Detroit system requires corporate approval of a new car project undertaken by an individual automotive division.)

Such a car, the original proposal stated, should appeal to two key groups: single young professionals in search of economical but "sporty" transportation, and smaller families seeking a thrifty, "sporty" complement to the traditional family sedan or wagon. Moreover, the car might be built by using some derivatives of existing components, thus saving millions in tooling and development costs. Recalls Hulki Aldikacti, father of Fiero (and now working on a similar project at Chevrolet), "... the Corporation didn't say 'No.' They listened to us, and said 'Why don't you go ahead and start designing one.' "

To the design staff this was a rare opportunity: they'd be drawing on a clean sheet of paper. There was no pre-existing corporate definition of "two-seat sporty economical car." Existing components would, and should, be applied in certain areas. Overall, though, the designers felt they had a license to create.

An early design choice for the new product was the "space-frame chassis." The *chassis* is any automobile's support structure, to which all else is attached. "Space-frame" refers to a fully integrated structure, akin to that of a model airplane with its network of triangulated struts and tubing, over which a lightweight skin is draped. Fiero's current manager of engineering Ron Rogers elaborates: "The space-frame is not new to automobiles, since most if not all NASCAR Grand National stock racing cars are built with them. But the space-frame is new from a production point of view."

On the Fiero assembly line, every completed space-frame is placed in a huge robot which machines simultaneously every point where body-parts will be mounted. This process has two specific benefits. First, the robot's "milling and drilling" allows almost no variance from car to car, and completed frames are well within specifications and very high in production quality. Second, the robot-machining takes place after all welding procedures are complete; this allows the space-frame to retain its integrity and quality. Says Fiero assistant project manager Tom Kalush, "Formerly in car-body building you would assemble stampings, weld two of them together into subassemblies, and then weld the subassemblies together to produce the whole. Variations were not unusual. Machining a space-frame has never been done before, and that really breaks through a barrier in body-building." Adds Rogers, "The old way we had tolerances of plus-or-minus four mils (a mil is one-thousandth of an inch). Now we're machining to plus-or-minus one-half mil. That's the magnitude of improvement."

After completion the space-frame is automatically dipped into a bath of corrosion-resistant primer paint. Almost half the steel used in Fiero's space-frame is galvanized to retard rust. The added protection provided by the primer-bath, particularly since the frame will receive no further drilling or piercing, should result in a long-lasting, easily maintained automobile.

The initial idea of the Pontiac product planners, in 1978, has become an exciting, high-quality, high-technology product in 1983. Says Donald Abelson, Pontiac Motor Division general superintendent, "When the completed space-frame comes off the overhead conveyor belt on the assembly line, it has no exterior panels or glass or interior trim—but they can start that car and run it." At the end of May, Fiero was presented at the most heavily-attended meeting of the Society of Automotive Engineers in that organization's history. By the end of July, orders for 25,000 Fieros had been received from dealers—fully one-quarter of planned first-year production.

that Firestone has maintained a 24-hour-a-day delivery schedule for two years at one Ford assembly plant in Kentucky.

Reese says the "up-front relationship" between Firestone and Detroit has had many significant benefits, one being an early decision to minimize tire sizes and types, allowing Firestone longer manufacturing runs, fewer changeovers and less down-time between runs. "The relationship is excellent, because it really does work both ways."

Fiero's is not the first non-metal body designed and produced in an American automobile, as anyone knows who recalls the 1953 Chevy Corvette. But most high-volume applications in Detroit tend to follow from earlier, more specialized applications. Now the Corvette may again be a precursor of a major production innovation: its 1984-model suspension and drive train, and many other parts, are engineered largely from aluminum and magnesium. The automobile is 200 pounds lighter, and thus more fuel-efficient, than its 1982 counterpart.

The Corvette represents manufacturer/supplier partnerships typical of the "new Detroit." After four years of R&D by Alcoa under Chevrolet's direction, strong, lightweight aluminum parts are fabricated by Martin Marietta, Dana, and several smaller corporations in Michigan, Ohio, Ontario. Supplier interest and cooperation thus merged with intensive new high-technology computer modeling and testing systems to allow a new process to begin. High performance and high quality have been attained with increased fuel-efficiency for the American consumer in the bargain.

The State of Michigan has been a major partner to the technological resurgence of Detroit's auto industry; the State, and its people, have benefited directly from Deming technology. Richard Cole, deputy director of marketing and public affairs at Michigan Department of Commerce, explains: "David Verway, the renowned automotive economist at Wayne State University here, predicts that just-in-time (JIT) inventory controls will increase supplier-related economic development activity throughout the State. Plus, by making training programs available and guaranteeing the excellent skilled work force which exists in Michigan, we were able to attract a major robotics equipment manufacturer to Sterling Heights, one which otherwise would have located elsewhere, perhaps overseas." Michigan has been particularly innovative in involving the State's educational system in the process of strengthening its economic base.

Martin D. Walker is executive vice president of Rockwell International Corporation, which adopted the Deming methods some time ago. "We use the term 'operator process controls' instead of 'statistical process controls,'" says Walker. "It may seem a small distinction, but in the final analysis the *operator* is the quality man, the guy who makes it go.

'The Deming methods surprised us. When we put them in, we quickly learned that our machines and processes were better than we thought they were. The more we taught our operators, the less we found ourselves adjusting our machines. We've tried to tell our own suppliers of the benefits of operator process controls. We tell them it doesn't cost — it *pays*.

"Operator process controls are important no matter what business you're in," Walker states. "We here at Rockwell, and the auto industry in general, believe in these methods. And you'll find that the automotive industry will soon be leading this country in terms of high-quality products."

Dave Denny is vice president/general manager of the EMS (transportation) Division of Premix, Inc., makers of Fiero's Enduraflex™ roof panel. Since their selection as a sole source, Premix engineers have worked closely with counterparts at Pontiac and Fisher Body Division to perfect the roof panel design. It is a process that Denny says has gone smoothly. "We've always wanted to have supplier input. I think it's terrific. I'm not sure I make any more money, but I prefer it. I like to know where I stand. I like to know my R&D dollars mean something."

Under the old system, Denny felt that sometimes quality suppliers were victimized by the low-bid process because they would spend money on research and design in order to build a quality part, then get undercut by a rival that spent less on quality. Denny also appreciates contracts for longer than the customary one-year term. "It's nice to know that, if I hold up my end, I'll still have the job several years down the road instead of having to bid on a year-to-year basis. It allows me to spend money and do the job right. I see a general trend in Detroit," Denny adds "I see a lot of emphasis on quality. And I believe it's real."

Jones & Laughlin Steel Corporation, a subsidiary of The LTV Corporation, manufactures many of the pieces that go into Fiero's all-steel space-frame. As at Premix, J&L engineers spent time with Pontiac engineers in materials development. Rich Cover, J&L's man-

The science of quality in steelmaking.

U.S. Steel initiated its breakthrough Quality Management Program (QMP) in 1979 to assure optimum quality products for quality-conscious customers. QMP has already made a dramatic difference—with much more to come on a continuing basis.

At U.S. Steel, we recognized years ago that higher and consistent quality was literally a matter of survival—for ourselves and for our customers as well. It was this recognition that prompted us to establish our pioneering Quality Management Program.

Managing for quality.

This long-range commitment to make quality U.S. Steel's number one priority started at the very top level of corporate management and spread to include all levels. This continuing undertaking assures that production decisions of management are made primarily on the basis of quality, rather than tonnage. This is what we, at U.S. Steel, mean by "managing for quality." The logic is that "it pays to make it right the first time."

Technology for quality.

In order to assure that decisions for quality are sound workable business decisions, we began to educate our operating management in the new and exciting technologies for analyzing and controlling process variables—the "nuts and bolts" of the science of quality.

We are convinced that managing for quality and the technology for quality are necessary. Each is essential, but neither is sufficient in itself.

The technology for quality, as we see it, consists of seven key parts:

1. Develop in-process and finished product standards.

2. Identify critical major and minor process variables.

3. Control process variables to achieve desired levels of product conformance with reduced variability.

4. Develop systems to measure and report conformance to product standards.

5. Implement systems to measure and control processes to assure leadership quality.

6. Implement corrective actions.

7. Analyze performance and progress using cost of quality, product conformance and customer acceptance criteria as feedback.

Points 4 and 5 constitute the heart of the technology: statistical process control. But we believe that alone, they are not enough.

For example, producing quality products for the automotive industry requires advanced input in science and engineering. However, knowing what needs to be done and knowing how to do it are not sufficient. Consistent production of quality products requires an organized and continuing Quality Management Program approach. And ours is recognized by American industry as the most thorough and most successful in steelmaking.

QMP: how does it work?

Quality Management operates through working and steering teams. At USS Gary Works alone, we have 65 QMP working teams and eight division steering teams who select the working team personnel and priorities.

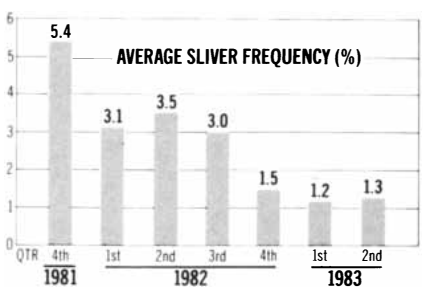
A typical working team consists of people from departments such as customer technical service, operating and maintenance, quality assurance, metallurgy, research, technical implementation, and, often, quality management consultants from outside U.S. Steel. Sometimes, the teams might also include marketing, accounting and industrial engineering personnel.

These multidisciplinary teams at Gary have played a major role in improving the surface quality and formability of steel sheet produced for the automotive industry. We have identified a number of critical product attributes which affect sheet steel performance. Included are chemical composition, surface texture and appearance and forming response. Here are but two examples of how our QMP at Gary has worked for our automotive customers.

Sliver imperfections decreased significantly.

Slivers are randomly occurring surface ruptures, discolored lines or streaks which are unacceptable on automotive body panels. During the fourth quarter of 1981, 5.4 percent of the sheet produced for exposed automotive applications contained sliver imperfections. A QMP working team was formed to attack this problem.

The team statistically analyzed steelmaking and continuous casting variables for possible correlation with sliver occurrence. In addition, our research laboratory personnel used scanning electron microscopy to examine a large number of samples so the sources of slivers could be identified. This work resulted in widespread process changes starting with the blast furnace and extending to steelmaking and continuous casting, hot rolling and cold finishing.



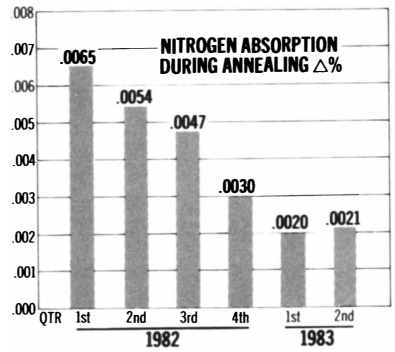
Reducing nitrogen absorption by two-thirds.

Early in 1982, a similar QMP working team was established to improve the formability of the automotive sheet produced at Gary Works. One of the goals was to reduce the amount of nitrogen absorption which occurs during annealing.

Cold rolled steel is annealed at elevated temperatures to develop the required level of ductility by recrystallizing the steel in a controlled manner. During annealing, nitrogen, which is a component of the protective atmosphere used to prevent oxidation, is absorbed by the steel sheet. Some nitrogen pickup can be tolerated, but at sufficiently high levels of absorption, free nitrogen will diffuse through the steel microstructure—leading to strain aging, which can adversely affect the formability of the steel sheet and the surface appearance of the formed part.

A significant challenge related to the task of the working team was to develop annealing practices which would reduce nitrogen absorption and still produce the desired recrystallized microstructure throughout steel sheet coils weighing an average of 25 tons. The work centered on two approaches.

One was to alter the protective atmosphere so there was less nitrogen absorption at the temperatures encountered during annealing. The other approach was to control the temperature gradients within the coils to minimize time and temperatures beyond those required.



These examples demonstrate how impressively effective our Quality Management Program can be. We are continuing to apply technology to further improve the quality of all our steel products. And we are relying heavily on statistical process control so that our customers can continue to benefit. We know, from several years of experience now, that assuring optimum quality is no "quick fix" or the simple adding of a few more hard-nosed inspectors. It is a full-time, all-out, long-range way of life. At U.S. Steel, it's here to stay and we think that's good for American industry.

United States Steel USS TRADEMARK

ager of auto industry development, talked about the advantages he saw in early sourcing. "Before the auto companies did all materials development on their own. The supplier wouldn't be involved until the actual order. There wasn't any time for the supplier to volunteer his know-how. Any problem at that point was a major crisis. Solving it was a fire-fighting exercise.

"We think we can be a better supplier if we can be involved early in the design program. GM cannot be expert in everything. They need the expertise of the companies that serve them."

Cover cites examples of how working together helped to avoid problems and reduce costs on Fiero, and is encouraged by evidence that more manufacturers are moving toward "up-front partnerships" with suppliers. Like Premix, J&L is heavily into process controls and, according to Cover, already seeing positive results.

When asked about a possible dark side to Detroit's bright new ideas, one supplier paused for a moment, then replied almost apologetically, "I can't think of a single disadvantage."

Alan Scuterud is sales manager of The Homer T. Bronson Company of Beacon Falls, Connecticut. "Detroit's statistical process controls systems have challenged us to upgrade our own quality processing," he says. "We make hinges for Detroit, but we make them for plenty of other companies—Xerox, for example. What we've learned from Detroit has helped us serve other customers better."

THE SUPPLIER'S SUPPLIER

Mobay Chemical Corp. of Pittsburgh supplies many of the chemicals used in the manufacture of Fiero urethane body panels. Worldwide, Mobay's parent company supplies chemicals to Japanese auto makers, second only to U.S. auto makers in their use of the so-called "friendly" plastic. Having compared notes informally with some of his counterparts abroad, Dave Ahlgren, Mobay's automotive marketing manager, Polyurethane Division, reported that, surprisingly, the "team" spirit shown by U.S. auto makers may be greater than that of the Japanese.

"They don't appear to have the same cooperation we have here—that's an opinion, not necessarily a fact. We have an extremely good, close relationship with our customers here."

Mobay is fully committed to SPC and other Deming principles, reports Ahlgren, and is pleased with the results.

"We've always thought of ourselves as a good supplier, but we're learning to use the methods even more than we have, which, in turn, I think is making us an even better supplier.

"For those companies willing to make the commitment, it's a real plus. Those who don't probably won't be around."

Sheller Globe Corporation's Iowa City Division is Pontiac's source for Fiero's interior console—its dashboard components. According to senior vice president Sid Jeffe, the teamwork approach has been an unqualified success. "The difference is day and night as it relates to manufacturing feasibility," he says. "We have improved productivity in cycle time and manufacturing time."

Jeffe relates experiences from the past in which manufacturers would send design prints where the designer just didn't understand fully the properties of the material. Such mistakes would result in a costly redesign.

Jeffe reports great success with the concept of the use of "quality circles," which allows everyone in the plant to get involved with problem-solving.

Like other companies, Sheller Globe has had some difficulty convincing its own suppliers to implement statistical controls. But Jeffe believes this, too, will change. "All we're telling our suppliers (about implementing SPC) is that it's a matter of survival. It's that simple. It's one of the major ways this country is going to regain its position of preeminence in world industry."

Cover photography courtesy: Pontiac Motor Division; Rockwell Int'l Corp.; Michigan Dept. Economic Dev.

PONTIAC'S NEW FIERO OVERSEAS

Fiero may create, for American automotive products, export markets which have not existed for years. U.S. auto makers (according to the International Trade Commission) sell about 450,000 cars annually in foreign markets. About 350,000 are sales to Canada, which has no local auto industry and which maintains an auto trade agreement with the U.S. Middle Eastern countries account for much of the balance; Japan, which sells more cars to the U.S. than any other nation, imported about 3500 American-made cars—an insignificant amount indeed given that Japanese consumers registered more than three million new cars last year alone.

The U.S. automotive industry's export performance has been affected most by the "red tape" of special regulations. Stiff import duties and tariffs, plus local-content laws which require a high percentage of locally-made parts in imported cars, have hurt American exports. Then, too, American cars are designed primarily for American roads, tastes and needs. A large option-laden car simply doesn't function on narrow Japanese roads, nor does it offer the fuel economy necessary in nations where motor fuel can be twice the U.S. retail price.

Although virtually all General Motors cars today are designed with export possibilities in mind, Pontiac Motor Division's Fiero probably comes closest to addressing the problems which have plagued U.S. exports in the past. Because of its unique design, Fiero offers unique opportunities. Division officials have not disclosed their plans, other than to say there will be no Fiero exports during the first year of production. They do state a likelihood that Fiero eventually will be a sales factor in foreign markets.

Most important, the Fiero space-frame design allows far greater flexibility to meet foreign-market wants. Says Ron Rogers, director of the Fiero project, "Because of Fiero's construction, if you think about the body panels and the way they're put on the car ... you could do other versions or styles for an export market much more easily than you could with a car of standard construction." When assembled, the Fiero's space-frame is a rolling chassis, a completely functional automobile in all respects except that it has no exterior. This method of construction allows Pontiac flexibility to build a radically different car simply by designing new panels to fit the existing chassis. Slight changes could even be made to the space frame itself to accommodate a new "skin." A car—or cars—with different character can easily be created for export; at the same time, modifications are possible to meet a nation's special regulations.

It is conceivable that Pontiac could export only Fiero's rolling chassis to an overseas manufacturer, perhaps an affiliate or international partner of GM. The final automobile could be assembled in the receiving country, using Pontiac-made body panels or panels supplied by a local manufacturer. In this fashion Pontiac/GM might satisfy requirements currently leading to import duties or local-content regulations.

Fiero may indeed open up a "whole new world" of business for Detroit.

BOOKS

Ecological energy, round cities, the goddess Inanna, Atlantic fishermen, the robot family

by Philip Morrison

ENERGY AT THE SURFACE OF THE EARTH: AN INTRODUCTION TO THE ENERGETICS OF ECOSYSTEMS, by David H. Miller. Academic Press ($54.50). It does not require the cunning devices of double entry to be quite sure that the account books of energy are in neat balance. That budget is scrupulously managed by a higher law. This comprehensive and interesting text is a study of the energy budget of living systems in the form best suited to dynamic life spread out under the sun: the chief currency we count is in fact power density, watts per square meter of ecosystem area. (The heat supplied by an ordinary electric blanket flows at a power density of about 30 watts per square meter.) The ecologist, however, is no auditor: it is not that he is trying to balance the books the better to compute the bottom line. The abstraction of energy balance serves him rather to analyze the variegated grasslands of Denmark or the bed of a dry lake in California; the interest lies not in the sum but in its terms, some familiar, some surprising, together presenting one unifying aspect of the diversity of life on the earth. There is even a chapter mainly on the city, "a fascinating artifact; even if it were inhabited by ants rather than human beings, it would still be a worthy object of study."

The rays of the sun are the most important input. The solar beam is a changing vector, affected by night shadow and cloud, by the march of day and season, by dust and molecular scattering. Expect an average of a couple of hundred watts per square meter over day and night during summer in the Temperate zones, and below that by an order of magnitude and more in a European or Canadian winter. The beam outside the atmosphere rises to about 1,400 watts per square meter, beyond any reality on the earth. Temperature is a key consequence of the net flow of energies. One basic threshold is the freezing point of water, at which temperature these rough surfaces emit about 300 watts per square meter; at the higher-temperature end an extensive sunlit surface of water cannot get hotter than the low 90's (on the Fahrenheit scale), limited by its evaporation.

But it is realistically rich detail, not simple numbers, that gives substance to this set of some two dozen chapters. They are firmly based on worldwide field measurements of what really happens, expressed with plenty of tables and formulas; the text is not easy and is somewhat given to jargon of the trade, but it is without difficult mathematics. If sunlight has important changes in time and direction, it also varies in photon energy and hence in its effects on ecosystems generally, on the eye and the green leaf in particular. The solar infrared serves only to heat and perhaps elongate plants: 51 percent of the radiant flux is in that band. The ultraviolet is less than 10 percent. The rest we can see and may in part feed on. Animals bask in the direct sun; some arctic insects warm their wing muscles in the focus of the beam formed by the concave petal disk of the arctic poppy. But the sky diffuses the sunbeam, particularly under overcast or cloud; that hemisphere of sky light is complex, variable and important.

"In a way it is a source of wonder that the atmosphere, as deep and massive as it is, transmits any energy" down to the surface. That is of course the mark of the wide-spaced quantum levels of the major diatomic molecules of the air. In fact, there is a large and rather steady invisible flux of deep infrared we seeing creatures tend to overlook. It comes from the air above warmed by the copious solar infrared, and it amounts to as much as 400 watts per square meter, even more when water droplets high above join in. It is the rare trace molecules with three atoms that supply this radiation: most of it is contributed by water and carbon dioxide. In the wavelength range from four to eight micrometers the flux is local, coming from the lowest 50 meters or so of the air.

Most of this energy flux comes in at still longer wavelengths from parcels of trace gases the better part of a kilometer up, and a little comes all the way from the ozone high in the stratosphere. No plants feed on this too soft photon stream, but its role in their overall heat balance is clearly major. What doth it profit a leaf to nourish its chloroplasts if the entire structure is destroyed by

freezing? This long-wave radiant income is always compensated for in large part by the upgoing thermal infrared emissions from the ecosystem at the surface temperature.

About a third of the book deals with this subtle radiation problem, ending in an overall balance struck among seven different fluxes: the solar direct beam and the sky income at short wavelengths, the infrared from gas and cloud, and the partial reflections and emission upward. Capable all-wave radiation sensors in national networks have been in service for years in many countries, with 100 or more deployed across the U.S.S.R. One feature of this text is its excellent coverage of the literature, with much space given to the extensive Russian and Western European work.

The second third of the text goes beyond the radiative base. It treats of the carbon fixation that sunlight spins out of carbon dioxide and water: the energetic harvest. In the end that store is broken down by grazers, decomposers and fire. From leaf-cutting ants to the human harvester every visible feeder is unimportant quantitatively. Even the energy fixed in a field of wheat goes to sustain the unseen and the lowly; they take six times the amount cropped as human food. Visible grazers become energetically important only rarely, as in times of a caterpillar population explosion; then the litter fall from tree leaves can approach the usual values of net primary production, about one watt per square meter.

A merino ewe is diagrammed in her energy environment in the sunbaked Australian shrubland; her thick fleece physically rejects most of the solar input by long-wave emission. The shorn lambs endure an opposite stress; they depend on a tempered wind. In winter their heat loss can easily become lethal. Now the subject matter gets more diverse. There is latent heat from the phase changes of water and sensible heat to worry about, in transfer to the air and the soil. There is the heat content and even the kinetic energy of hail, wind and rain, often important as trigger processes. There is stratification: the tree canopy sees radiant flux and turbulent air quite unlike those of the forest floor. Not much is ignored; many of these items are small in the mean but serve to turn natural valves, so to speak, for the larger flows.

Finally enter the inputs from our species, by fire and tractor, by fertilizer and reaper. The closing chapters seek integration, and some careful accounts have been given. The text ends with a remarkable diagram, plotting on a triangular field the three major nonradiative fluxes, that of latent heat, sensible heat (given to the air) and soil heat, expressed as fractions of the net all-wave radiation, the three corners all idealized pure cas-

es. Desert ecosystems plot along the edge between the soil-heat and sensible-heat corners; the farm plots are watery enough to dwell near the latent-heat corner. There is an entire world implied: cactus stems, deer, bogs and the typical citizen of Christchurch, New Zealand, have all been modeled in such an energy-flow domain. Scale is important; the energy-budget method has been widely applied to food and feed crops, from an initial effort at single leaves. The hotlands sheep is a radiator, but insects are convectors, "keeping cool purely by virtue of their size."

The city treatment is brief but provocative. One result worth citing is the effect of the coming of electric power about a century ago. The cities' structure changed; they got much less intense (compare the inner heart of a walled city with the present sprawl), but the energy conversion needed for circulation has compensated for the increased area, and the overall flux density has remained at about 20 watts per square meter. It is not only fossil-fuel use that contributes: the city is an investment in energy-rich matter. Amortized over 40 years, the material inventory requires an energy flow about as great as fuel use. The heat island over cities is well established; its causes and changes are not yet fully known. Cities warm the night because they store heat underground; they give off more long-wave radiation, and they disturb the atmosphere both compositionally and thermally. The manifestly powerful world of furnaces, cooling towers and smokestacks lies in quite another regime.

CITIES IN THE ROUND, by Norman J. Johnston. University of Washington Press ($29.95). Eye-catching illustrations ornament and vivify this delightful study of a struggle between the ideal and the real nearly as far-flung over time and space as settled humanity itself. First a word of explanation for the title is needed. The circle is a precise concept, but its infinite symmetry has been seen ever since the great Florentine Leone Battista Alberti as only the limit of that considerable group of finite rotations in the plane. "It is manifest," he wrote, "that Nature delights principally in round Figures.... We find too that Nature is sometimes delighted with Figures of six Sides." He went on to admit other polygons as well. So does our author, a professor of architecture and urban planning and design at the University of Washington. Symmetrical forms as intricate as snowflakes in all their reentrant concentricity dominate the visual impression of this handsome book; true circles are scarcer, usually implicit.

Put aside the recent pivot irrigation that grows clusters of big green circles across the flatlands of some modern farmers. Otherwise the translational de-

mands of the plow, like those of the carpenter and the mason, strongly favor the rectangle, or at least less regular ways of filling the plane. It is the circle as symbol that the round city celebrates, not any rotational way of work. It is true that the royal Zulu cities of the 19th century took the simple kraal to great dimensions: the king at the center, the warriors' huts ranged around him in four- or fivefold ranks to the scale of an imposing circular town of thousands. The Zulus were proud of a livelihood of cattle raising; their range was effectively unbounded, not divided by land deeds or barbed wire.

Other camp and village circles can be found, as among the nomad Cheyenne, or the gardening groups of the Amazon. Those peoples have neither plowed fields nor stone houses. Great China, and the Asian cultural domain it may have influenced or reflected, from the four-square pueblo to the stupa and the Purple Forbidden City, have a distinct cosmological need. Theirs is an earth of four cardinal directions; it is the sky alone that forms a celestial circumpolar circle. These shapes may be combined, as in a mandala or for the imperial ritual instruments of jade, but it has never been an Eastern plan to occupy this earth circularly.

Herodotus tells the tale of Ecbatana of the Medes, with its seven concentric walls in color, one for each luminary, from the golden central sun wall of the king to the outermost white wall for Jupiter. This is more likely to preserve myth than matter, but in fact there were circular cities in the ancient Middle East. One drawn here in aerial perspective is Gur of the Sassanians, built in A.D. 226 and left in ruin when Islam came to southern Iran. Its cosmic plan, centered on kingship, recalling the sun itself, persisted. Baghdad was planned by the caliph al-Mansur as a City of Peace and a paradise on earth; no form other than a circle would do, centered on the Golden Gate Palace of the caliph with its green dome. The fabulous city was built just so in four years. The purity soon departed, and development rapidly breached the ring wall. No sign of circles is found in Baghdad today.

The Classical world built no round cities; medieval towns were also walled orthogonally, although the City of God remained a circular ideal, theoretical and latent, "like embers." A remarkable example from that same time, but far from the culture of Europe, is the near-circular town of Mexcaltitán, on the west coast of central Mexico, built on an island in a lagoon. Its citizens hold that its form has cosmic meaning; they have retained the rounded wall and the central quartering by crossed streets with "singular resistance."

Theory caught up the Renaissance planners; theirs was a time of human reason. Domes burgeoned, and with the lofty circles of the central form came the idea of the perfect city. By the end of the 16th century, however, a strange alliance arose between philosopher and military engineer: the cosmic idea was linked to "a melange of trigonometry, cannon fire traceries and bombardment analyses." The prince at the center needed those convoluted bastions and lunettes; wide roads axially outward to the gates in the frowning multiple reentrant walls seemed necessary to quick reinforcement. The fortress town of Palmanova, the finest of the day, was sponsored by no single prince but by the rich Republic of Venice. Its ideal was fortification, and the swiftly realized plan, still more like a snowflake than any other city still standing, had to bend toward the practicality of a working city.

What any lesser prince could do, Louis XIV and Peter the Great would do even more grandly. The planned baroque town-forts multiplied from France to Finland; the great Vauban remodeled more than 160 fortresses and built 30 new ones, while directing 53 sieges. He was created Marshal of France, but his concern for the masses of the people and their taxation did not please the court; he died in disgrace.

The autocrats diminished, and artillery range outgrew the most ambitious walls. The new theories nonetheless retained a place for the city in the round, no longer to be justified by the centrality of a ruler or by the cosmic view. Now they were arguably pragmatic and egalitarian. (Theorists are up to a certain amount of rationalization in the interests of simplicity of form.) There are plenty of projects for such cities and a few realized ones, with more than one circle that was squared once the populations got their hands on the decisions.

A kibbutz called Nahalal is an open sunburst town, its fields radial strips out from the final ring of houses. Brasilia is no round city, but the runner-up for its planning competition of 1957 was a design by the brothers Roberto for a cluster of seven hexagonal urban units, housing 72,000 souls each, a plan that could expand by replication. Even later the workers who built the first stage of the power-station project on the river Paraná were housed in a circular town around a model farm. It was hoped the small city would take root. "But once construction ended, the residents hastened elsewhere." Poor Jupiá is a neat page in the architectural treatises, but the army took over half of the rings and the rest of the settlement was bulldozed.

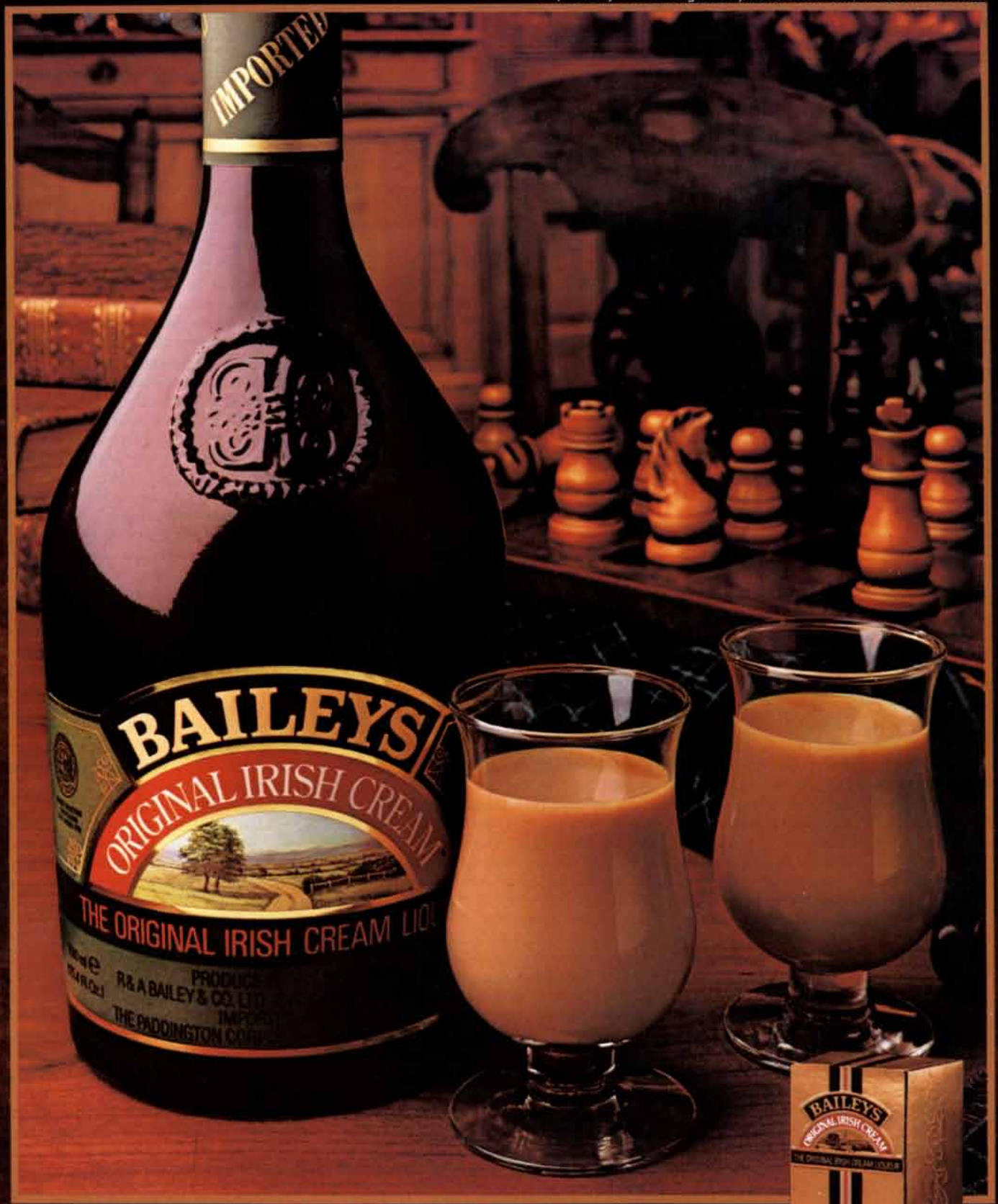
Professor Johnston concludes that the persistence of the circle-city idea is a signal we can still make out amidst the noise of the shifting arguments for it. Somehow it is built into the mind and the heart. We need cities we can love, all right, but it is not the planners, however indispensable, whose harmonious emotional response to city form should stand first in priority.

INANNA, QUEEN OF HEAVEN AND EARTH: HER STORIES AND HYMNS FROM SUMER, by Diane Wolkstein and Samuel Noah Kramer. Art compiled by Elizabeth Williams-Forte. Harper & Row, Publishers ($16.95). At the eastern edge of the alluvial plain of the lower Euphrates in southern Iraq the archaeologists have for two generations been working at the mounds of Uruk, biblical Erech and modern Warka, one city-state of ancient Sumer. The site has disclosed marvels, the oldest written documents and the first great monumental temples, their mud-brick walls, huge columns and high platforms encrusted with a colorful patterned mosaic of cones and beakers of painted terra-cotta. The time of Uruk's flowering was a period of 500 years and more from about 3500 B.C.; Sumer endured, waxing and waning in the flux of human affairs, for another couple of millenniums.

The glory that was old Uruk was not forgotten: its beliefs and forms were recorded with learning and passion on clay. That very technology was Uruk's accomplishment. Here and there in newer cities throughout the land between the two rivers there accrued libraries of the hand-size tablets, marked in swift cuneiform by scribes and scholars who knew the past, even though they were of a different people. In the 19th century tens of thousands of tablets were found and preserved; it has been a triumph of our century to have translated many of them. Among all those temple accounts and tribute lists and school lessons we hold as well a literary treasure, "more than thirty thousand lines of text, mostly in poetic form, [constituting] the oldest written literature of significant quantity and variety so far uncovered." It includes "twenty myths, nine epic tales," 200 hymns, with laments, dirges and diverse texts of antique wisdom. The principal source tablets for the Inanna cycle are dated at about 1800 B.C.; their story is surely much older.

The poets and the people of Uruk listened and sang; the scholars of later Sumer recorded their liturgy in all piety; the dusty tells held the bone-old records safe until the artful diggers came; the scholars unraveled the crowded wedge signs into English, French and German texts. The lapidaries represented the sacred date palm and the Holy Fly of the Underworld, the nude Lilith and the radiant Inanna.

This volume of collaboration takes us one inviting step further. The young senior author is a gifted storyteller, an experienced folklorist, with a sense rare in our literate times of the demands and the rewards of the spoken tale. Searching for a grand story of a woman, she



FOR MAJOR CELEBRATIONS
AND MINOR VICTORIES.

BAILEYS.® TASTE THE MAGIC.

came to realize that the tale cycles of Diana, Demeter, Cybele and Persephone and the others are all scattered and incomplete. It is Inanna, the oldest story of all we know, who alone spans the whole of the mythic life.

A girl, Inanna claimed her womanhood with the aid of her hero-brother Gilgamesh; she brought the sacred *me,* the root of all order, to her city Uruk to enter first on her queenship. She made joyous love with her chosen shepherd-king Dumuzi. Reigning, she journeyed to suffer the tyranny of the Underworld in death; she returned to the Great Above after exacting a partial sacrifice from Dumuzi. Finally she ruled Sumer in all her aspects, celestial and temporal, "mighty, majestic, radiant and ever youthful," patroness alike for sweet fruitful love and the bitter emptiness of death. Like Venus, she is together the Morning Star and the Evening Star, 2,000 or 3,000 years before the astronomers of Hellas.

The distinguished junior author, Samuel Noah Kramer, is the recognized dean of Sumerologists. His own scholarship has for 40 years given us most of the meaning we can now find in the tablets. He prepared the relevant Inanna texts in up-to-date form, some drawn from very recent translations and newly pieced fragments, taking account of all current work. Those texts, the best we have, he turned over to Diane Wolkstein, the storyteller. She has spent three years preparing her cycle of Inanna, more than 100 pages true to the resonant but unrhymed verse line of Sumerian. Not one tired archaism is left, no days of yore. She has shaped order and flow, keeping "as close as possible to the power, wonder and mystery" of the old texts. She has eliminated enough repetition to allow the story to breathe, and yet she has retained enough of it to give the novelty of a ritual authenticity long hidden.

Half of the book is this newly alive story of Inanna, half is a readable, varied and documented commentary from three points of view: that of the epigrapher, that of the writer and storyteller and that of the art historian and archaeologist. The gloss explains the complex written and visual material of this unusual and exciting volume, at a little-visited frontier between meticulous scholarship and vivid theater. Within the text there may well be lightly encoded one important constituent of the astronomical understanding of the time, only hinted at in this book.

"As Inanna ascended from the underworld,

The *galla,* the demons of the underworld, clung to her side.

The *galla* were demons who know no food, who know no drink,

Who eat no offerings, who drink no libations,

Who accept no gifts.

They enjoy no lovemaking.

They have no sweet children to kiss.

They tear the wife from the husband's arms,

They tear the child from the father's knees,

They steal the bride from her marriage home."

The hymns celebrate the bride's return in peace:

"My Lady looks in sweet wonder from heaven.

She looks in sweet wonder on all the lands

And on the people of Sumer as numerous as sheep....

I sing your praises, holy Inanna.

The Lady of the Morning is radiant on the horizon."

DISTANT WATER: THE FATE OF THE NORTH ATLANTIC FISHERMAN, by William W. Warner. Little, Brown and Company ($17.95). The drama is at the cod end. Studded with the heads of live fish bulging through the mesh, clouded over by screeching flocks of excited kittiwakes, it broaches heavily up in the wake of the trawler, also catching every fisherman's eye in that moment of visible triumph. The cod end is the socklike bag into which the caught fish collect as the big net is dragged through the sea. A trawler out of Boston on Georges Bank may net as much as a ton of fish in one lucky cod end; her company of 10 men reckon to spend a backbreaking week or so at sea between times ashore, and they will divide with the owner the proceeds of a catch of some 40 or 50 tons of well-iced cod and blueback pollock.

In competition with the bands of New England fishermen there arose a hunting system of a very different kind: an engineered enterprise of urban proportions afloat, taking fish at an order of magnitude greater rate, with 10 tons to the cod end, trawlers of 10 times the displacement and every crew 100 men—and women too. They spend months at sea, rotating by air to a home port as far away as Murmansk. Fleets of 200 such ships like cities afloat until recently drew their "big Jesus nets" across the Banks. This beautifully written book is an ethnography of that system, a loving, firsthand "foredeck chronicle" by a writer who spent months on shipboard among the enduring and skillful people of half a dozen nations who follow the last great hunting way of life.

The new way began with the *Fairtry,* a minesweeper converted in Aberdeen to fish the Grand Banks first in 1954. That British prototype launched 1,000 factory trawlers. (If we are to credit the account here, the first such Russian ships were built from her blueprints, cunningly wheedled out of her designers on a pretext of orders.) Four innovations defined the class: a stern ramp for the big nets, an automated fillet-making line sheltered belowdecks, a quick multiplate freezing plant aboard and fish-meal equipment to convert the part of the catch that is unmarketable as human food. Such a ship is big enough to offer movies and showers to the crew, and costly enough to justify powerful electronics, for example a set of sonars mounted on the elaborate nets, whose mouths may be 10 acres in area, guiding the mid-water trawl in three dimensions to envelop with precision the big sonar-detected schools. The quick-frozen morsels of white fish are nothing like the sallow week-old cod at the bottom of a dirty pile of ice that earn a longshoreman's grimace on the Boston Fish Pier.

They that do business in great waters earn our respect simply by completing their voyages; much more must be offered to those who also work hard and dangerously almost every hour at sea. We meet them through Warner's openly friendly sharing afloat. The West Germans are held to be the most expert. Their big instrumented mid-water catches do not stir the bottom but come up "clean"; regularly the cod end yields 98 or 99 percent of the fish, say herring, that they had trawled for. The fish-processing machinery is itself a worldwide near-monopoly of the Lübeck firm of Baader. History is plain on the fishing grounds; we ought not to be surprised that the best fishing in all waters and weathers is done from ships built for Hanseatische Hochseefischerei, nor that crews from new fishing nations, such as Cuba, show they have much to learn in distant cold waters.

It is on board a big Kaliningrad trawler that we glimpse something of the life of the Russian working people. Their trawlers are generously staffed, perhaps by half again as many crew as serve a larger West German ship; the frenzy and crushing fatigue of the work are gone, shared among many hands on a kinder watch system than the 12 hours on and six off of most fleets. Their captains cooperate, calling their colleagues to share a find instead of voicing the covert success and open deceit heard over the radio from the fiercely competitive masters of the West. The crews, men and women, are more diverse in career, ambitions and education than the tough fishermen of Grimsby or Boston; they go to sea for wages three or four times what a factory worker might earn.

We witness calisthenics and film after film of the Great Patriotic War, meet an interesting crew that serve unbonded by shared experience to any single ship or master and dine with them heartily, if predictably, on rich tasty soup to weak fruit compote in a mess hall decorated with eight hortatory posters. One reads in translation: "BALLS OF FIRE! The Brigade of Second Fishmaster A. T. Abybikhanov... has processed 5 TONS....

Helping engineers change gears.

The relentless ingenuity of America's engineers has made technological revolution commonplace.

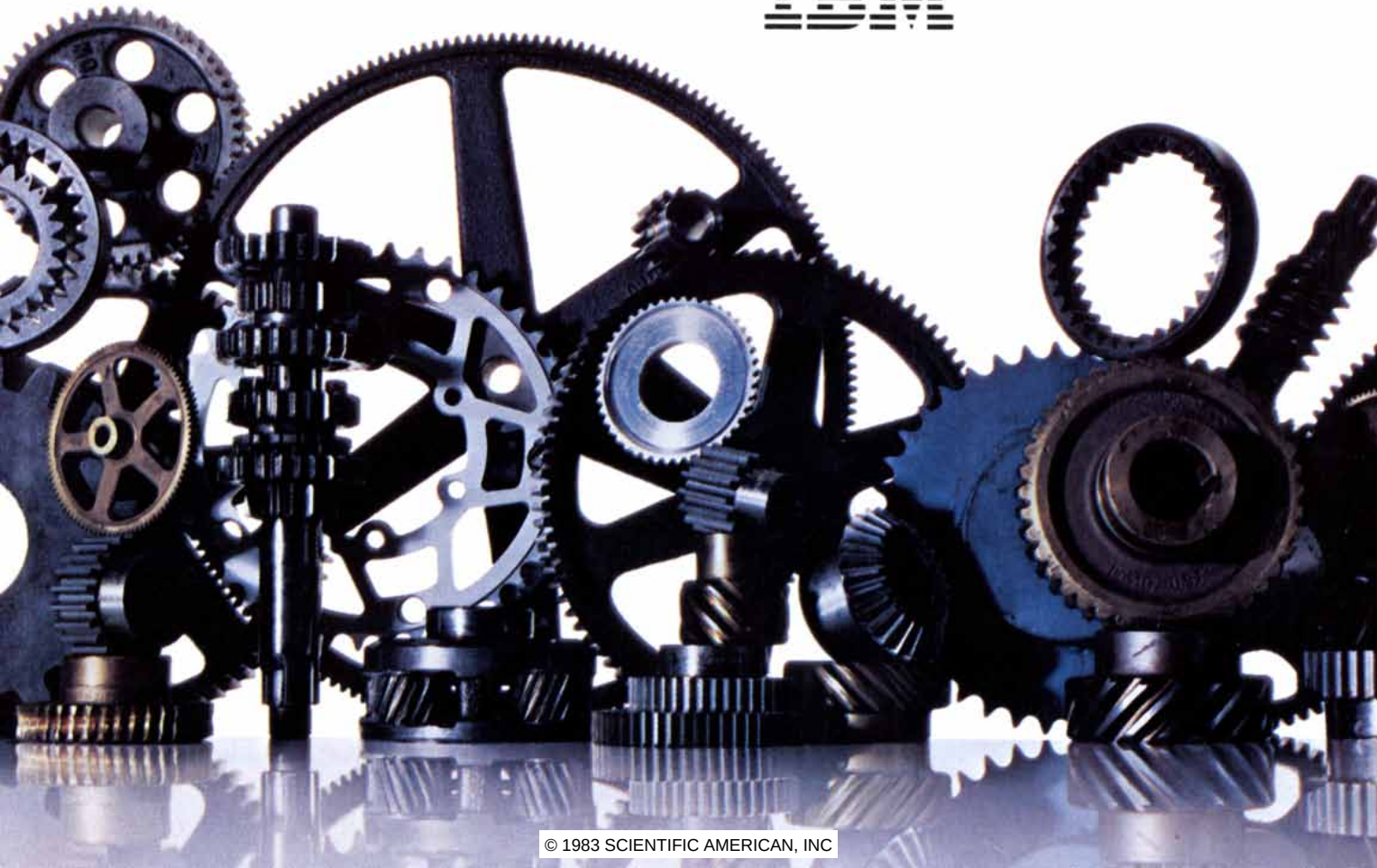
But today, manufacturing engineers face a relentless challenge: to produce goods of ever-higher quality at ever-lower cost. The marketplace, domestic and foreign, demands it.

To meet that challenge, engineers need state-of-the-art training and state-of-the-art tools. This, of course, is a job best done by America's universities. But universities can't do it alone. All sectors of society must help.

That's why IBM is giving $50 million in money and equipment to 22 universities for the creation and expansion of engineering programs in manufacturing systems. The curricula, in part, will include computer-aided design and manufacturing, robotics and lasers, quality control, systems management, and automation.

We expect this investment in education to pay off by helping to keep America's manufacturing in high gear.

And that will pay off for all of us. IBM®



STEADY AS SHE GOES!" Only Russian deckhands remain universal fishermen, complaining, bantering, horny and cynical. It was a happy ship, a safe one, its many jobs secure, and it evoked the air of a serious schoolroom, with grades and messages from the principal on constant display. The farewells to Warner, from the laundrywoman's gift of perfume to the captain's three hugs, left him with that long-familiar but still moving reflection: "To work and to live closely with the Russian people is to know generosity, warmth and a sense of community matched by none."

The factory fleets have departed now from the North Atlantic. The last of the big "floating cities" glowed offshore there some five years ago. In 1976 the U.S. and Canada led in the establishment of the 200-mile treaty limit on foreign fishing. Controls soon spread to all coastal states. The nutrient waters at the boundary of the Gulf Stream, just north of whose mixing flow the riches of the North Atlantic fishing grounds arch from Nantucket Shoals to Skolpen Bank eastward of the North Cape, support plenty of fish but not enough to sustain those megaton catches of the 1970's.

Nobody launches such big trawlers today; they are not well suited to the multiple species of the tropical Pacific waters whither the new fleets have moved. The British trawlers are laid up or are plowing Cornish waters. The Germans tried New Zealand, but it was hard to match the huge uniform schools of the cold North Atlantic shallows and the quotas fell swiftly. The Spanish pair boats that share one net drawn between them remain a small-scale exception. The Russian fleet has dispersed to the seven seas, often not fishing but merely processing at sea the erratic catches of local fishermen along the Benguela Current off West Africa, or creaking and groaning while they wait out sellers in the slow California swells.

The fish-bearing shelves of the world ocean are now nationally subdivided, "a staked plain"; the world catch remains about the same overall, but it is now far more diffuse. The North Atlantic shoals are livelier, not with big trawler fleets but with fish and birds. Only in the Norwegian Arctic do the catches still decline; elsewhere they are becoming stable, at levels higher than those of the past for local boats but severalfold below the transient peak of those too-well-supported hunters. The affectionate *nuk nuk* girls of Godthaab, like the Stardust Club of quiet St. John's, must miss their foreign fishermen nowadays. The Boston boats still arrive one or two at a time at the Fish Pier almost every day, each laden with 40 tons.

INDUSTRIAL ROBOTICS HANDBOOK, by V. Daniel Hunt. Industrial Press Inc., 200 Madison Avenue, New York, N.Y.

Magic Baloney

You'll love the way we hated the Magic Stat thermostat until an amazing thing happened.

It had no digital readout, an ugly case and a stupid name. It almost made us sick.

You're probably expecting our typical sales pitch, but get ready for a shock. For instead of trying to tell you what a great product the Magic Stat thermostat is, we're going to tear it apart. Unmercifully.

When we first saw the Magic Stat, we took one look at the name and went "Yuck." We took one look at the plastic case and said "How cheap looking." And when we looked for the digital readout, it had none. So before the salesman even showed us how it worked, we were totally turned off.

REAL LOSER

So there it was—at first blush a real loser. But wait, we did find one good feature—a feature that led us to a discovery. The Magic Stat installs in a few minutes and no serviceman is required. Thermostat wires in your wall follow standard color codes. So when you install Magic Stat, you attach the red wire to the red location and the white to the white. That's playschool stuff. And it's safe. Conventional thermostats installed over the past 20 years are generally only 24 volts, so you can either turn off the power or work with the "live" wires without fear.

OK, LET'S TEST IT

The Magic Stat installation was so easy that the least we could do was test it. And that's when we made an incredible discovery. We discovered that the Magic Stat was probably the most consumer-oriented, technologically-advanced and most sophisticated thermostat ever developed on the face of this earth and in our galaxy for all times ever. What made us switch from hating the thing to loving it? Read the following.

The Magic Stat has six setback settings per day and a seven day program. That means that you could set it for 70⁰ when you get up in the morning, drop the temperature to 54⁰ when you go to work, raise it to 68⁰ when you return for dinner, raise it up to 72⁰ after dinner as you watch TV and then drop it down to 62⁰ when you go to sleep. Count them—five settings with one to spare.

In one day the Magic Stat is programmed for the whole week and for the weeks to come. If you want a different schedule for weekends, you can individually program the thermostat for those days, too. "Big deal," you might think. "What's so great about that?" Read on.

You set most electronic setback thermostats to the time you want the furnace to go on in the morning, so when you wake up, your room is once again warm. But what if one morning it's bitter cold outside and the next morning it's much warmer? This means that setting your furnace to go on at the same time may, on one morning, leave you cold and on the next morning cause you to waste energy by warming up your house too soon.

By golly, the Magic Stat has everybody beat on this one too. Throughout the night it senses and computes the drop in temperature and the time it will take to get your room to your exact wake up temperature. So if you want to wake up at 7 AM to 70 degrees—that's the temperature you'll wake up to every time. Because it's a patented concept, no other thermostat has this feature. But wait. There is also a patent on the setting feature.

SIMPLE TO SET

To set the thermostat, you press just one button. A small LED light scans the temperature scale until you reach your desired temperature and then you release the button. You change the temperature naturally, throughout the day, up to six times. The unit responds and remembers that exact living pattern. The present temperature is displayed by a glowing red LED on the scale.

The system also computes the ideal length the furnace should stay on to keep the temperature within a range of plus or minus one and one-half degrees. A battery backup lets you keep your stored program in its memory so power outages as long as eight hours won't let your unit forget. And if something happens and your power is out for a few days, the unit will automatically maintain 68 degrees when the power is restored.

Quite frankly, we were so impressed with the unit, its ease of installation and setting plus its many energy-saving features, we seriously considered advertising it until we realized that our customers would probably not want to trust their future comfort to a product called Magic Stat. What if something went wrong with the unit? How substantial was this Magic Stat outfit? Remember, a thermostat is something you live with as long as you live in your home, and they're supposed to last ages. After all, your comfort depends on it.

Well, we did our homework, We found the company to be a sound, well-financed organization. They have been in business for several years, and they back their products with a three-year limited warranty. In addition, the company has a policy of buying back your unit in one year if you haven't saved its full cost in energy savings. We were satisfied with the company, the people, the product, its incredible features, the company's commitment to the product and above all, the energy savings.

We are so impressed now with the Magic Stat that we're going to make buying one irresistible. Buy one from us for only $79. Install it yourself in a few minutes or hire a handyman to install it.

Or order the new deluxe unit for $99 with the exact same features as the regular model, but with a beautiful new case.

Then enjoy the savings this next winter, Not only will you save up to 30% on your heating bills, but you're eligible for the 15% energy tax credit. Then if you're not absolutely in love with this product one year later, return it to JS&A. You'll get all your money back and you can reinstall your old thermostat.

REALIZE SAVINGS

But we're counting on a few things. First, you will realize an energy savings and a comfort that will far surpass what you are currently experiencing. Secondly, you probably will sleep better breathing cooler air yet wake up to just the right temperature.

Beauty is only skin deep and a name doesn't really mean that much. But we sure wish those guys at Magic Stat would have named their unit something more impressive. Maybe something like Twinkle Temp.

To order, credit card holders call toll free and ask for product by number below or send check plus $4 delivery for each unit ordered.

Magic Stat (0040F) **$79**
Deluxe Magic Stat (0041F) **99**

JS&A®
One JS&A Plaza
Northbrook, Illinois 60062
CALL TOLL FREE 800 323-6400
IL residents add 6% sales tax. ©JS&A Group, Inc.,1983

10157 ($32.50). The engineering handbook has come to have a generic look: a squat, heavy volume on thin paper tight with long tables of well-tried numerical data. The book bears the name but is no standard member of the genus. All the same it is a timely and useful book; routine specification and design of robots have simply not yet arrived.

This rounded compilation of matter of diverse source and nature fills a volume of unexceptional size and weight, neatly produced. It is an overview for readers with a broad understanding of engineering and economic topics; only here and there, particularly around its account of computer programs and robot control, does the level taken enter the domain of the specialist, say a would-be designer. The text begins with what amounts to a small book on robots in general, their configuration, sensors, tools, programs and control, safety and socioeconomic impact. Then we come to a look at the state of the art: a field guide to "current robotic systems" and a few pages of specifications and figures from each of the 28 U.S. manufacturers of robots, more than 80 species overall. Not at all provincial, the compiler then goes overseas; there is a review of industrial-robot manufacture in 10 countries, including a major review of the industry in Japan, although not in the U.S.S.R. The last 40 pages take a look at the robot and the future, by way of invited or cited statements from a wide range of expert and interested sources. The book is completed by a glossary, a bibliography and a brief summary of robot R&D organizations in the U.S.

Scale determines. There are industrial workers by the 100 million in the world. The robot population, by any plausible definition, is a thousandfold less. Growth is spectacular, but even by extrapolation from ebullient Japan it does not seem that robots can staff as much as a few percent of the work over the next few decades. The entry points for working robots seem understandable. Hard automation, say the familiar wonders of the light-bulb industry, is not robotic; its repetitive operations are already highly optimized for a well-defined product, and they are slow to change. Most small batch production, with hand assembly and inspection, changes so often and requires so little training of modestly paid human workers that it does not appeal to robots.

The robot's role lies in between, moving parts and assembling them up to a point, where the electrical-appliance and machine-tool industries offer plenty of niches. Other familiar tasks, notably welding and spray painting, and eventually work with hot metal, demand too much from human workers, who have the habit of breathing and require strict temperature control. A robot that works no faster than a human welder can triple output; the masked and overheated welder can work with that glaring arc only 30 percent of the work time.

Experience bears out this view: Nissan and Toyota and their counterparts everywhere are the biggest employers of robots. These automotive robots are playback devices; they learn on the job as a skilled worker leads the apprentice step by step through the hand task, typically making his points through the use of a hand pendant control. A Cincinnati-Milacron T-cubed robot, able to work a couple of shifts every day, sells for $63K, and it will store in a microprocessor the locations and sequence of more than 400 points taught it, moving between them by means of continuous-path servo, able to define positions absolutely and to reproduce them within about 1.3 millimeters. Its hydraulic drive will swing a couple of hundred pounds around six axes, and it has been certified as a spot welder, a parts-transfer-machine tender, a drill operator and more. The big one-armed deaf-blind fellow stands on a heavy three-foot base from which it can reach much of an eight-foot hemisphere. This is an experienced arm; it is state of the market, in stock today.

Control and program for robots transcend the ingenuities of the more familiar symbol-handling computers. The robot dwells in an untidy real universe, and the problems of mechanical oscillation, hydraulic drifts and urgent exceptions to the program commands (something fell!) are surely moving the designs toward smarter, more attentive devices. Breakaway wrists for tool arms sound crude; the T-cubed arm can drill far more precisely once it is given a smart drill, one with its own template, contact sensors and dedicated microcomputer. Robot locomotion is just ahead: more need for good robot sense and sensors. Ship welders, coal-face miners, underwater workers and window cleaners are ahead, and medium assembly seems wide open for the near term.

The robot future is unclear in detail, except for growth in number and sophistication. Two analysts, one for the United Automobile Workers, Daniel D. Luria, and one, James S. Albus of the National Bureau of Standards, offer clear-eyed views near and far. U.S. metalworking employment is bound to shrink. American white collars also will get bluer as offices increase in capital cost and require multiple shifts. Unless output grows with unexpected speed, serious dislocation is sure. The "bad" jobs should go to the robots first; the unions need a voice in technology choice; the market cannot determine the new structure for the U.S. economy. The workweek should dwindle; robot factories making robots, with an exponential hiding in there somewhere, loom on the far horizon.

SCIENCE/SCOPE

The space shuttle's new "eyes, ears, and voice" will revolutionize future missions, tests aboard the shuttle Challenger last June indicate. The integrated radar and communications system, also called the Ku band radar because of its operating frequency, uses an antenna dish at the front of the cargo bay. The system will let shuttle crews talk to Earth or transmit TV, high-speed data, and payload telemetry through NASA's tracking and data relay satellites. Crews now communicate with the ground less than 20% of the mission because the spaceship passes beyond the range of ground stations. With the Hughes Aircraft Company system, communications time will increase to over 90% of the mission.

Pioneer 10 is streaking into interstellar space with navigational help from its electronic imager. The spacecraft, which made history last June upon leaving the solar system, is using its imaging infrared photopolarimeter (IPP) to fix on the star Sirius. Pioneer 10 previously oriented itself with a sun sensor, but the sensor, now well beyond its design range, is reaching its limits of sensitivity 2.9 billion miles away. Pioneer 10 needs a reference point for spacecraft attitude control and interpretation of scientific data on solar wind. The IPP had been repeating various cruise-mode experiments since giving scientists their first close-up pictures of Jupiter and its four largest moons in late 1973. The IPP was built by the Santa Barbara Research Center, a Hughes subsidiary.

An advanced antenna farm designed with the aid of a computer will be carried into space by Intelsat VI communications satellites. The system will provide many different kinds of coverage -- beams transmitting to entire hemispheres, "global" beams, focused regional beams, and very narrow spot beams for broadcasting high-speed data. Hundreds of computer patterns were created to predict antenna performance. These studies led to the choice of transmit reflectors 3.2 meters in diameter instead of 4 meters. The larger size was rejected because it offered only slight improvement at the cost of being much heavier, larger, and more complex. Hughes heads an international team building Intelsat VI.

The new Landsat 4 spacecraft measures surface temperatures with an emitted thermal energy band not available on previous Earth resources satellites. The band, part of an instrument called a thematic mapper, adds a new dimension of data to that of bands that measure reflected sunlight. The new band can identify and map surface composition for geological studies and for mineral and petroleum exploration. It also can identify vegetation types and monitor their health. Hughes and its Santa Barbara Research Center subsidiary built the mapper for NASA.

"Diversification" characterizes Hughes Industrial Electronics Group, located in the Southern California communities of Carlsbad, Irvine, Newport Beach, Sylmar, and Torrance. Our facilities are like small companies with 500 to 2,500 employees, but each offers the resources and benefits of a multibillion-dollar company. Our diverse technologies include silicon and GaAs semiconductors, fiber optics, microwave and millimeter-wave communications, microprocessors, lasers, and solar cells. Send your resume to B.E. Price, Hughes Industrial Electronics Group, Dept. SE, P.O. Box 2999, Torrance, CA 90509. Equal opportunity employer.

Established 1845 SCIENTIFIC AMERICAN October 1983 Volume 249 Number 4

Labor-intensive Agriculture

The $18-billion U.S. fruit and vegetable industry is increasingly reliant on illegal-immigrant labor. By postponing mechanization it is becoming vulnerable to cheaper produce from other countries

by Philip L. Martin

Agriculture is the largest single industry in the U.S., employing 4 percent of the labor force and generating 4 percent of the gross national product. The enterprise consists of 2.5 million farms that combine family labor and hired labor, land and water, seed and fertilizer, and energy and machinery to produce livestock and commodities worth nearly $150 billion per year. The U.S. food system is the envy of the world because it provides a wide variety of foods to consumers at low cost. The average family in the U.S. spends about 17 percent of its disposable income on food, whereas in Europe 25 percent is common and in developing countries the fraction can go as high as two-thirds.

Most farms in the U.S. are diversified operations where the farmer and his family plant and harvest several crops and tend livestock as well, all without any help from hired farm workers. Seventy percent of the nation's farm work is done by farmers; only the remainder is done by hired workers. Another part of the picture, however, is that 5 percent of the farms produce half of the nation's food and fiber, and it is these commercial farms that employ most of the hired workers. Many of the commercial farms that grow fruit, vegetables and nursery products—all labor-intensive crops—resemble nonfarm businesses, with hired managers and up to several thousand seasonal workers to do the farm work. These seasonal farm employees are increasingly illegal aliens or undocumented workers (people working in the U.S. without proper authorization). Agriculture's growing dependence on alien workers runs counter to U.S. law and policy, retards the pace of the labor-saving technological changes that have made the rest of U.S. agriculture a paradigm of efficiency and sends the wrong signal to farmers who face increased international competition. The continued availability of alien workers discourages farmers from making necessary labor and production changes, thereby increasing their vulnerability to foreign competition.

The annual farm-wage bill of $12 billion is divided into thirds: one-third is paid to workers on farms that produce fruit and vegetables, one-third to workers in field crops such as wheat, corn and cotton, and one-third to livestock workers. Livestock farms have few problems getting year-round salaried workers, and most field-crop farms can find as many seasonal equipment operators as they need. The major problems of farm labor arise in the $18-billion fruit, vegetable and nursery industry, which hires more than one million seasonal farm workers and usually pays them piecework harvest wages, for example 40 cents per bushel of apples.

Fruit and vegetable farms need workers for several weeks or months. Across the U.S. three times more farm workers are required for the harvests of September than are required for the winter tasks of January. Most fruit and vegetable farms grow only one or two commodities, thus increasing the ratio between peak and trough seasonal employment to as much as 20 : 1. The farm-labor market must match more than a million seasonal workers annually with farm jobs of short duration and must do so under conditions that include many workers who do not speak English, few incentives such as seniority and fringe benefits to hold workers to a particular farm, and perishable crops that may be lost if the harvest is delayed.

Most fruit and vegetable farms recruit hundreds and sometimes thousands of workers who are willing to be employed on one farm for a short time and then to look for another seasonal job. Traditionally the task of stringing together a series of farm-labor jobs has fallen on the worker. Since many seasonal farm workers speak little English, bilingual farm-labor contractors and other intermediaries such as employer associations and hiring halls have emerged to recruit, supervise and pay farm-worker crews that are moved from farm to farm. Seasonality, the contractor system and piecework wages have fostered a condition in which workers and jobs are interchangeable: farmers know the piecework cost of harvesting, and so they are indifferent about who picks their crops; since piecework wages are quite uniform, workers do not care who owns the field they are working in.

Debates over farm labor would leave less room for contradictory assertions if farm-labor statistics could provide an accurate profile of the workers. Unfortunately the statistics are incomplete and unreliable, with the result that each data series provides a glimpse of a scene that remains obscure in its details. This obscurity allows contradictory assertions to coexist: most seasonal farm workers are American students; most seasonal farm workers are illegal Mexicans, proving that Americans will not do farm work.

The profile that emerges from the statistics of the Department of Agriculture is that the typical hired farm worker is a 22-year-old white male college student who does one month of farm work during the summer. Since even department spokesmen testify in Congress that an immigration reform reducing the availability of alien farm workers would disrupt the fruit and vegetable industry, one can infer that the department's sta-

tistics systematically undercount seasonal fruit and vegetable workers.

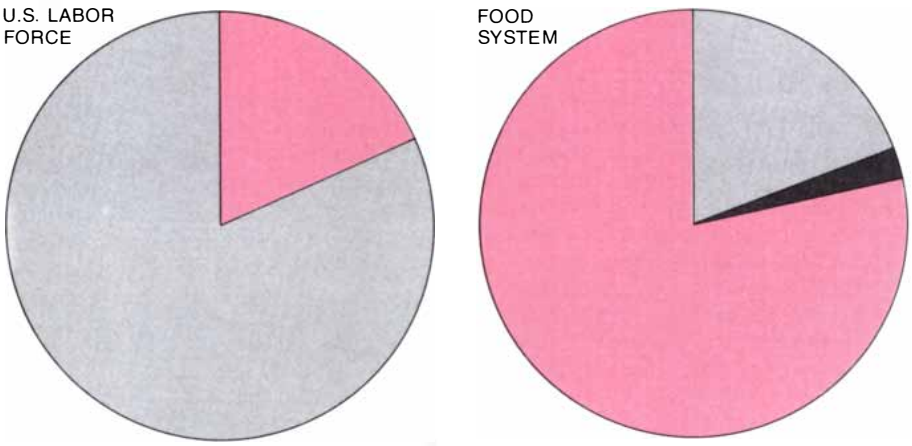
There are two major sources of farm-labor data. Each July the Department of Agriculture asks farmers how many workers are employed, what they are paid and what fringe benefits they receive. Every other December the department pays the Bureau of the Census to attach farm-labor questions to the monthly Current Population Survey, which is the source of the national figures on employment and unemployment. About 1,500 of the households in the survey include at least one farm worker, and the responses from this group serve to generate a profile of farm workers.

The July survey estimates the employment of farm workers, that is, the number employed during the week of the survey. The December survey estimates the hired farm work force, that is, the number of people who did farm work for wages sometime during the year. An industry's total work force is always larger than employment because of turnover among workers.

The Department of Agriculture reports that the average employment of farm workers is about 1.3 million throughout the year and that the total farm work force is about 2.5 million. The implication is that a farmer must normally hire two workers during the year to keep one job slot filled. Since the workers on many livestock and field-crop farms are employed year-round, a reasonable assumption is that the turnover is highest on the fruit and vegetable farms hiring seasonal workers. Indeed, some farmers have reported hiring 200 workers in one month to maintain a 20-person harvest crew; at an annual rate this would be 120 workers to keep one job slot filled for 12 months.

Such an extreme turnover precludes a clear picture of who does farm work. The employment survey of July, 1982, reported that 1.8 million workers were employed on 475,000 farms, earning an average of $3.96 per hour. Farmers reported that they provided fringe

MANUAL LABORERS pick green peppers on a farm in Gilroy, Calif. Like most fruits and vegetables intended to be sold fresh, the green peppers must be picked by hand; mechanization extends mostly to fruits and vegetables that are processed before they are sold.



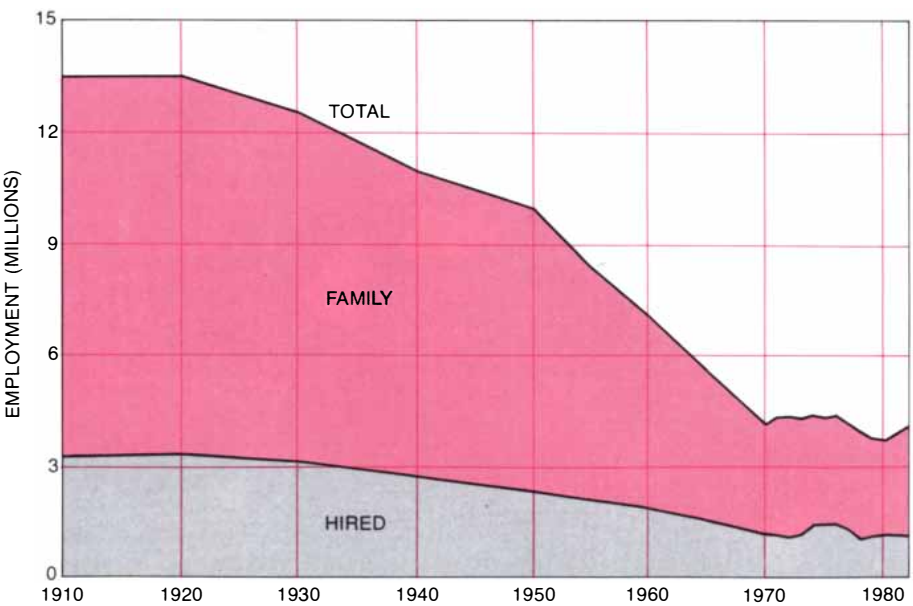
COMPONENTS OF EMPLOYMENT are analyzed. Of 95.9 million people employed in the U.S. in 1980 some 17.6 million, or 18.3 percent, were in the food system (*color*). That group is further analyzed in the chart at the right. Food processing and distribution accounted for 13.8 million workers, or 78.5 percent of the food-system work force, farming (*gray*) for 3.3 million (about 19 percent) and farm inputs such as seed and fertilizer (*black*) for 411,000 (2.3 percent).

benefits such as housing, meals and transportation to 45 percent of their employees, although the actual value of these benefits ranged from a carton of the crop being harvested to free room and board. An "average" farm worker employed during the week of July 11–17, 1982, worked 35.3 hours at $3.96 per hour, a weekly wage of $139.79. (In 1982 the average wage of production workers in industry was $7.89 per hour.)

The work-force survey in December, 1981, estimated that 2.5 million people did farm work for wages sometime during the year. They were (according to the survey) mostly white (73 percent), male (77 percent), young (55 percent under age 25) and poorly educated (median 11 years). Most respondents worked for only a short time in agriculture, 73 percent of them for fewer than 150 days. The people who worked more than that constituted only 26 percent of the farm work force but did three-fourths of all the farm work done by hired hands. Migrants (people who cross county or state lines and stay away from home at least overnight to do farm work) made up only 5 percent of the total work force. According to this survey, the average farm worker in 1981 earned $27 per day for 98 days of farm work, or $2,659 from agriculture.

The picture derived from these statistics on the work force is distorted because the "average" characteristics are determined by the large number of students who do a few days or weeks of farm work in the summer and are easy to find in December. Indeed, the data indicate that 34 percent of the "farm workers" were primarily students, considerably more than the 28 percent whose primary activity was hired farm work.

Farm-labor data are the source of much frustration to farmers, farmworker representatives and policymakers. Notwithstanding the evidence that the seasonal farm work force in the Southwest is largely Mexican, the data from the Department of Agriculture would have it that young, white American men predominate. The people who are skeptical of these statistics assert that a survey conducted every other December will find students and will miss the many Mexicans who leave the U.S. during the winter months. Indeed, a survey in 1981 of 472 seasonal-farm-worker families in the Central Valley of California found that more than 90 percent of the workers were Mexicans and Mexican-Americans. Most representatives of farmers, farm workers and government agencies say the work force of from 700,000 to one million in the fruit and vegetable industry consists largely of Mexican nationals, many of whom are working in the U.S. illegally.



TREND IN FARM WORK between workers who are members of the family and workers who are hired shows that although employment has declined in both categories, the fraction of hired workers was significantly higher in 1980 (35 percent) than it was in 1910 (25 percent).

Four kinds of aliens do seasonal farm work: immigrants, border commuters, H-2 workers (named for the section of the Immigration and Naturalization Act of 1952 that authorizes their entry) and illegal residents. Immigrants are aliens admitted to live permanently in the U.S. Although most of them settle in urban areas, from 10 to 15 percent find jobs in rural areas. Border commuters are immigrants who maintain a home in Mexico or Canada and commute daily or seasonally to jobs in the U.S. There are about 60,000 of them, many working on farms.

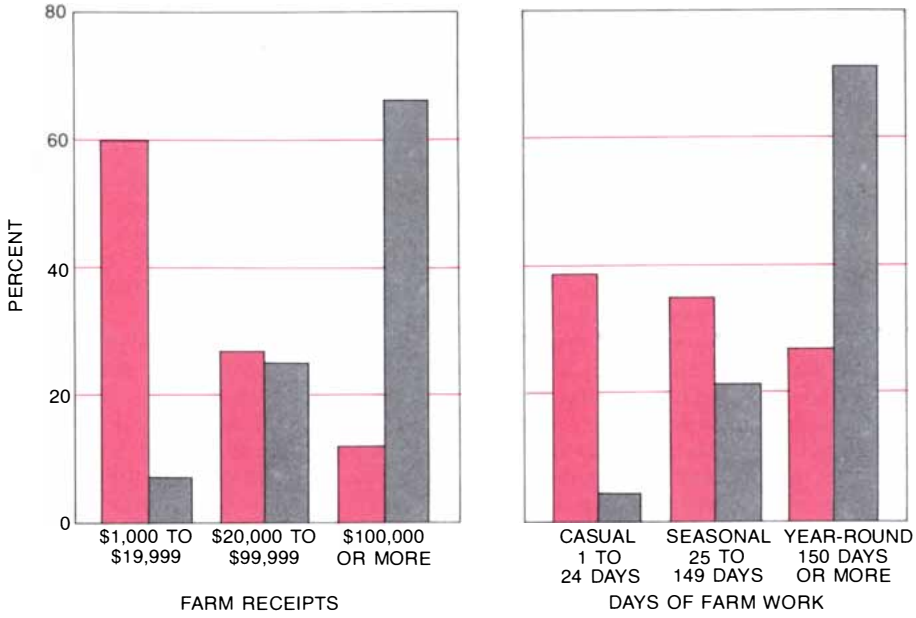
The H-2 program was enacted in 1952, when the separate bracero (manual laborer) program was almost at its peak. Under the H-2 section aliens are admitted to the U.S. for temporary jobs if unemployed U.S. citizens are not available and if the employment of alien workers will not adversely affect similarly employed Americans. The agricultural part of the program admits about 15,000 aliens annually for farm jobs that last from two to six months. H-2 workers cut sugarcane in Florida, pick apples in the mid-Atlantic states, harvest citrus fruit in Arizona and herd sheep in the West. Although they are only a small fraction of the total seasonal farm work force, they are predominant in the areas where they work and in the tasks they do.

The largest alien work force in agriculture consists of illegal aliens or undocumented workers, who come primarily from Mexico and other Latin-American countries. The bracero program, which lasted for 22 years, admitted almost five million Mexican farm workers to the U.S.; after it was terminated in 1964 farmers obtained immigrant

status for many of their best workers. The former braceros who settled in the U.S. and those who continued to commute across the border developed efficient networks that informed relatives and friends about jobs in the U.S. and provided advice on how to cross the border illegally. The networks are still in place and can deliver additional workers to farmers in the U.S. on short notice. A new network is created whenever a venturesome or desperate worker leaves another one of Mexico's 75,000 villages and finds work in the U.S.

The Simpson-Mazzoli bill on immigration reform and control that is now before Congress would (1) make it a Federal crime to knowingly hire or employ an illegal alien, (2) grant amnesty to certain aliens living illegally in the U.S. and (3) modify the H-2 regulations to make it easier for employers to get alien farm workers. The assumptions behind these three related changes are that sanctions will reduce the influx of illegal alien workers, that amnesty will encourage some people to leave agriculture for nonfarm jobs and that a modified H-2 program will be necessary to prevent "disruptions" in agriculture.

The basic administrative question in the H-2 program is simple: Where does the duty of the farmer to hire an American work force stop and the obligation of the Federal Government to open the border start? Clearly if farmers have to scour the U.S. looking for workers and must offer high wages, transportation, adequate housing, inexpensive food and other amenities, they will find more American workers and will need fewer foreign ones. They will also have a greater incentive to mechanize. On the other hand, if farmers have few obligations in recruitment, wages and housing, they will find it easier and cheaper to simply hire aliens. The H-2 program is controversial because it is trying to strike a balance between conflicting goals: protecting American farm workers and ensuring a plentiful supply of low-cost farm labor.



ECONOMICS OF FARMING are indicated in these related charts of cash receipts (*left*) and hired workers (*right*). In the chart of farm receipts the colored bars show the fraction of all farms in each category and the gray bars show how the farms in each category shared in the cash receipts. The biggest share of the income went to the largest farms. Similarly, in the chart of hired workers the colored bars represent the percentage of all such workers in each category, the gray bars the percentage of work they did. Year-round employees did most of the work.

The debate over the need for alien workers in fruit and vegetable farming diverts attention from an unsettling shadow on the horizon: competition from other nations. The automobile industry faced a similar juncture in the late 1960's. In an affluent and health-conscious society the demand for fruits and vegetables is expanding, and farmers envision continued expansion and profits if the Federal Government does not enact costly new labor regulations. Just as the automobile industry waged largely successful battles against air bags and environmental controls that diverted attention from increasing foreign competition, so fruit and vegetable farmers are fighting to continue using seasonal alien farm workers in order to compete with the fruits and vegetables other nations are beginning to export in quantity. Cheap labor benefits agriculture in the short run, but it also helps to blind farmers to the technological changes they will have to make in order to compete with foreign producers who have access to even cheaper labor.

Products such as citrus fruits, strawberries and tomatoes require relatively little land but a great deal of labor. The cost of hand harvesting is 20 percent of the price the farmer gets for oranges and lemons and up to 40 percent of the price for lettuce, strawberries and tomatoes. The wages of farm workers in the U.S., however, are five times higher than they are in Greece and 10 times higher than they are in Mexico. As other nations expand their labor-intensive agriculture, the already loud complaints by American farmers about Brazilian oranges, Greek raisins, Mexican tomatoes and Italian wine will intensify.

The increasing dependence of American fruit and vegetable farmers on alien workers confronts policymakers with two options: (1) preserve the status quo by approving an open-ended temporary-worker program or (2) encourage the fruit and vegetable industry to mechanize in order to limit its need for alien farm workers. If the U.S. gradually reduced the supply of alien farm workers, the production of labor-intensive commodities that cannot easily be mechanized could be shifted abroad by removing import barriers, thereby increasing employment in Mexico and the Caribbean basin and decreasing incentives to migrate illegally to the U.S.

Debates on farm labor often fail to recognize these linkages of immigration, trade and technology. Instead many fruit and vegetable farmers believe the optimal strategy is to preserve the status quo with an open-ended temporary-worker program. They recognize that mechanization is inevitable, but they want to decide when and how machinery will replace workers instead of being confronted with the sudden elimination of traditional labor supplies. Organizations of farm workers oppose a temporary-worker program because they believe aliens selected from a huge pool of foreign labor will always be preferred to Americans, who are often the castoffs of other labor markets. These organizations also oppose mechanization that displaces farm workers.

Machines have taken the place of seasonal workers in the fruit and vegetable industry in an uneven pattern since research on this kind of mechanization was begun in the 1940's. Most of the root vegetables such as potatoes are dug mechanically, some of the leafy vegetables such as spinach and processing cabbage are lifted and cut by machine, and a few of the field crops such as pickling cucumbers and processing squash can be machine-harvested. Crops that are intended to be sold fresh, however, still call for hand labor; for example, most carrots and green onions are still pulled and bunched by hand, and iceberg lettuce, broccoli and celery are hand-cut and hand-packed. Strawberries, melons and most fresh-market tomatoes are hand-picked.

Mechanization slowed in the 1970's

because workers were readily available. Nevertheless, harvesting machines are still being adopted by some farmers. Grapes that are processed into wine can be mechanically harvested by a machine operating over the row to shake the grapes loose and catch them on conveyor belts. This machine is being modified to harvest the raisin grapes that are now picked by hand. Most nut crops such as almonds, pecans and walnuts are harvested by a hydraulic arm that grasps the tree trunk and shakes the nuts to the ground, where they are swept up by another machine. A tree shaker with a padded catcher can harvest prune plums, cling peaches, apples and tart cherries, but the machine damages the fruit so much that the crop must be processed soon after harvesting.

Several of the crops that are now picked by hand could be harvested mechanically if workers were not available; among them are peaches, lettuce and tomatoes. The mechanization of many others will require the coordinated efforts of plant scientists, engineers, growers and processors. Trees and plants that yield uniformly ripening crops able to withstand machine harvesting could be developed. Growers would have to prune or plant them in such a way as to facilitate mechanical harvesting. Engineers could improve the optical and laser sorting devices that can sort the crop in the field, thereby cutting costs, but processors would have to schedule their work precisely so that the harvested and sorted produce would not deteriorate. Equipment manufacturers and seed companies could work with growers to diffuse new technology on the one hand and new plant varieties on the other.

The most plausible coordinator of this systems approach to mechanization is government, primarily through the established land-grant universities. These nonprofit institutions do the basic plant and engineering research that growers, processors and equipment manufacturers do not undertake. Moreover, the academic people who are engaged in this work have enough influence on both growers and processors to encourage changes in the practices that impede mechanization.

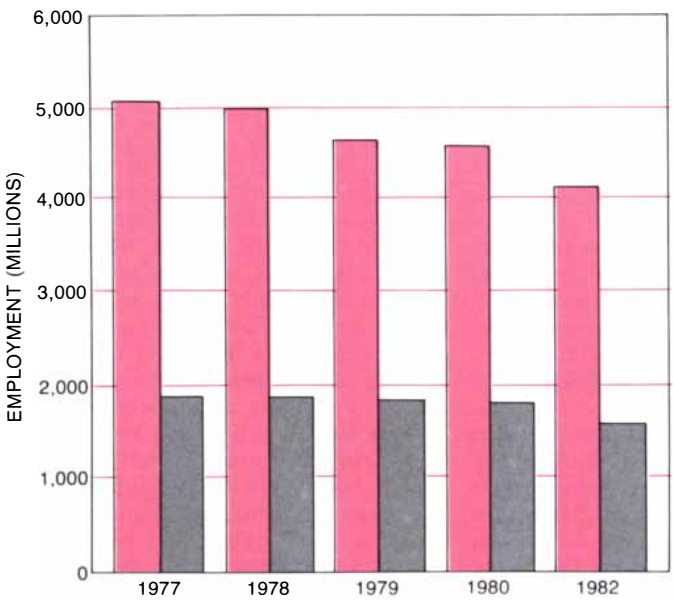
An increased role by the universities will be controversial, particularly in California, where the University of California is defending itself in a lawsuit brought by representatives of farm workers. The suit charges that the university's research on mechanization is biased in the direction of helping the operators of large farms and undermining farm-worker unions. Universities can head off some of the controversy by making clear the importance of mechanization in preserving a profitable fruit and vegetable industry and by taking pains to avoid conflicts of interest in research programs.

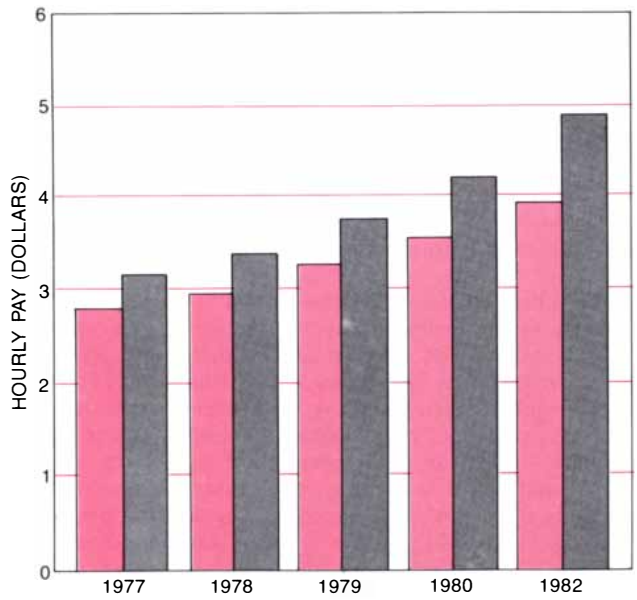
Public policy is trying to discourage agriculture from using aliens by enacting laws and making regulations forcing farmers to meet certain standards of recruitment, wages and working conditions. A better way to reduce dependence on alien workers is to link immigration reform to a plan for restructuring the fruit and vegetable industry. One way to forge such a link is with an H-2 trust, which would levy a tax on the wages earned by alien farm workers and would apply the funds to restructure the production of commodities that depend on alien workers.

Such a trust could be established for each commodity whose growers asked for alien workers. The amount of money available to each trust would be determined by the level of the payroll tax and the extent of the commodity's dependence on alien labor. One can arrive at an estimate of what the level of taxation might be by taking into account the fact that farmers do not now have to pay the Social Security tax of 6.7 percent or the Federal unemployment-insurance tax of .8 percent on the wages of H-2 workers. In addition most states exempt those wages from the state unemployment-insurance tax (ranging from 3 to 6 percent) that farmers must pay on the wages earned by most of the farm workers who are U.S. citizens. These various exemptions suggest an H-2 wage tax of at least 10 percent. If a modified H-2 program admitted 300,000 alien farm workers annually and the average worker earned $5,000 during the year, the H-2 trusts would collect 10 percent of $1.5 billion, or $150 million per year.

Farmers are familiar with the concept of assessments to support commodity-related research and promotion. Since H-2 trusts could be established on a commodity-by-commodity basis, administrators familiar with the problems associated with the particular commodity could fine-tune the programs for reducing dependence on alien labor, choosing from a variety of options including research on mechanization, the training of workers and changes in processing. A commodity-specific H-2 trust would create both a direct link between a commodity's dependence on alien workers and the means to end that dependence.

The U.S. Select Commission on Im-





EMPLOYMENT AND WAGES in agriculture are characterized. In the chart at the left the colored bars show the number of farm workers in each year, the gray bars the number who were hired workers. In the chart at the right the colored bars show wages paid at an hourly rate, the gray bars piecework wages. The data are based on a survey made each July by the United States Department of Agriculture.

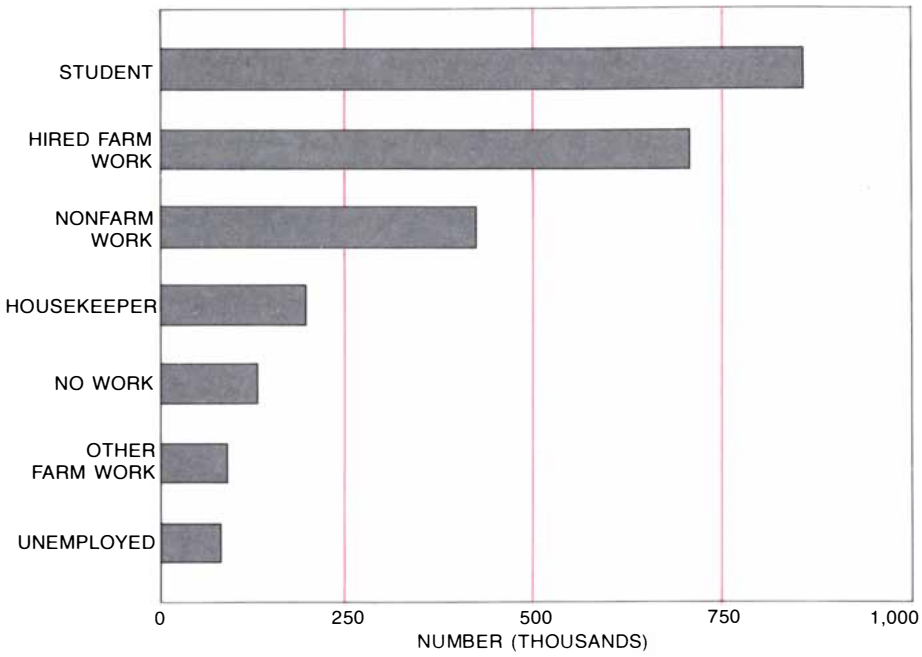
migration and Refugee Policy, which studied the subject from 1979 to 1981, recommended that no industry depend indefinitely on alien workers. The commission argued that such workers constitute a subsidy to employers unable or unwilling to attract American workers, to mechanize or to produce abroad, and it could find no justification for such a subsidy just to maintain a given industry in the U.S. If one accepts this reasoning, H-2 trusts would provide a way of emphasizing the transitional nature of alien farm workers in fruit and vegetable agriculture.

Mechanization is not the only way to reduce agriculture's dependence on alien workers. Intermediate back-saving technologies such as conveyor belts to eliminate heavy field bags and hydraulic lifts to replace ladders and fruit bags would help to encourage women and older workers to harvest crops. Experienced farm workers might prolong their average of from five to 10 years in harvest work if more farmers and employment associations offered a series of jobs that reduced unemployment.

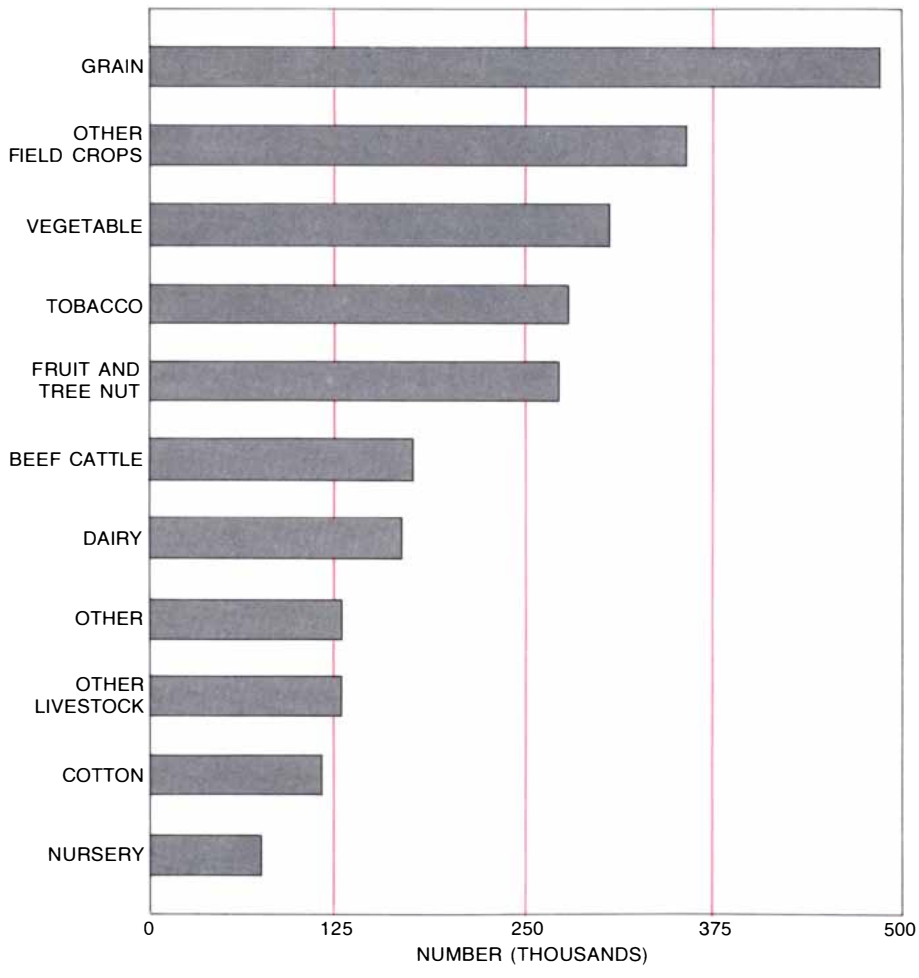
The continued dependence of the $18-billion fruit and vegetable industry in the U.S. on alien farm workers for handwork spells disaster in the long run. The industry has two choices: it can move toward mechanization, meanwhile trying to improve conditions for handworkers by adopting modern personnel policies and installing equipment that facilitates handwork, or it can obtain access to a rotating pool of alien farm workers with another program of the bracero type. The second option would imply an indefinite dependence on an alien work force.

Few U.S. citizens will become seasonal hand-harvest workers at the prevailing wages or even at higher wages because workers with options reject the uncertainties of the seasonal farm-labor market. The U.S. will have an American work force in fruit and vegetable agriculture when that industry is mechanized. The farmers who grow wheat, corn and soybeans can find Americans to operate their machinery, and the fruit and vegetable farmers who have mechanized are having the same experience.

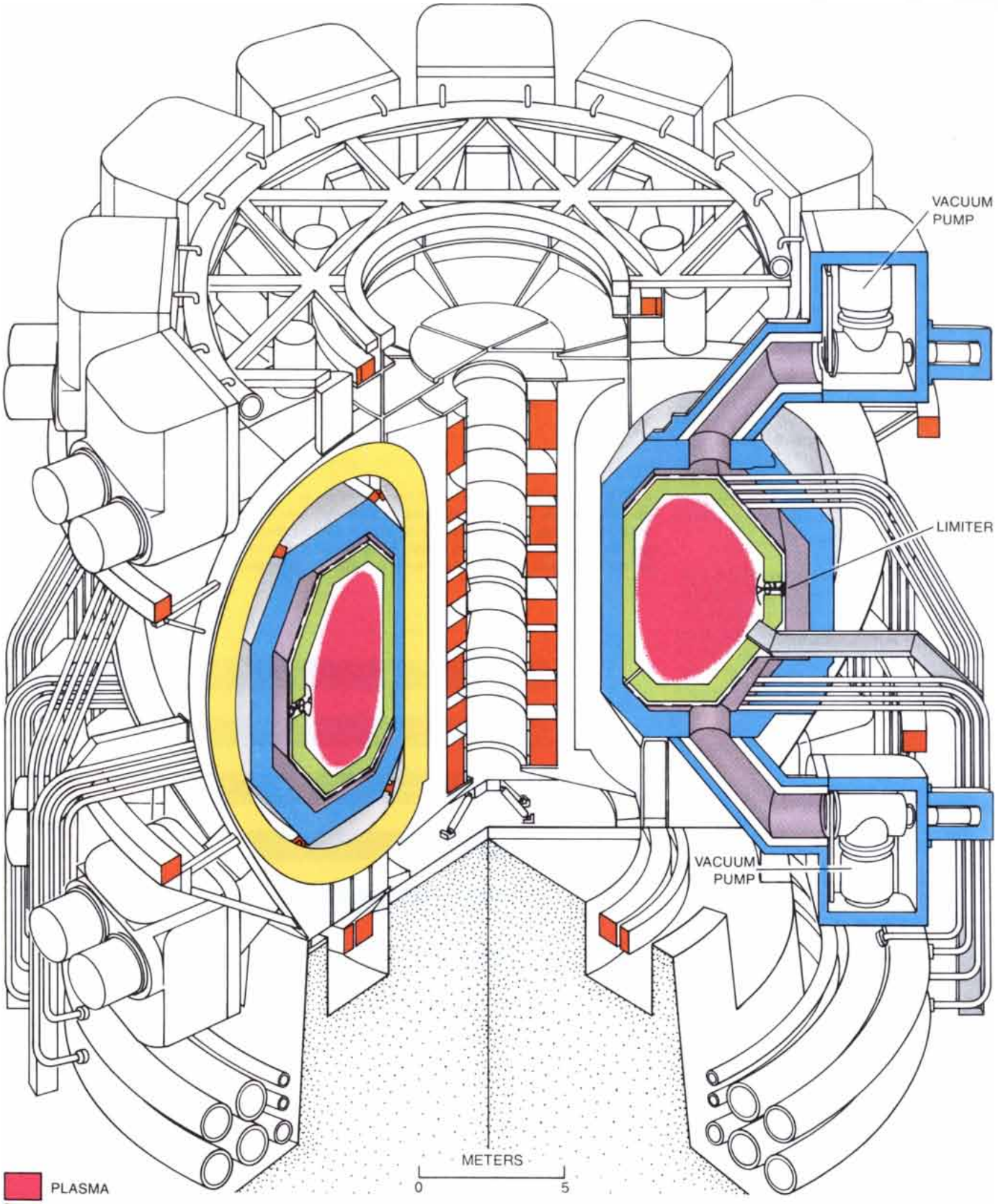
Mechanization is one answer to the problems of productivity, labor and immigration in fruit and vegetable agriculture. Without mechanization the U.S. must both accept an isolated, alien-dominated labor force for seasonal handwork and erect trade barriers to keep out produce grown abroad at even lower wages. If farmers successfully oppose the immigration reforms that could begin to alter this picture, they may win the short-run battle over labor but will lose the long-run war for survival in the increasingly competitive international fruit and vegetable economy.



PRIMARY ACTIVITY of hired farm workers in 1981 was in many cases something other than farm work. The data are based on a survey made every other December by the Bureau of the Census. They have been challenged by representatives of farm workers as overemphasizing the role of students, who can readily be found in December, and as underemphasizing the role of alien workers, mainly from Mexico, who do not all remain in the U.S. during the winter.



KIND OF FARM WORK done by hired workers in 1981 is charted according to the number of workers in each type of crop production. In the fruit and vegetable sectors many of them are aliens doing handwork; most of the hired workers for other types of farm are U.S. citizens.



STARFIRE FUSION REACTOR emerged on paper from a two-year design study led by the Argonne National Laboratory; it employs magnetic fields to confine a fusion plasma (a gas of ionized deuterium and tritium, the heavy isotopes of hydrogen) inside a toroidal chamber. Two cuts through the torus are shown. The left cut passes through one of the 12 superconducting magnets that form hoops around the torus. Other superconducting magnets are concentric with the torus. The right cut shows the equipment positioned between the hooping magnets. Vacuum pumps remove the plasma, which makes contact only with a "limiter" protruding through the "first wall" of the reactor. Pipes carry coolant to the first wall and a "blanket." Ducts guide radio-frequency waves through the blanket. The waves help to drive a current in the plasma and also help to heat the plasma to a temperature of tens of millions of degrees. In each fusion reaction deuterium and tritium combine to produce helium, a neutron and energy.

The Engineering of Magnetic Fusion Reactors

Design projects under way and experimental reactors now being built will test the practicality of schemes for generating power from the thermonuclear fusion of ions trapped by magnetic fields

by Robert W. Conn

The quest to tap the energy of nuclear fusion by employing magnetic fields to confine an ultrahot plasma (an electrically neutral gas consisting of charged particles) and generate electric power has been in progress for more than three decades. It is now approaching fruition. At a construction cost of $314 million the U.S. has built the torus-shaped Tokamak Fusion Test Reactor (TFTR), which began operating last December at the Plasma Physics Laboratory in Princeton, N.J. The European Economic Community is building the Joint European Torus, also called the JET tokamak, at the Culham Laboratory near Oxford. Initial operation has recently begun. A comparable device, the JT-60 tokamak, is being built in Japan; operation is expected in 1985. Together these three reactors represent a worldwide investment of more than $2 billion. The experimental campaigns planned at TFTR and JET will culminate in 1986 with the "burning" of a deuterium-tritium mixture. (Deuterium and tritium are the heavy isotopes of hydrogen: H-2 and H-3. They are also the fuel that a commercial power-generating reactor will consume.) The JT-60 will consume only deuterium and the abundant, light isotope of hydrogen: H-1.

An alternative to the toroidal confinement scheme of a tokamak is also being explored. In the U.S. the Mirror Fusion Test Facility B (MFTF-B) is under construction at the Lawrence Livermore National Laboratory in California. It is a tandem mirror, a device in which a plasma is confined by magnetic and electrostatic barriers at each end of a linear sequence of magnets. At a potential construction cost of $209 million, it is scheduled for operation in 1986. The aim of MFTF-B is to confine a deuterium plasma under conditions approximating those required for a commercial tandem-mirror reactor. In this sense the MFTF-B will test the scientific feasibility of the tandem-mirror approach. In order to minimize its consumption of electricity the MFTF-B is being constructed with superconducting magnets. An important set of coils, a pair of *C*-shaped magnets called a yin-yang configuration, has already been built and successfully tested. Two large tokamaks, the *T*-15 in the U.S.S.R., scheduled for completion by 1986, and the TORE-SUPRA in France, scheduled for completion in 1988, will also have superconducting magnets.

The decisions to construct these major experimental machines were taken in the 1970's in recognition of three key factors. First, there had been (and continues to be) a series of remarkable achievements in magnetic-confinement research. Second, the vulnerability of the industrialized world to interruptions in its energy supply had been amply demonstrated by events such as the Organization of Petroleum Exporting Countries (OPEC) embargo of 1973. Third, there arose an awareness of possible limits to both the amount and the use of fossil fuels. In the 1980's, then, the fusion experiments will get under way, and if they perform as expected, the scientific feasibility of a magnetic fusion reactor will be established. Still, a question will remain. Is magnetic fusion practical in terms of engineering, economics and safety?

The fusion reaction between deuterium and tritium requires that a stringent condition be met: the electrostatic repulsion between the deuterium and tritium nuclei (deuterons and tritons), which each have one unit of positive electric charge, must be overcome by making the relative speed of the two equivalent to an energy of about 100,000 electron volts (100 keV). A gas of deuterium and tritium has a broad distribution of energies; hence an average of 5 keV is enough for the gas to sustain its thermonuclear burning. That corresponds, however, to a temperature of 58 million degrees Celsius. At such a temperature electrons are not bound to nuclei, giving rise to the fusion plasma.

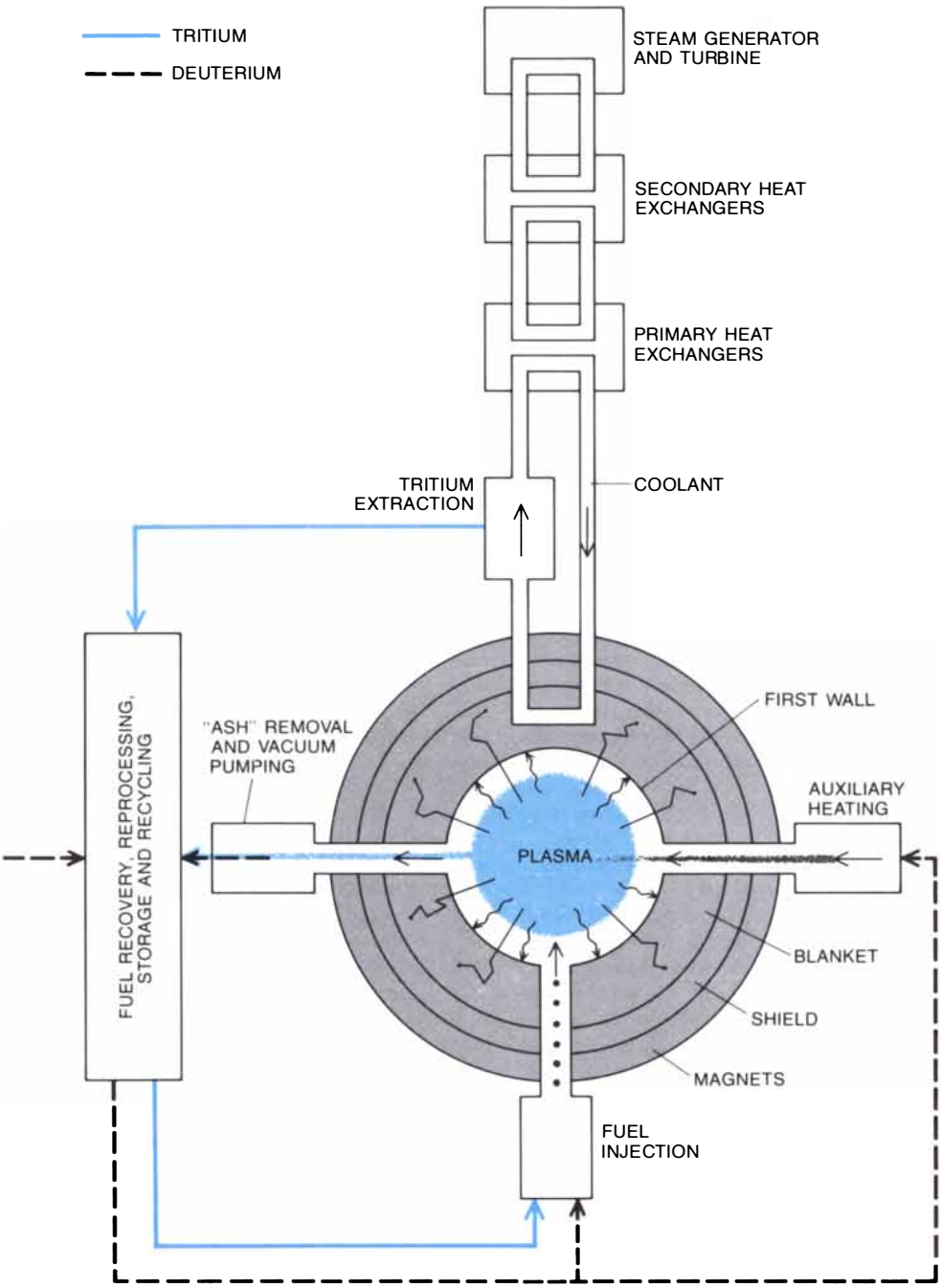
Each fusion reaction produces an energetic helium-4 nucleus (an alpha particle) and a high-velocity neutron. Because the neutron is electrically uncharged, it escapes from the plasma. The alpha particle does not escape; its positive charge of two units means it is trapped by the same magnetic field that serves to confine the plasma. With an energy of 3,520 keV it is much more energetic than the particles in the plasma, and so as it is slowed by collisions it gives its excess energy to the deuterons and tritons, thereby helping to maintain their temperature.

The necessary condition for the plasma to sustain its own thermonuclear burning—in a word, the requirement for ignition—is that the "confinement parameter," the product of plasma density (in particles per cubic centimeter) and average energy-leakage time (in seconds), exceed 3×10^{14}. If the confinement parameter is less than that value, the plasma's temperature cannot be maintained without auxiliary heating. The plasma can nonetheless yield energy. In effect it can act as a high-gain amplifier of the auxiliary power. The measure of the gain is the Q value, where Q is the ratio of the fusion power produced to the power injected to sustain the plasma temperature. At ignition Q becomes infinite. A reactor with finite Q is termed a driven machine because its fusion rate responds to changes in the auxiliary power input.

How should the plasma be confined? The broadest classification of magnetic confinement schemes depends on whether the magnetic lines of force are closed or open. Field lines that define a torus-shaped volume are the basic example of the former. Each charged particle in the plasma is locked to one of the lines. Specifically, it gyrates around the line but is free to move along it, thus

describing a corkscrew trajectory. Since the line meets itself, the particle is trapped. In the early approach called the stellarator the lines are produced entirely by coils outside the plasma. The plasma, once it ignites, can burn without external infusion of energy, and so the Q is infinite. In another approach, the tokamak, the lines are produced in part by external coils and in part by an electric current induced to flow in the plasma itself. In essence some of the external coils employed in a stellarator are replaced by a set of coils that act as the primary windings of a direct-current transformer. The plasma acts as a one-turn secondary winding.

Unfortunately a transformer cannot drive current in the secondary in one direction continuously because the current in the primary would then have to increase indefinitely. The transformer must thus be reset, and so the thermonuclear "burn" must be allowed to terminate periodically. Present estimates call for tokamak reactors to produce energy in pulses lasting for about 1,000 seconds with pauses of from 30 to 60 seconds. An energy-storage system would ensure a continuous supply of power to the turbines generating electricity in a commercial reactor installation, but the pauses would clearly impose design limitations on reactor components because of an increase in cyclic fatigue.



ENGINEERING PRINCIPLES common to all magnetic fusion reactors are diagrammed. A magnetic field must confine the fusion plasma; an auxiliary heating system must help to raise its temperature; a fuel-recycling system must keep it pure and well supplied with thermonuclear fuel. The heat the plasma releases must be withstood by the first wall of the reactor. The neutrons the plasma releases must penetrate into the blanket, where the energy the neutrons deposit must be transferred (in the form of heat) to a coolant. In turn the coolant can generate steam, the steam can drive turbines and the turbines can generate electricity. Nuclear reactions in the blanket must also "breed" tritium, which is radioactive and is extremely rare in nature.

Other ways to drive a tokamak's plasma current are therefore being investigated. If they are successful, they will enable tokamaks to operate steadily, or at least in very long pulses, on the order of one day. The most promising idea is to launch unidirectional radio-frequency (R.F.) waves into the plasma at a frequency of about three billion hertz. The waves' momentum can be transferred to the electrons, pushing them along the magnetic field and thereby driving electric current. Experiments at the Massachusetts Institute of Technology and at Princeton University have demonstrated the process. The key question is whether it works efficiently at the density of a fusion plasma. Theoretical estimates give values of from 10 to 20 for the Q of a reactor with R.F. current drive. A Q of 20 is about as low as one can accept for a commercial tokamak reactor.

In the second broad class of magnetic confinement schemes the field lines are open. The most basic configuration is a single-cell magnetic mirror. Here a set of magnets produces a field that has two peaks in its strength. Each peak is a "bottleneck" region, where the lines of force are close together. Consider a charged particle locked to one of the lines somewhere between the two peaks. As the particle approaches either peak it must continue to conserve energy and angular momentum; thus its energy (and motion) parallel to the field is converted into energy (and motion) perpendicular to the field. The motion parallel to the field can actually be reversed, so that the particle is trapped between the peaks.

A single-cell magnetic mirror is not a perfect container: particles colliding and scattering off one another can leak through the throat of a bottleneck. Electrons scatter much more rapidly than ions and therefore leak out faster. As a result the remaining plasma develops a positive electrostatic potential, which reduces the further flow of electrons just enough so that the currents of electrons and ions match. To sustain the density of ions, beams of neutral atoms at an energy of some 200 keV could be injected into the plasma. The neutral atoms would pass through the magnetic field unaffected and be ionized and trapped

when they collided with the plasma's electrons. The Q of a single-cell magnetic mirror sustained in this way is calculated, however, to be only about 1.

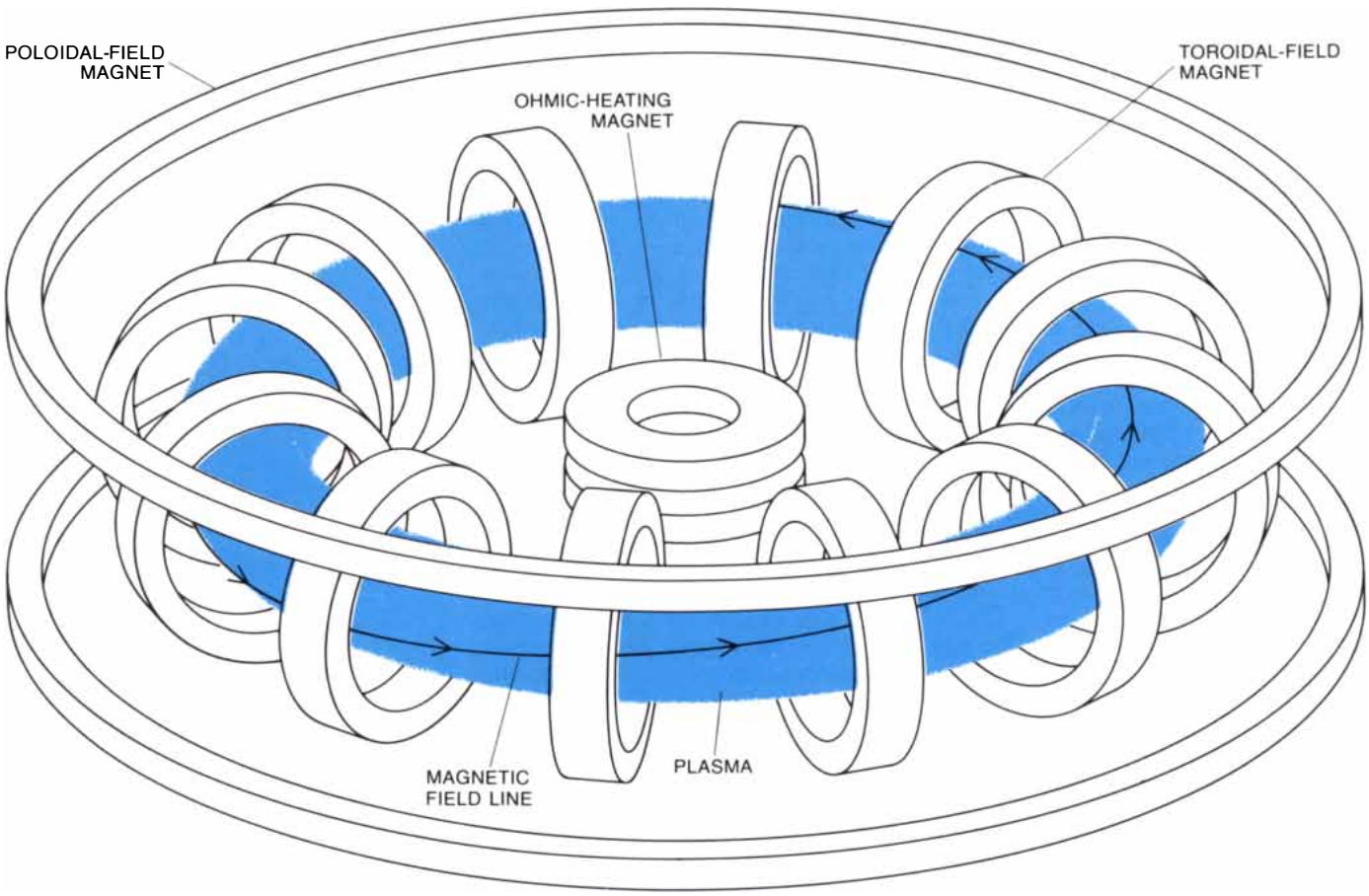
Alternatively two mirror cells can be connected magnetically to form a tandem mirror. The peak of electrostatic potential in each cell now acts as a "plug" to trap ions electrostatically in a central valley of potential between the mirror cells. Meanwhile a smaller but deeper valley inside each mirror cell serves to isolate the electrons in the cells from those in the central valley. This barrier allows the mirror-cell electrons to be heated to a high energy, thus creating the mirror-cell potentials quite efficiently. The electrons are heated by R.F. waves whose frequency, typically from 30 to 100 billion hertz, matches the electron cyclotron frequency (the frequency at which electrons gyrate around magnetic field lines in the plasma). The heating of end-cell electrons and the plugging of central-cell ions have both been demonstrated recently at Livermore.

Energy is required continuously to sustain the mirror-cell plasmas in a tandem mirror. Estimates are that its Q is between 10 and 30. It is important to note, however, that the energy of charged particles that do leak from the ends of the reactor can be recovered by directing the particles into devices that are in essence the reverse of particle accelerators. The production of electricity by such "direct convertors" (to supplement the power produced by the fusion reactions) can be 50 percent more efficient than the production of electricity by heating water and directing steam into a turbine. The estimates suggest that the minimum Q required of a practical tandem-mirror reactor is roughly 10, or about half the minimum Q required of a practical tokamak.

Investigations into the engineering practicality of fusion reactors began in earnest about 10 years ago. There were at least two motivations. One was to determine the dimensions of the more difficult engineering problems. The results often served as a guide to specific further research. The second was to make it clear that certain aspects of the physics of a reactor may compromise the engineering of a particular scheme of confinement. The results often encouraged ideas in physics that helped to mitigate the engineering problems.

The main engineering features of magnetic fusion reactors are common to all confinement schemes. In the first place, most concepts for magnetic fusion reactors call for superconducting magnets to minimize the power required to maintain the magnetic field. Typically a field strength of 50,000 gauss is needed over a volume of from 3,000 to 10,000 cubic meters. (The average value of the earth's magnetic field is about half a gauss.) If nonsuperconducting magnets were used, the power consumed by the magnets would exceed the reactor's output.

Superconductivity is a property that is shared by many metals and alloys. Basically a phase transition takes place when the material is cooled below some critical temperature, so that the electric resistivity of the material drops to zero. In practical alloys such as niobium-titanium in a ratio of one to one or niobium-tin in a ratio of three to one, superconductivity occurs at temperatures less than 20 degrees Kelvin (degrees C.



TOKAMAK scheme of plasma confinement is the one employed in STARFIRE. It requires three groups of magnets. Toroidal-field magnets set up a field whose lines of force are concentric with the torus formed by the plasma. Ohmic-heating magnets act as the primary turns of a transformer; they induce an electric current in the secondary turn, which is the plasma itself. The current heats the plasma. In addition it sets up a poloidal magnetic field: a field whose lines of force are loops at right angles to the toroidal field. Poloidal-field magnets contribute some of the transformer action. In addition they set up a magnetic field whose vertical lines of force counteract the plasma's tendency to spring outward from a torus. The net magnetic field consists of helical lines of force. Each charged particle in the plasma gyrates around a line and advances along it, but since each line is closed (it meets itself after a few turns around the torus) the particle is trapped.

above absolute zero). The alloy is made into filaments, which are twisted together in groups and embedded in a copper matrix. The resulting conductor is then set in additional copper in order to stabilize it and to ensure that the magnet will continue working even if some malfunction causes the loss of superconductivity. A typical current density is from 20,000 to 40,000 amperes per square centimeter. Layers of conductor are generally interleaved with stainless steel supports; layers of insulation intervene between the two. The interleaving is surrounded by a stainless steel dewar, or cooling vessel.

The coolant is liquid helium, which boils at 4.2 degrees K. A common approach is to provide passages for the helium so that the conductor makes contact with a helium bath. Heat generated in the conductor causes the helium to boil, and the resulting vapor carries the heat away. The vapor is then condensed in a refrigerator. A modern liquid-helium refrigerator requires about 500 watts of power to remove one watt of heat deposited at 4.2 degrees K. Nevertheless, the consumption of power by the magnet refrigerators in a reactor generating a million kilowatts of electricity is expected to be modest, on the order of 10,000 kilowatts.

A substantial part of the magnet-design problem is structural. Superconducting magnet coils can be regarded as large pressure vessels containing the energy stored in the magnetic field. In tokamaks and tandem mirrors the amount of energy is from 50 to 100 billion joules. The forces arising from that storage are both in the plane of the coil and across it. In a tokamak, for example, the toroidal component of the magnetic field (that is, the component concentric with the torus) is produced by circular or *D*-shaped coils through which the toroidal plasma passes. The in-plane load produces a radial force on each coil that amounts to about 15,000 pounds per square inch; it places the coil in tension. Meanwhile an out-of-plane load that varies with position acts to overturn the coil.

There is every indication that the investment made so far to develop stable, steady-state superconducting magnets will make such magnets available when fusion reactors need them. Magnets generating fields that change over time at rates as high as 10,000 gauss per second present more difficult problems. The changing fields entail time-varying forces and also induce eddy currents in the coil casings. The eddy currents dissipate as heat in the helium coolant and add to the refrigeration load. Will reactors need time-varying fields? Tandem-mirror reactors will not, but tokamaks might, unless radio-frequency waves prove capable of driving the plasma current up to its operating value. Here, then, is an instance in which the outcome of physics experiments will profoundly influence the technology (perhaps even the engineering feasibility) of a confinement scheme.

A second engineering feature common to all confinement schemes is that auxiliary heating is required to raise the temperature of the plasma. If the plasma carries a current, the resistive heating will help but will generally be insufficient. The two commonest auxiliary-heating techniques employ radio-frequency waves or intense beams of high-energy neutral atoms or molecules.

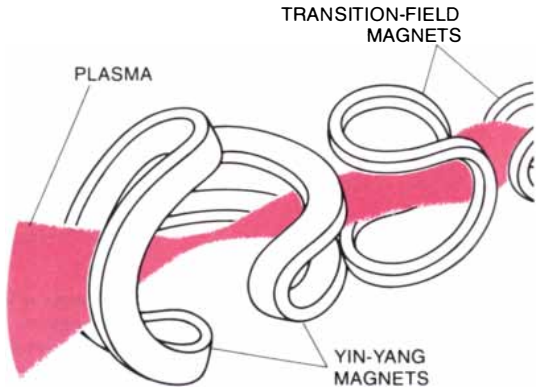
Radio-frequency heating occurs when electromagnetic or electrostatic R.F. waves are converted into thermal energy by a resonant interaction between the waves and the plasma particles. Three frequency regimes are receiving much attention. The first ranges from 50 to 100 megahertz, where the wave frequency matches the ion cyclotron frequency or one of its harmonics. The second ranges from one to three gigahertz, where the wave frequency matches the frequency of fluctuations in the density of ions in the plasma. The third ranges from 50 to 100 gigahertz, where the wave frequency matches the electron cyclotron frequency.

All R.F. heating systems are in essence transmitting stations. They include an R.F. source, an amplifier, a transmission line and a launching structure at or inside the plasma-chamber wall. The source and the amplifier are tubes, klystrons or masers, depending on the frequency regime; the transmission line is a coaxial cable or a waveguide; the launcher is an antenna or a waveguide. The launcher must be hardened against damage from the neutrons and other forms of radiation emitted by the plasma. In addition a dielectric window must be interposed in the transmission line to pass the waves while preventing tritium, which is radioactive, from streaming into the system.

Intense beams of high-energy neutral particles (atoms or molecules) are the alternative method of plasma heating. In some schemes, such as tandem-mirror reactors, they are essential. The neutral particles move unaffected through the reactor's magnetic field and are ionized and trapped by collisions with the plasma's ions and electrons. The plasma is then heated as the fast ions are slowed by further collisions. The beam itself begins as a plasma produced by an R.F. plasma generator or by a high-current discharge. It is typically ionized hydrogen and deuterium atoms, with a significant admixture of diatomic and triatomic ionized molecules. The plasma is accelerated in one or more stages by a series of metal grids that must be continuously cooled and must not distort the beam. The objective is to produce particles moving parallel to one another at a single velocity.

Next the particles are neutralized by passing the beam through a chamber containing cold neutral hydrogen or deuterium gas. The ions each pick up an electron from a cold neutral atom in what are called charge-exchange reactions. The cold neutral atoms, which have now become ions, drift to a wall of the chamber and are collected. Meanwhile the beam passes into a drift tube. The small fraction of ions remaining in the beam is deflected by a magnet. The main beam, consisting of neutral atoms, passes across the reactor's magnetic field and into the plasma.

The technology of neutral-beam systems is made difficult by the combination of energy, power and current that fusion reactors will require. For adequate penetration of the beam into the fusion plasma the beam's energy will have to be 100 to 200 kilovolts. And since the heating of the plasma may require as much as 100 megawatts a beam of, say, 200-kilovolt particles will have to transport the particles at a rate equivalent to a current of 500 amperes and at a current density equivalent to about one ampere per square centimeter. Such needs are enormous in comparison with the attributes of ordinary particle accelerators in the laboratory, whose current at 200 kilovolts is measured in thousandths of an ampere.



TANDEM MIRROR scheme of plasma confinement is an alternative to the tokamak. It relies in part on magnetic fields, in part on the

Nevertheless, the progress in neutral-beam engineering has been truly remarkable. Neutral-beam systems developed in the early 1970's at the Oak Ridge National Laboratory and the Lawrence Berkeley Laboratory delivered about 100 kilowatts of power in a beam with an energy of about 10 kilovolts. The pulse length was very short: less than .05 second. Today beam systems on test stands deliver 10,000 kilowatts of power at an energy greater than 100 kilovolts for periods approaching half a minute.

The heat deposited in the plasma by the auxiliary heating system must eventually come back out, accompanied by the heat that alpha particles have transferred to the plasma. The rate can be predicted: in a reactor intended to generate perhaps 1.2 million kilowatts of electricity it will be between .5 and one million kilowatts. Clearly the engineering of the components surrounding the plasma to handle heat is a major concern.

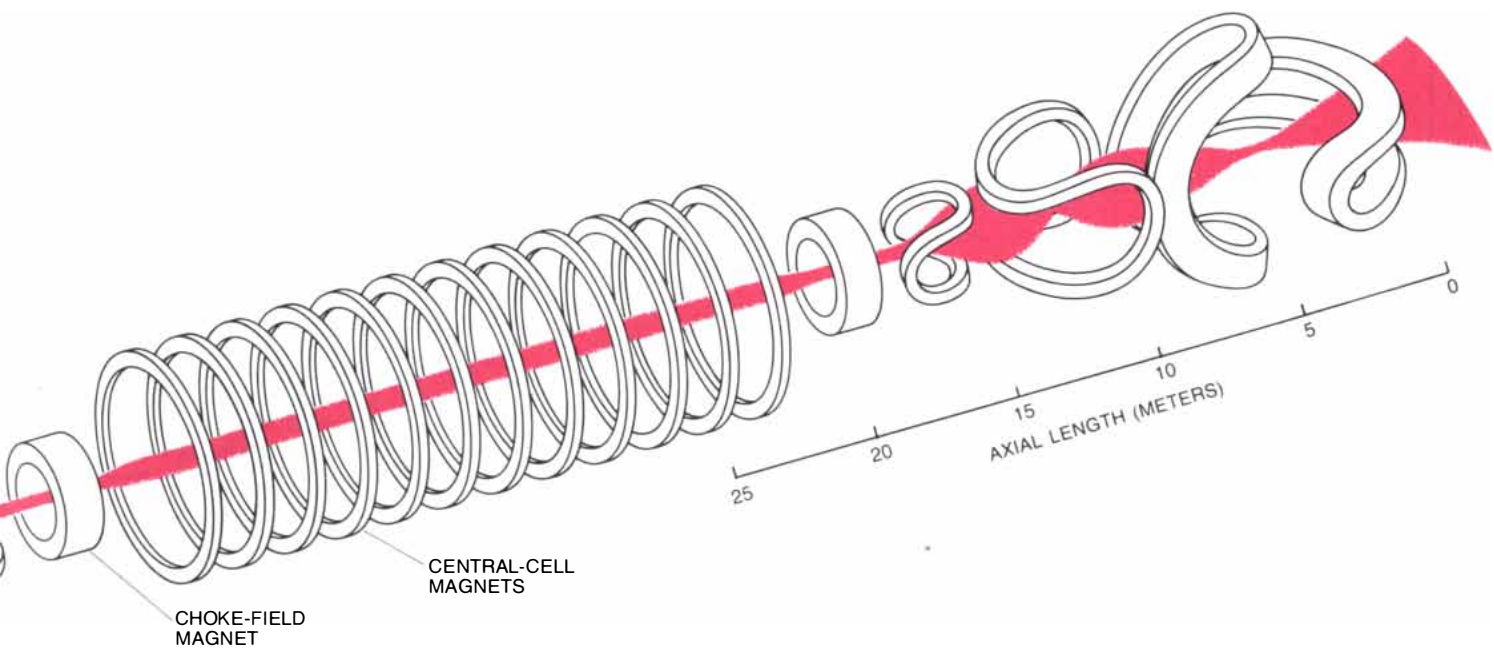
The heat losses will take several forms. For example, electromagnetic radiation (primarily X rays) will be emitted by the plasma. Impurity atoms in the plasma can greatly increase the rate of such radiation; hence attention is being given to maintaining the purity of the plasma and minimizing the erosion of the first wall (the inner surface of the plasma vessel) and the various in-vessel structures. In open-ended designs such as tandem mirrors charged particles are lost primarily from the ends of the plasma; they can be handled at a place remote from the plasma vessel.

In toroidal reactors the situation is different: charged particles diffusing radially outward from the center of the plasma represent the major loss. Such particles will interact with a limiter, a specially designed device capable of handling a heat loading as great as 10 million watts per square meter. Situated inside the first wall, it is a material contact point for the plasma. In some designs a special magnetic-field configuration will divert plasma particles, and the heat they carry, from the plasma vessel to a "divertor region," where the heat can be removed from the reactor by collector plates and the backstreaming of neutral gas and impurities can be minimized.

The related problem of first-wall erosion under the impact of plasma particles has been controlled in recent experiments by making the limiter out of materials such as graphite (carbon) that have a low atomic number. (The emission of radiation by impurities in a plasma tends to increase with increasing atomic number.) Chemical reactions between hydrogen and carbon, however, are likely to prevent the use of graphite inside the first wall of a reactor. Workers at the Sandia National Laboratory and elsewhere are developing special materials such as silicon carbide and titanium carbide for use as coating on components that must withstand both a heat flux and a plasma-ion bombardment.

I come now to the production of power by the reactor. Only a fifth of the energy released in the reaction of a deuteron and a triton is taken away by an alpha particle. The remaining four-fifths is taken away by a 14-million-electron-volt (14 MeV) neutron, which flies freely out of the plasma, into the first wall and the surrounding region: the blanket. The blanket has two functions. First, it recovers the neutron's energy. A 14-MeV neutron typically travels about 10 centimeters between collisions with the nuclei of solids or liquids. At each collision the neutron transfers energy to the target atom, its trajectory is changed and heat is deposited locally in the blanket. Coolant flowing through the blanket removes the heat and transports it to a relatively conventional power plant consisting of heat exchangers, steam generators and turbines. The neutron can also be absorbed by a nucleus, transforming the atom into one that may be stable or radioactive. The neutron flux attenuates with distance from the first wall; hence the blanket is typically 60 to 80 centimeters thick. Neutrons leaking from the back of the blanket are captured by a shield designed primarily to protect the superconducting magnets from radiation damage and excessive heating.

The second function of the blanket is



electrostatic field arising from the distribution of electric charge in the plasma. Here the required magnets are shown. Ring-shaped magnets surround a central cell of plasma. Then at each side of the cell is a choke-field magnet, a pair of transition-field magnets and a pair of magnets in what is known as a yin-yang configuration. The scale toward the right matches the scale in the chart on the following page.

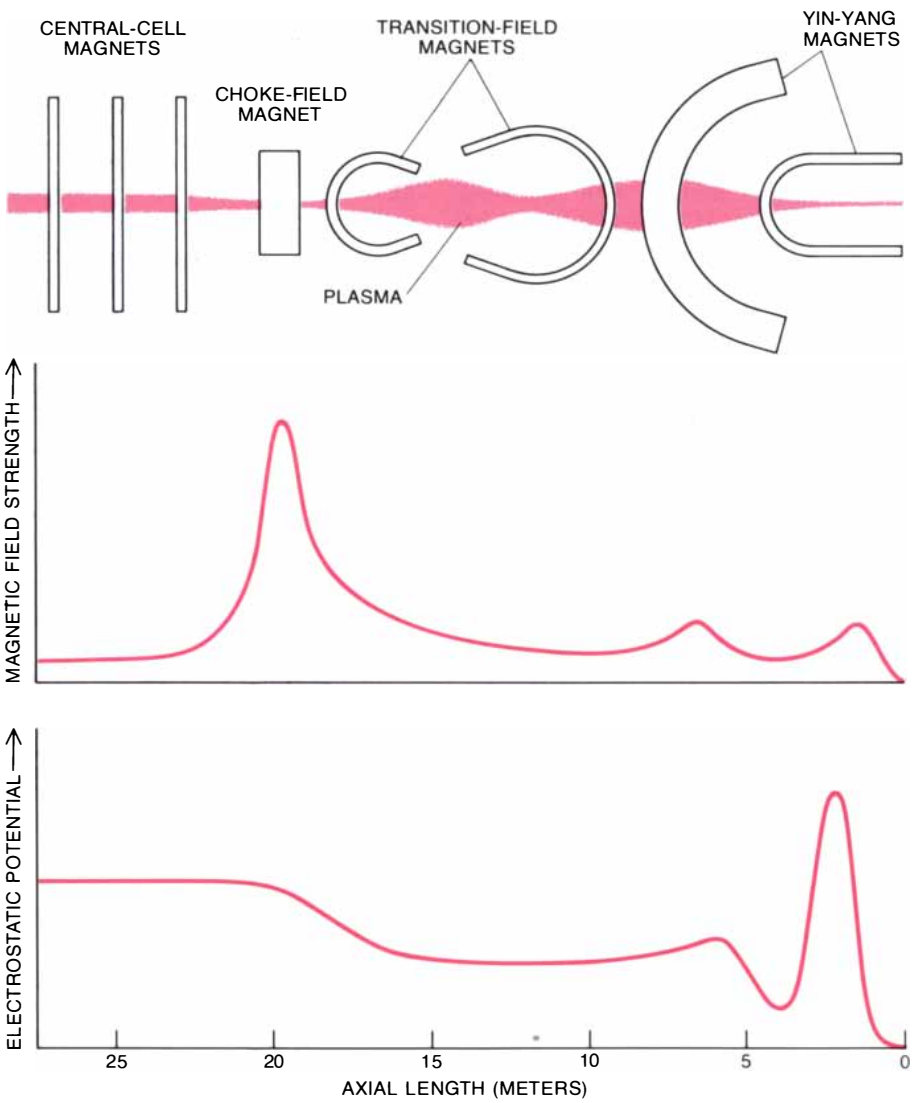
to make fuel for the reactor. Deuterium is plentiful (it is found at a ratio of about one part in 5,000 in ordinary water), but tritium is radioactive, with a half-life of 12.35 years, and so it is not abundant in nature. (Minute amounts of it are produced by cosmic-ray reactions in the upper atmosphere.) Fortunately tritium can be "bred." Specifically, the 14-MeV neutron produced in the fusion reaction can be used to induce nuclear reactions with the two naturally occurring isotopes of lithium: lithium 6 and lithium 7. Neutrons of any energy can be captured by lithium 6 to produce tritium and helium; neutrons with an energy greater than 2.87 MeV can be captured by lithium 7 to produce tritium, helium and another, slower neutron. The breeding ratio of the reactor (the number of tritons produced per triton consumed) depends on details of the design, but it can be as high as 1.5.

The ingredients of a blanket design are thus the structure, the coolant and the tritium-breeding material. Leading candidates for the structure are stainless steels, ferritic or high-manganese steels and vanadium alloys. Leading candidates for the coolant are water, a gas (such as helium) or a liquid metal. The leading liquid metals are lithium and lithium-lead compounds and eutectics. Liquid lithium is attractive because it has a low melting point (186 degrees C.), excellent heat-transfer properties, good chemical compatibility with most structural alloys and acts simultaneously as the tritium-breeding material.

The tritium could be recovered from a side stream of the lithium. Since it would be in the form of lithium tritide, one recovery method would be to bring the side stream into contact with an equal volume of a molten salt such as a mixture of lithium fluoride, lithium chloride and lithium bromide. The lithium tritide would tend to pass into the salt, but the two are readily separated because the lithium tritide is three to four times lighter. The tritium is then recovered by electrolysis. The overall process is a simplified version of the molten-salt reprocessing technique that was developed to reprocess fission-reactor fuel.

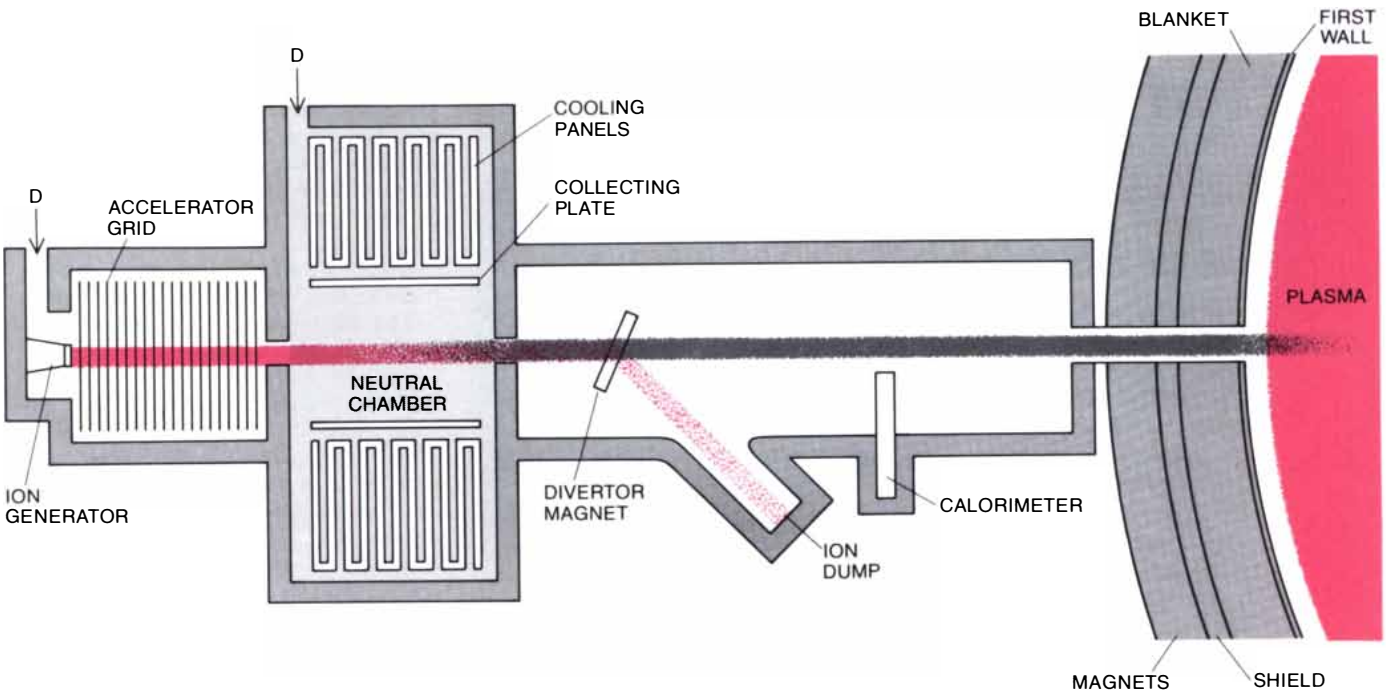
Ceramic compounds including lithium oxide, lithium aluminate and lithium silicate are alternative tritium-breeding materials. Two of their advantages are that the amount of lithium in the reactor can be modest and that the compound is chemically stable. On the other hand, a breeding ratio greater than one will be difficult to achieve. In lithium aluminate ($LiAlO_2$), for example, aluminum and oxygen atoms compete with the lithium to scatter neutrons or absorb them. What is needed is a neutron multiplier. Positioned in the blanket just behind the first wall, it converts one very fast neutron into two slower neutrons by means of a nuclear reaction. The best neutron multipliers are beryllium and lead.

The recovery of tritium from a ceramic is difficult since it relies on the diffusion of tritium out of the solid. The typical diffusion rate is low, and so the ceramic must be fabricated in pellets composed of grains whose size is on the order of 10^{-3} millimeter. Yet the ceramic must not sinter, even when its temperature approaches or perhaps exceeds 1,000 degrees C. The tritium diffusing from the ceramic would be transported from the blanket in a purge stream of helium gas flowing through the pellet beds. Whether the breeder will perform according to the design is a major question likely to be answered only through experimentation.



FIELD STRENGTH AND ELECTRIC POTENTIAL at each end of a tandem-mirror reactor result from magnets, from the heating of the plasma by beams of high-energy electrically neutral particles and from the pumping of ions out of certain regions of the plasma. The charts show the strength of the magnetic field and the electrostatic potential toward either end of a tandem mirror. Ionized atoms in the plasma tend to be trapped in the central cell by the magnetic peak at the choke magnet. In essence they are reflected by a bottleneck in the magnetic field. The bottleneck acts as a mirror. The ions that do get through the mirror tend to bounce off the electrostatic peak inside the yin-yang configuration. Electrons in the plasma tend to be repelled as they approach either side of the electrostatic valley inside the transitional region. The electrons isolated electrostatically in the end cell can thus be heated efficiently.

Certain engineering problems affect several components of a reactor. One such problem is neutron radiation damage. When a neutron is scattered or absorbed in a collision, some of its energy is transferred to the atom that it struck. The atom recoils from the site of the collision and displaces other atoms, some of them permanently. These other atoms, which are called interstitials, leave vacancies behind. The interstitials can form loops, and so can the vacancies. Indeed, the vacancies can form permanent voids, particularly if some agent such as gas is present to stabilize them. In the metallic components of a fusion reactor gas is indeed produced. For example, hydrogen and helium are produced when neutrons with an energy



NEUTRAL-BEAM INJECTION is one way to heat a fusion plasma. The particles in the beam (often deuterium atoms) are ionized and accelerated. Then they capture electrons from cold deuterium atoms, becoming neutral again. They can now cross a magnetic field, enter the plasma and transfer energy by collisions. An alternative is to heat the plasma with electromagnetic radiation at radio frequencies.

greater than about 5 MeV interact with metal atoms. In the course of the interactions some of the metal atoms can be transformed into radioactive isotopes of the same elements or different ones. As a result of all these changes the material's properties change. Commonly the material hardens and loses ductility.

The flux of 14-MeV neutrons through the first wall of a fusion reactor is measured in units of megawatts per square meter. A flux of 4×10^{17} neutrons per square meter per second represents a wall loading of one megawatt per square meter. The actual wall loading may be from three to five times as great. It is possible to calculate how many times per year an atom in the wall will be displaced from its site in the lattice of a material for each megawatt-per-square-meter load. The number is staggering. In a stainless steel first wall every atom will be displaced 10 to 20 times. Since practically all the displaced atoms come to rest at some vacant site, the steel does not turn to jelly. The problem is nonetheless clear. The same load will also produce about 150 helium atoms and 500 hydrogen atoms per million metal atoms per year.

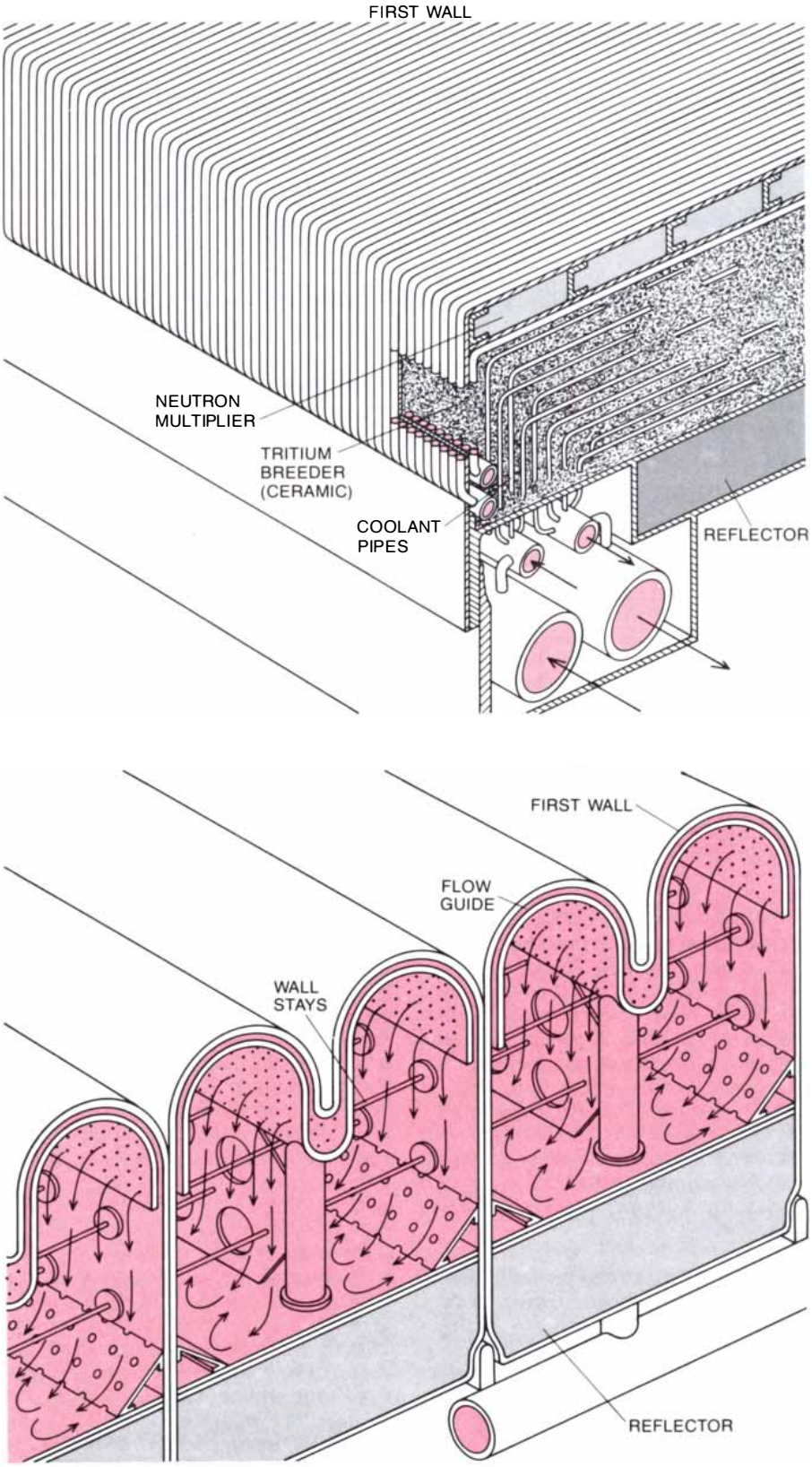
After plasma confinement the changes in materials due to radiation damage are perhaps the most challenging problem confronting the engineers of fusion reactors. Research has begun with the irradiation of metal samples in fission reactors such as the High Flux Isotope Reactor at Oak Ridge, which is designed to produce great numbers of neutrons having a wide spectrum of energies. When the sample is an alloy including nickel, thousands of helium atoms per million metal atoms are produced, and changes such as swelling and embrittlement have been observed. A preliminary estimate is that the first wall and the blanket in a working fusion reactor would retain adequate properties for from three to six years. The implication is that fusion reactors must be designed with a first wall and blanket that can be replaced periodically throughout the life of the plant. Clearly much further research is needed. A special high-flux 14-MeV-neutron-source facility, the Fusion Materials Irradiation Test, is being considered for construction by the U.S., possibly in collaboration with Western European countries and Japan. It will be an important part of a program to develop adequate materials for fusion reactors.

In both tokamaks and tandem mirrors the rate of leakage of thermonuclear fuel from the plasma is 10 to 20 times greater than the rate of fuel consumption. This makes fuel recovery and recycling an imperative. The recovery is a challenge because the pumping rate must be high, ranging from one to 10 million liters per second, and the vacuum left behind in the reactor vessel must be impressive, about 10^{-7} atmosphere. Currently cryosorption pumps operating at the temperature of liquid helium appear to be the best of the technical alternatives.

Cryopumps include an array of molecular sieves that are cooled by liquid helium to a temperature of 4 degrees K. The sieves are surrounded by chevrons that are cooled by liquid nitrogen to a temperature of 77 degrees. Volatile gases such as hydrogen, deuterium and tritium condense on the sieves; less volatile gases such as oxygen, nitrogen and methane are adsorbed by the chevrons. Helium can also be captured if liquid argon is sprayed onto the surfaces of the pump; the argon traps the helium by overlaying it. Cryopumps have a high pumping speed but require periodic removal of the gases they trap. Moreover, the trapping entails a high inventory of tritium in the reactor. In response to these difficulties designs have been developed in which devices such as magnetic divertors or pump limiters raise the gas pressure at the beginning of the pumping ducts to about 10^{-5} atmosphere. Pumps that do not trap fuel can then be employed.

Once the exhaust stream is purged of its elemental impurities (including the helium "ash" produced by the fusion reactions) it is necessary to separate the unburned deuterium and tritium so that they can be combined in proper proportion with tritium recovered from the blanket. The separation is most straightforwardly accomplished by distillation at cryogenic temperatures, making use of the difference in the boiling points of H_2, DH, D_2, HT, DT and T_2. The least volatile is H_2, with a boiling point of 20.39 degrees K.; the most volatile is T_2, with a boiling point of 25.04 degrees. Acceptable purity can be obtained using distillation columns with about 60 stages.

The reconstituted deuterium-tritium mixture must then be reinjected into the



FIRST WALL AND BLANKET vary in design depending on the choice of coolant and of tritium-breeding material. In the design at the top the coolant is water (*color*) and the breeder is lithium aluminate or lithium oxide, each a solid ceramic. Neutrons escaping the fusion plasma transform lithium in the ceramic into tritium, helium and additional neutrons. The tritium then diffuses out of the ceramic and is flushed out of the blanket by a stream of helium gas. The production of tritium is increased by a neutron reflector (graphite) under the blanket and by a neutron multiplier (beryllium or lead) above it. Nuclear reactions in the multiplier absorb fast neutrons from the plasma and emit twice as many slower ones. In the design at the bottom the coolant and the breeder are the same: they are liquid lithium (*color*). The tritium is recovered by removing it from the coolant on its way to the reactor's heat exchangers. Both designs in the illustration were prepared as part of the STARFIRE study of the design of a tokamak.

plasma. In current experiments with hydrogen plasmas puffs of gas are aimed at the edge of the plasma, which readily ingests them. In a reactor the ingestion may not be as effective; the gas atoms would be ionized no farther than 10 centimeters in from the plasma's edge. Ten or more puffing systems would be required, each consisting of a nozzle and a fast-acting valve. Each would produce puffs lasting 50 to 100 milliseconds.

The alternative is the high-speed injection of frozen fuel pellets. The process has been demonstrated in an experimental tokamak at Oak Ridge and seems sure to work in a commercial reactor. Each pellet is truly a snowball in hell: made at a temperature of less than the freezing point of deuterium (18.73 degrees K.) and tritium (20.62 degrees), it would be shot into a plasma whose temperature is tens of millions of degrees. It is envisioned that each pellet would be two to four millimeters in diameter and would contain 10 to 15 percent of the total number of fuel atoms in the plasma at any instant. The pellets would be accelerated to a speed of about two kilometers per second and then injected at a rate of 10 to 20 pellets per second. Except for the injection rate these operating parameters have already been achieved.

Two types of injectors have been proposed. Centrifugal injectors consist of a high-speed rotating plate on which two *U*-shaped tubes are mounted. A feed line cooled by liquid helium extrudes solid fuel into one of the openings of each *U,* and a knifing action cuts the fuel to form a pellet inside the tube. The rotation of the plate then accelerates the pellet so that it emerges from the tube at high velocity. In experiments at the Max Planck Institute for Plasma Physics in Garching and at Oak Ridge one-millimeter deuterium pellets have been accelerated to speeds of 290 meters per second. The devices should ultimately be able to accelerate pellets to speeds of from two to five kilometers per second. A high repetition rate is a built-in characteristic of the scheme.

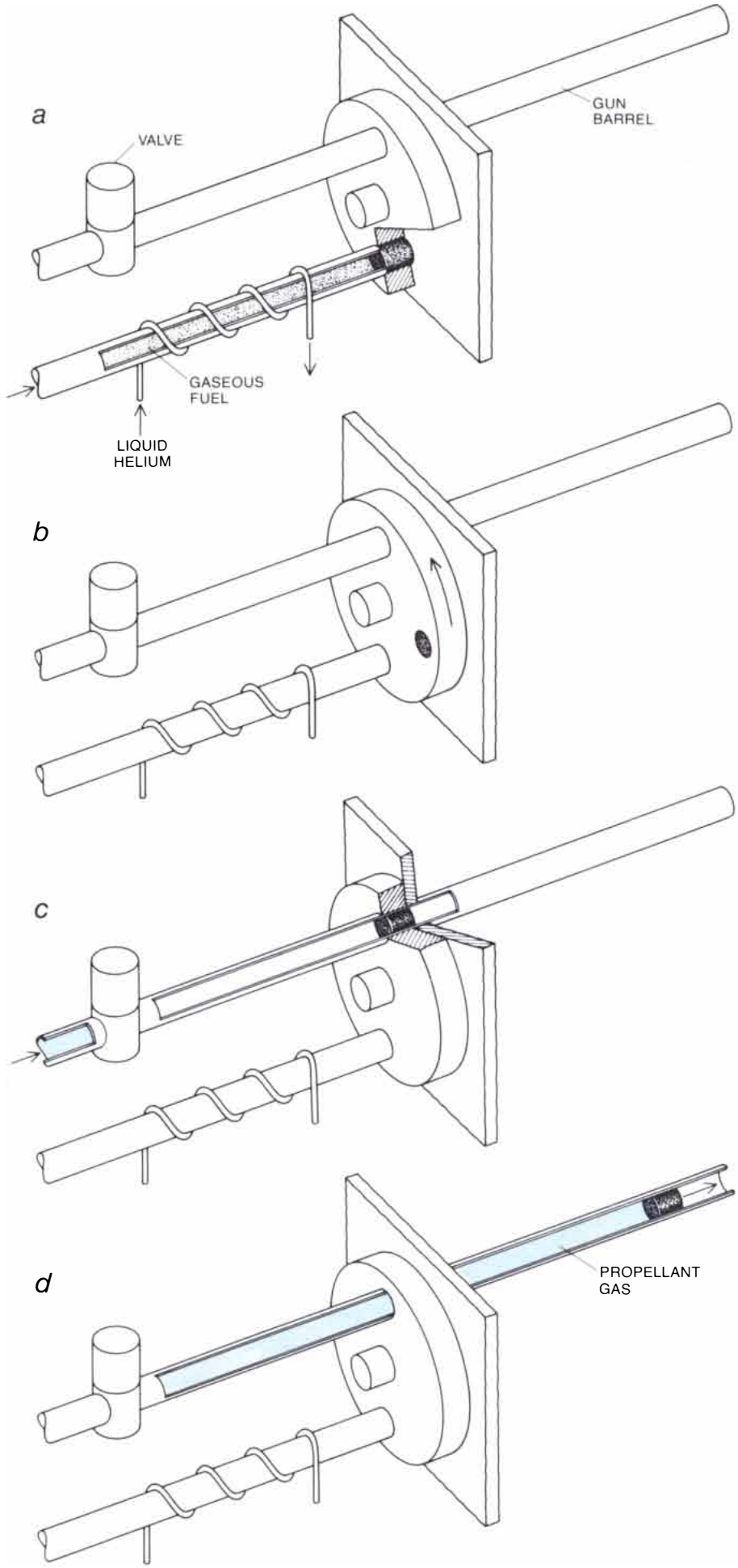
Gas guns are also being developed. Indeed, they have accelerated one-millimeter pellets to a speed of one kilometer per second. In a design worked out at Oak Ridge a disk cooled by liquid helium is in a copper housing; one-millimeter holes have been drilled through the disk. Gaseous fuel freezes in each hole, and the disk is rotated so that the resulting slug of fuel comes into line with a fast-acting valve at the end of a gun barrel 16 centimeters long. The valve releases helium gas, which has been compressed to a pressure of 30 atmospheres. The gas propels the slug. Performance can be improved by using hydrogen as the propellant and by increasing the length of the barrel.

Since tritium is radioactive one must

ensure that throughout the fuel cycle the tritium is well contained in the reactor. The required degree of containment can be determined by a simple calculation. The inventory of tritium in a power-producing reactor is expected to be about 10 kilograms, or about 100 million curies of radioactivity. (One curie is equivalent to 30 billion nuclear disintegrations per second.) A safe and allowable escape rate has not yet been established, but research groups contemplating reactors have used figures ranging from one to 10 curies per day. This means that the reactor must routinely lose no more of its tritium per day than one part in 100 million.

The containment can be achieved by providing at least three physical barriers at each point in the tritium handling. The first barrier is the structural element containing the tritium, say a pipe. Then comes a barrier surrounding the structural element. For example, a pipe could be within a second pipe or a group of tritium-handling components could be within a glove box. The third level of containment would be the reactor hall, the rooms containing the tritium-processing equipment and so on. Each would contain a tritium-cleanup system. It is estimated that a kilogram of tritium that had escaped in the reactor building could be removed in less than a day. The Tritium System Test Assembly, an experimental mockup of the entire tritium fuel cycle, has been constructed at the Los Alamos National Laboratory and is scheduled to begin operation soon. It should provide the information necessary to ensure the safe handling of tritium in future experimental facilities and then in reactors.

There is only one other source of radioactivity in a fusion reactor: the reactor itself, and in particular the first wall, the blanket and the shield, are made radioactive by the flux of neutrons through them. The amount and the nature of the radioactivity will depend on the materials of which the reactor is made. A useful figure of merit is the biological hazard potential, or BHP. The Federal Government lists the maximum permissible concentration of various radioisotopes in air or in water; the BHP is the ratio of the actual radioac-



FUEL INJECTION can be accomplished by propelling frozen pellets of deuterium and tritium into the plasma. In an injector devised at Oak Ridge National Laboratory a stream of gaseous fuel is frozen by liquid helium so that a slug of solid fuel is emplaced in a hole in a disk (*a*). The disk rotates (*b*), bringing the slug into line with a valve at the end of a gun barrel (*c*). The valve releases spurts of propellant (*color*): high-pressure helium gas (*d*). The injector in a fusion reactor will have to give pellets a velocity of two kilometers per second.

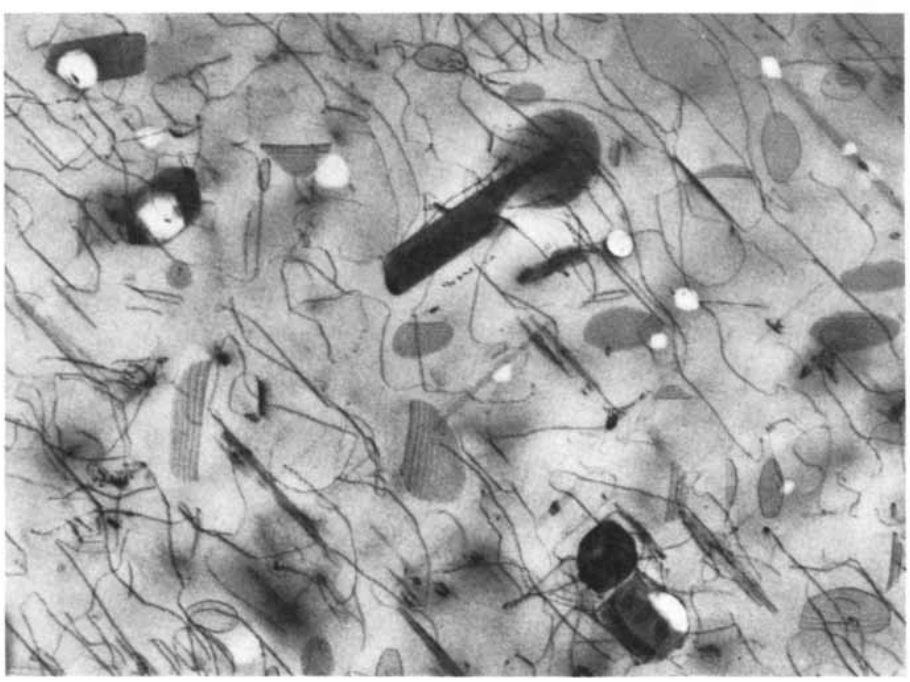
tivity (in curies per unit volume) to the Government's permissible level. For all materials of practical interest the BHP for a fusion reactor will be at least a factor of 10 below the BHP for a fission reactor. In many cases the factor of improvement will be more than 100.

Perhaps it is more important to ask whether the waste materials from a fusion reactor could be disposed of by shallow-land burial. Federal guidelines for such burial have recently been proposed. Under them three classes of waste are described. Class *A* waste is material that attains an acceptably safe level of radioactivity after no more than 10 years of shallow burial. "Acceptably safe" is defined to mean that a person inadvertently entering the burial site and staying there would receive a yearly dose of radiation no greater than five times the natural background level. Class *B* waste is chemically stabilized material that attains an acceptably safe level within 100 years. The material must stay stable and must be buried so that the dose to a person at the site would be no more than a few percent above the background level. Class *C* waste is chemically stabilized material that attains an acceptably safe level within 500 years. The material must be buried under at least five meters of earth and the site must have natural or engineered barriers to trespass. Materials that fail to meet these prospective guidelines would presumably require a more extreme disposal method such as deep storage in a suitable geologic formation.

Fusion reactors can be built of materials that would be suitable for shallow-land burial. Specifically, calculations show that fusion reactors built of an iron-manganese-chromium steel will yield waste materials of Class *C*. And if the reactors could be built of titanium, vanadium or aluminum alloys or of ceramics such as graphite and silicon carbide, the waste materials would be of Class *B*. Moreover, it may be possible to modify alloys that have useful mechanical properties but a tendency toward high radioactivity into ones that at least meet the Class *C* criteria. Attempts to eliminate nickel and molybdenum from steel alloys are an example of such an effort.

In the longer run it may even be possible to tailor the isotopic composition of a material so that its mechanical and chemical properties are unchanged while its tendency toward radioactivity is altered dramatically. Again consider molybdenum. In most steels it imparts high-temperature strength. It is typically 1 percent of the alloy. The natural isotopes of molybdenum that react with neutrons to form long-lived radioactive elements in a fusion reactor are those with atomic weights of 92, 94, 98 and 100. Suppose the molybdenum for the steel in a reactor consisted of only the remaining natural isotopes: 95, 96 and 97. Then the molybdenum could be added and the steel would nonetheless meet the criteria for Class *C* waste.

The economics of isotope separation are not yet firmly established; the present techniques were developed to separate only isotopes of uranium. A new technique being developed at TRW, Inc., could be used to separate lighter elements such as nickel and molybdenum. Moreover, a goal of $220 per kilogram has been established for uranium enriched to 3 percent in the isotope U-235. Suppose the isotopic tailoring of molybdenum proves to cost four times that much. The cost of a fusion-reactor blanket made with tailored-molybdenum steel instead of an untailored alloy would be increased by less than 5 percent.



NEUTRON-RADIATION DAMAGE that the materials in a fusion reactor will suffer was simulated by placing a sample of stainless steel in the core of a research fission reactor at a temperature of about 590 degrees Celsius and exposing it for a year to a high flux of neutrons. The total flux (1.9×10^{26} neutrons per square meter) displaced each atom in the lattice of the steel an average of 10 times. Some of the vacated sites in the lattice aggregated into voids (*white areas*); some of the displaced atoms aggregated into regions called dislocation loops (*medium gray areas*). In addition the chemical elements in the steel segregated (*dark gray areas*). As a result the steel swelled and became less ductile. The electron micrograph was made by F. W. Wiffen, J. O. Stiegler and E. E. Bloom at Oak Ridge; it enlarges the steel 110,000 diameters.

Two comprehensive design studies, one of a tokamak, one of a tandem mirror, have recently been completed. Each provides a glimpse of what fusion reactors may be like. The tokamak study, STARFIRE, was led by the Argonne National Laboratory in association with the McDonnell-Douglas Astronautics Company, GA Technologies and the Ralph M. Parsons Company. It took two years and cost more than $2 million, and it contemplated the design of a 1,200-megawatt fusion reactor. The device is impressively large: its toroidal plasma has a major diameter of 14 meters and a cross section of 4.2 meters. The plasma is confined by superconducting magnets. The toroidal field is generated by 12 such magnets that form hoops around the plasma's cross section. They generate a maximum field strength of 111,000 gauss, and together they store 50 billion joules of magnetic-field energy.

The plasma in STARFIRE is fueled by a combination of gas puffs and pellets, is heated by R.F. waves and carries a current of 10 million amperes. The current is sustained by R.F. waves in a process that has not yet been fully demonstrated. Without it the plasma burn would have to be allowed to terminate periodically, perhaps every 20 minutes or oftener, while the magnets representing the primary turns of a transformer were reset. In the course of the resetting the reactor chamber and the blanket would cool somewhat, thereby changing the stresses in the materials. The resulting mechanical fatigue would limit the life of the structures. The R.F. driving comes at a price, however; the price is power consumption. It is estimated that 150 megawatts, or more than 10 percent of the electric power produced by the reactor, must be recirculated to supply the R.F. system. The net efficiency of

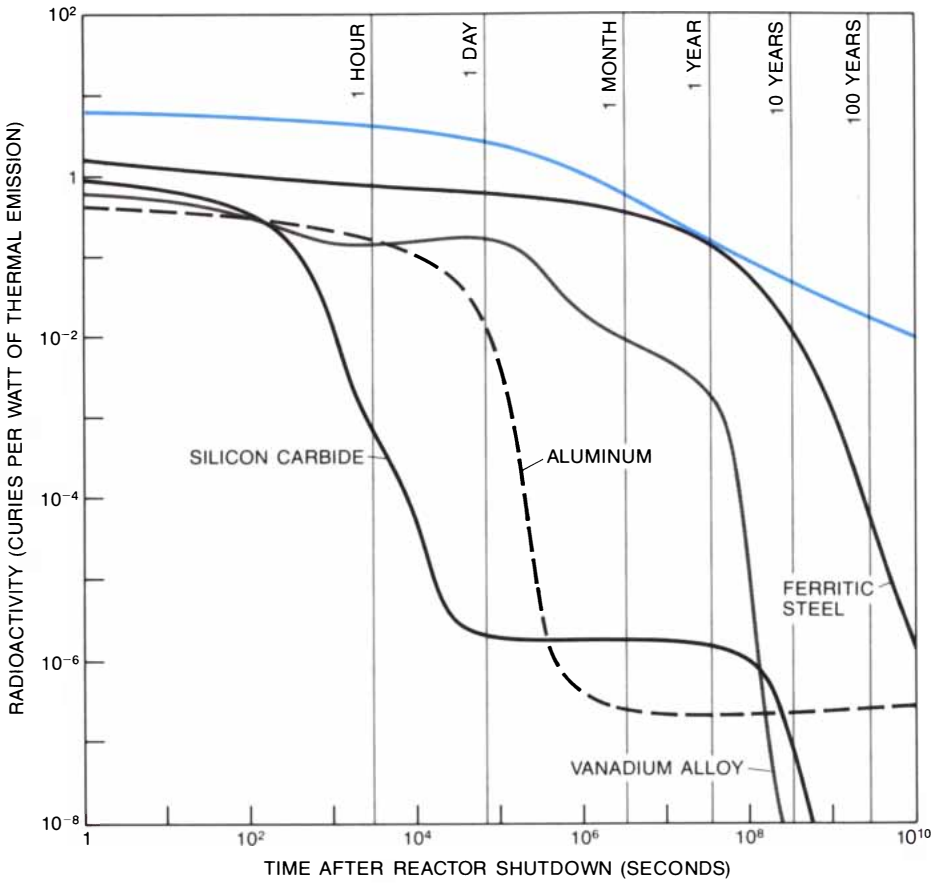
STARFIRE (30 percent) will have to be improved in future tokamak designs.

The blanket in STARFIRE is cooled by water pressurized to 2,200 pounds per square inch. The water enters the reactor at a temperature of 280 degrees C., picks up heat as it circulates through the blanket and leaves at a temperature of 320 degrees. As it circulates it passes through stainless steel tubes surrounded by tritium-breeding ceramic. A layer of zirconium-lead along the inner surface of the blanket serves as a neutron multiplier. Even so, the breeding ratio of the reactor is estimated to exceed one by no more than 5 percent. That is likely to be inadequate. Alternative designs are being developed.

The tandem-mirror study, the Mirror Advanced Reactor Study (MARS), is being led by the Lawrence Livermore National Laboratory in association with TRW, the General Dynamics Corporation and the University of Wisconsin. After two years it is nearing completion. It contemplates a long, linear reactor with a central plasma cell 129 meters long between a pair of end cells acting as mirrors that together add 48 meters. The central cell holds 75 cubic meters of plasma; it yields a continuous power output of 2,575 megawatts. The end cells are sustained by the continuous injection of neutral beams and R.F. heating. The central cell is fueled by gas puffs and pellets. A "halo" plasma surrounding the main cylindrical plasma keeps impurities from entering.

The magnets in MARS include 41 circular superconducting rings in the central cell; they generate a field of 47,000 gauss. In addition superconducting end-cell yin-yang magnets produce a maximum field of 75,000 gauss, and a magnet of special construction, combining water-cooled nonsuperconducting magnets and a superconducting magnet, produces a "choke field" of 240,000 gauss between the central cell and each end cell. A field of such intensity cannot be produced over large volumes by any wholly superconducting magnet known today. The entire magnetic field stores about 50 billion joules. Power is required to drive the nonsuperconducting magnets and refrigerate the superconducting ones, to circulate coolant, to sustain the end-cell plasmas and to operate auxiliary equipment. Indeed, 20 percent of the power produced by the reactor must be recycled. Nevertheless, the net efficiency of the reactor is 35 percent.

Three features of MARS contribute to that efficiency: the electrostatic barrier that separates hot electrons in the end cells from somewhat cooler ones in the central cell, the use of direct convertors to make electricity from the energy of charged particles escaping from the ends of the reactor and the use of a high-temperature coolant, lithium-lead, which enters the blanket at a temperature of 350 degrees C. and leaves at 500 degrees. Not all these features have been demonstrated experimentally. In addition the physics of tandem mirrors is not yet as advanced as the physics of tokamaks. Thus MARS embodies more assumptions than STARFIRE.



DECLINE OF THE RADIOACTIVITY induced by neutrons in the materials of a fusion reactor varies markedly from one material to another (*black curves*), suggesting that materials such as alloys could be tailored in composition so that they retain useful structural properties while becoming less hazardous. In general the decline of radioactivity of a fusion reactor is far more rapid than the decline of the radioactivity inherent in nuclear fission, exemplified by radioactivity in waste from one type of fission reactor, the liquid-metal fast breeder (*colored curve*).

The electrostatic barrier for electrons is an example. It is a region of low electrostatic potential that repels electrons on either side. Positive ions are attracted to the region, and if they are not removed, the dip will disappear. The designers of MARS have therefore incorporated a removal technique called drift-orbit pumping. So far it is entirely theoretical. Special half-moon-shaped coils modulate the magnetic field strength in the end cells by .03 percent at a frequency of about 100 kilohertz. The modulation induces ions to drift radially outward until their orbits extend beyond the realm of electrostatic and magnetic trapping. At that point they escape through the end of the cell.

The designs for tokamaks and tandem mirrors differ in many details. Sometimes the differences result from the need for unique technologies such as direct convertors. The designs have much in common, however, including technologies for vacuum pumping, fuel handling, superconducting magnets, plasma heating and fuel injection. Both STARFIRE and MARS point toward reasonable concepts for fusion reactors, and both show clearly where improvements are required.

Is magnetic fusion practical? The question cannot yet be answered definitively, but sufficient groundwork has now been laid so that the answer can be determined. The U.S., the Western European countries, Japan and the U.S.S.R. all have specific engineering development programs under way, and all of them participated in a multinational study to advance the design of tokamak reactors (INTOR). Perhaps a bilateral or multilateral agreement will facilitate the next major experimental steps. If it does not, the experiments now in progress are sure to be markedly upgraded. Either way, the coming decade will tell much about magnetic fusion engineering.

The Large-Scale Structure of the Universe

Across billions of light-years space is a honeycomb of galactic superclusters and huge voids. The structure may result from perturbations in the density of matter early in the big bang

by Joseph Silk, Alexander S. Szalay and Yakov B. Zel'dovich

Astronomers have long recognized that the distribution of matter on a cosmic scale must somehow bear the imprint of a very early stage in the history of the universe. A consistent account of that distribution and its evolution must be developed within the context of the big-bang theory, since there is almost universal consensus among cosmologists and astrophysicists that the big bang provides an empirical framework within which all cosmological issues can be examined. According to the big-bang theory, the universe began as a singular point of infinite density some 10 to 20 billion years ago and pulsed into being in a vast explosion that continues to this day. In the simplest version of the theory the universe expands everywhere uniformly from the singular point. The uniformity of that expansion accounts remarkably well for much important observational evidence: Extragalactic matter recedes from our galaxy at a rate that varies smoothly with its distance, and a cold bath of radiation in the microwave region of the electromagnetic spectrum pervades the sky at a temperature that varies over a few angular degrees to less than one part in 30,000. In spite of these successes, there is compelling evidence that the expansion is not precisely uniform. If it were, matter would fail to coalesce and the universe would become an increasingly rarefied gas of elementary particles. The stars and the galaxies would not exist.

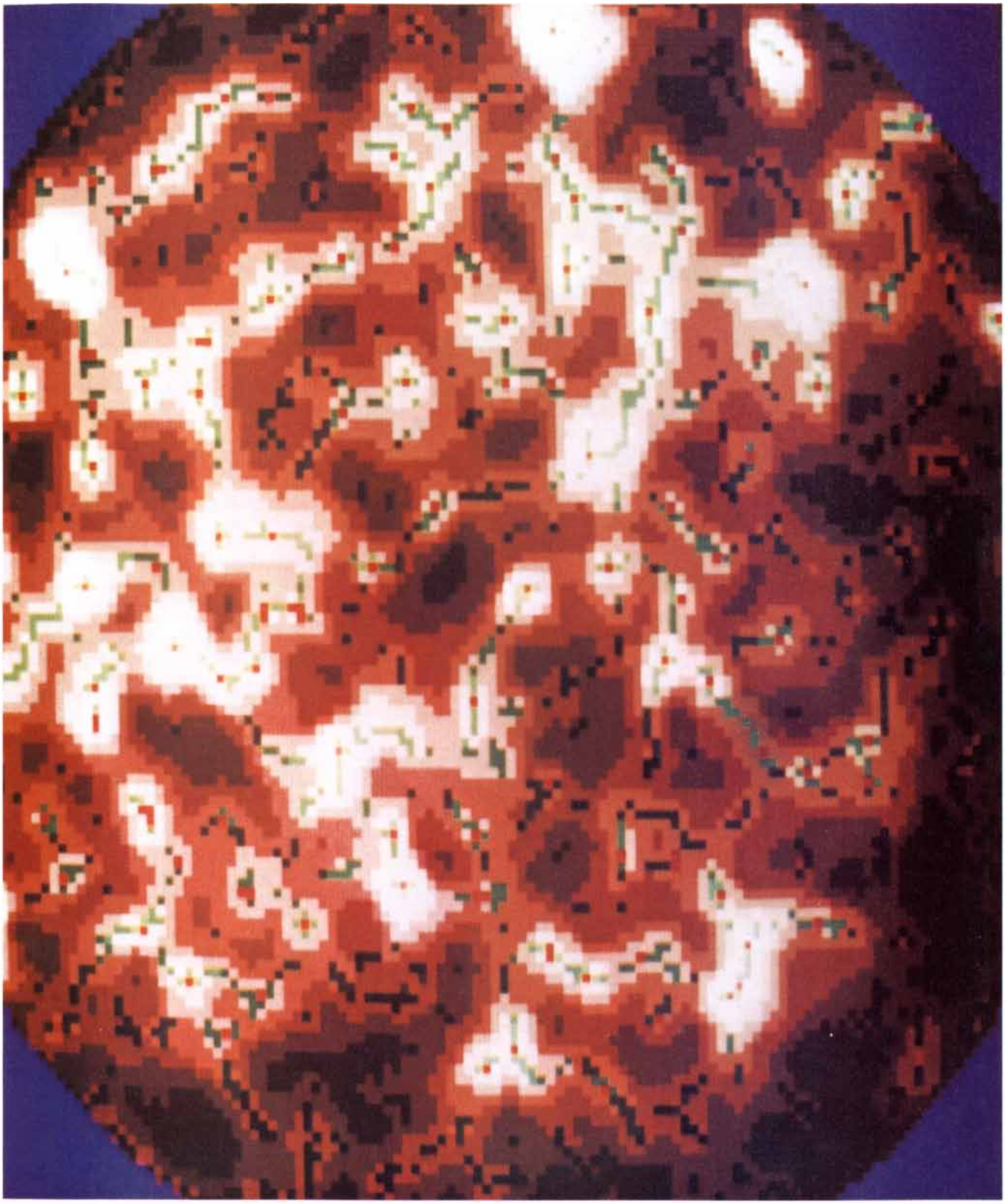
In order to account for structure in the present state of the universe the big-bang cosmologist must therefore acknowledge some degree of clumpiness early on. Such early inhomogeneities might be smooth and nearly indistinguishable against the homogeneous background; small fluctuations in the curvature of the early universe would take the form of slight compressions or rarefactions of matter and energy from region to region throughout space. The amplitude of the fluctuations must be large enough (that is, the variation from the average density must be great enough) to grow into the currently observed aggregations of matter in the time since the universe began; precisely what that amplitude must be, however, is a matter of much theoretical delicacy. If the initial fluctuations were too large, they would cause variations in the temperature of the microwave background radiation that are not observed. Furthermore, the fluctuations must give rise to the structures of relatively special scale that make up the universe and not to structures of arbitrary size. Stars, galaxies, clusters of galaxies and even superclusters, or clusters of clusters, can now be identified, but at scales of mass larger than that of the supercluster the universe is fairly uniform.

The convergence of cosmology and the physics of elementary particles has recently made it possible to satisfy all these requirements without making any strong assumptions about the early state of the universe. In particular, no appeal is made to any special scales or patterns of mass and energy at the outset of the expansion, and no new forces are invoked. What is assumed is that soon after the beginning of the big bang there were small variations in the density of matter and energy everywhere in the universe. The variations were the result of superposing low-amplitude, sinusoidally varying fluctuations in the density at every possible wavelength, or scale of length; the amplitudes of the fluctuations were distributed randomly, and so the resulting variations in density were random and chaotic. Thereafter the present structure of the universe could have evolved according to reasonably well-understood principles of physics.

As the universe expanded, the random, free streaming of elementary particles in all directions suppressed all the initial fluctuations below a critical size: the only fluctuations that survived were those that compressed or rarefied masses at least 10^{15} to 10^{16} times the mass of our sun. Gravity then caused some of the compressed masses to contract preferentially along one of the three spatial axes. The initial spectrum of fluctuations thereby gave rise to gigantic, irregular clouds of gas that resembled flattened pancakes. Where the pancakes intersected, long, thin filaments of matter took shape. Some of the clouds remained intact; others broke up to form galaxies and clusters of galaxies. The emergence of an appropriate characteristic scale for the fluctuations was first explained by one of us (Silk). The gravitational formation of the thin layers of matter was discovered by another of us (Zel'dovich). We shall refer to this model as the pancake theory.

The pancake theory in its present form is a tale of two objects at the extremes of physical scale. One is an astronomical system large enough to fill 10^{23} cubic light-years of space; the other is the neutrino, a weakly interacting elementary particle that is almost vanishingly small. If the pancake theory is to be confirmed, both objects must be observed and a nonzero mass must be assigned to the neutrino. Since the two masses, if they both exist, span 80 orders of magnitude, extraordinary procedures are needed to measure them from our own vantage of middle dimensions.

Remarkably, the existence of the required scale of the astronomical system has recently been verified, and its mass offers tantalizing evidence that the pancake theory is on the right track. Systematic measurements of distance for several thousand galaxies have been carried out by determining the red shift in their spectra: the displacement of spectral lines toward the long-wavelength end of the electromagnetic spectrum. The red



DISTRIBUTION OF 400,000 GALAXIES across 100 degrees of the sky is mapped by a computer program designed to enhance the filamentary structure that is perceptible in other maps. The number of galaxies within each pixel, or small square area of the map, is indicated by a color code: black pixels represent areas having the least number of galaxies, and an increasing density of galaxies is indicated by increasingly lighter shades of brown through white. Green and red pixels correspond to local ridges and peaks in the distribution. The green pixels designate regions where the galaxy count is greater than it is in all the adjacent pixels in two or three directions, either horizontal, vertical or diagonal. Red pixels designate regions where the count reaches a local maximum in all four directions. The green filamentary ridges may correspond to superclusters of galaxies in space; if they do, they extend across 100 million light-years. The map is based on a survey made by C. Donald Shane and Carl A. Wirtanen of the Lick Observatory. Its center is the north pole of the galaxy, in the constellation Coma Berenices; its edge is the galactic parallel at 40 degrees north, and the map is oriented so that the center of our galaxy is toward the top. The map was constructed at Princeton University by John E. Moody, Edwin L. Turner and J. Richard Gott III.

SMALL PERTURBATIONS IN THE DENSITY of matter and energy were present throughout the universe shortly after the start of the big bang. The perturbations can be understood as wavelike fluctuations of the density around an average value, randomly distributed over all wavelengths. A snapshot of such a random fluctuation is shown in cross section in the upper half of this computer-generated image. Yellow, green and blue mark relatively compressed regions; orange, red and purple mark regions that are increasingly rarefied. In the lower half of the image all fluctuations encompassing a mass of less than 10^{16} times that of our sun have been filtered out by the interaction of matter and radiation in the early stages of the universe. According to the "pancake" theory proposed by the authors, the remaining fluctuations gave rise to galaxy superclusters and intervening voids that are now observed. The computer simulation was carried out by S. Djorgovski of the University of California at Berkeley.

shift is a Doppler effect, caused by the recession of a distant galaxy from our galaxy. The velocity of the recession can be calculated from the red shift according to a simple mathematical formula, and the distance of a galaxy varies directly with its recessional velocity because the universe is expanding. A redshift measurement combined with the coordinates of a galaxy on the surface of the sky enables the astronomer to fix the galaxy in space. Three-dimensional maps of the distribution of galaxies have thereby been worked out.

The maps show features quite unlike those of most other astronomical objects: the galaxies are concentrated in enormous sheets and filamentary structures whose greatest dimension, roughly 100 million light-years, is an order of magnitude larger than its lesser dimensions. Such a structure can include as many as a million galaxies; its mass is on the order of 10^{16} suns. Moreover, within each structure the galaxies are not evenly distributed: one can distinguish more densely populated clumps and strings, many of them at the intersection of two sheets. Finally, interspersed among the largest structures are huge voids, virtually free of galaxies, that are between 100 and 400 million light-years across [see "Superclusters and Voids in the Distribution of Galaxies," by Stephen A. Gregory and Laird A. Thompson; SCIENTIFIC AMERICAN, March, 1982]. Much of this picture is based on the work of Jaan Einasto of the Tartu Observatory in the Estonian S.S.R.

The detection of a massive neutrino is much more problematic. Several years ago theoretical physicists assigned to the neutrino a rest mass of zero, but some more recent theories of elementary particles suggest the neutrino does have a small mass. Several kinds of experiment are under way seeking to detect it. In the most direct method the mass can be inferred if certain variations are found in the decay rate of radioactive isotopes. In 1980 Valentin Lubimov, Evgeny Tretyakov and their colleagues at the Institute of Experimental and Theoretical Physics in Moscow measured the decay rate of tritium, the radioactive isotope of hydrogen. At that time they reported results consistent with a small but nonzero neutrino mass, between 14 and 46 electron volts, which is less than a tenthousandth the mass of the electron. Recently the same investigators have confirmed their findings and narrowed the limits of error: they now report a neutrino mass of from 20 to 40 electron volts.

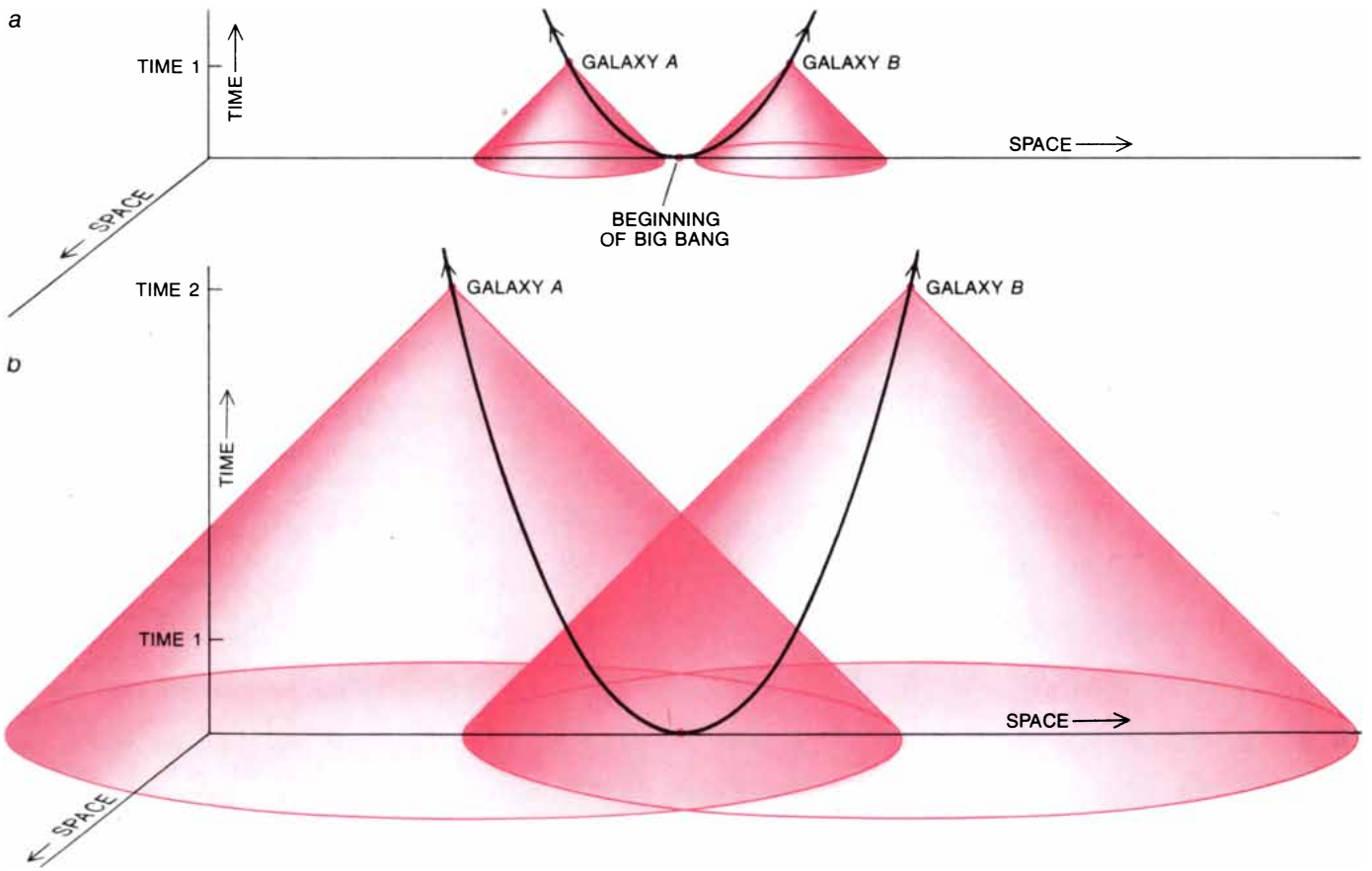
Unfortunately there has been no independent verification of these results, and so there remains no general consensus on the question of neutrino mass. A second kind of experiment, pioneered by Ettore Fiorini of the University of Milan, is based on the rate of a

mode of radioactive decay called double-beta decay that is observed in certain isotopes. Fiorini has reported the neutrino mass can be no greater than 10 to 20 electron volts, based on the decay rate of the isotope germanium 76. The method is less direct than the measurement of tritium decay; the results of Fiorini's experiment can be interpreted as a measure of neutrino mass only if it is assumed that the neutrino is its own antiparticle. On the other hand, if the neutrino and the antineutrino are distinct, the double-beta decay of germanium 76 is modified and a value for the neutrino mass cannot be inferred.

A third method of detecting neutrino mass was first proposed by Bruno M. Pontecorvo of the Joint Institute of Nuclear Research at Dubna in the U.S.S.R. The method exploits the fact that there are three kinds of neutrino: the electron neutrino, the muon neutrino and the tau neutrino. If the three kinds of neutrino have mass, if the three kinds can appear with varying probability and if the difference between the squares of the masses of any two kinds of neutrino is not equal to zero, quantum mechanics implies that the three kinds of neutrino could oscillate, or freely exchange their identities. Since the oscillations would cause the population of one kind of neutrino to vary with time, the oscillations should be detectable as a change in the population of, say, electron neutrinos along the path of a neutrino beam. Several such experiments have been done in the past few years, first in 1980 by Frederick Reines and his colleagues at the University of California at Irvine and later by Felix H. Boehm and his colleagues at the California Institute of Technology and by other workers. At this writing no experimental group has reported unambiguous evidence for neutrino oscillations. Unfortunately the absence of oscillations could merely indicate that the difference between the squares of the masses of two kinds of neutrino is zero; a failure to detect oscillations is therefore consistent with a finite, or nonzero, neutrino mass.

The prevailing attitude among physicists is that the experimental results do not yet warrant a firm conclusion about the mass of the neutrino. Nevertheless, if the evidence for mass is accepted, the cosmological consequences are far-reaching. More than a decade ago, following an early suggestion by Semyon Gershtein of the Serpukhov Institute of Physics in the U.S.S.R. and one of us (Zel'dovich), György Marx and one of us (Szalay) at Eötvös University suggested that massive neutrinos could make a dominant contribution to the mass and evolution of the universe as a whole. This suggestion was made concurrently by Ramanath Cowsik and John McClelland of the University of California at Berkeley. A massive neutrino would also lead inevitably to pancakelike structures on large scales. Before we discuss this effect, however, it will be useful to describe an earlier version of the pancake theory, a theory that ultimately failed certain critical observational tests but that has given rise to the current more successful theory.

Astrophysicists believe they have a fairly sound understanding of the physical processes that must have taken place after the first few milliseconds of the big bang. The energies of particles colliding with one another at that time



HORIZON OF AN OBSERVER grows with time and encompasses an increasingly great fraction of the universe. The horizon is a sphere, centered on the observer, whose radius is equal to the distance light can travel since the beginning of the big bang. Here the horizon is a circle at the base of a cone; the expansion of the universe since the beginning of the big bang is indicated by the divergence of two galaxies with time. In the early stages of expansion the galaxies recede from each other at an apparent velocity that exceeds the speed of light, and so at this epoch there has not been enough time for an observer in one of them to see the other galaxy at any previous stage (*a*). Because the expansion is slowing, however, light from an early stage of one of the galaxies will eventually reach an observer in the other galaxy (*b*). The edges of the cones are the paths of light signals in space; since no signal can propagate faster than light, they represent a spatial limit to causal interaction at any given time as well as a limit to observation. Hence any fluctuation in the density of the universe on a scale larger than that of an observer's horizon will have no effect on the observer or on the distribution of matter and energy within the horizon.

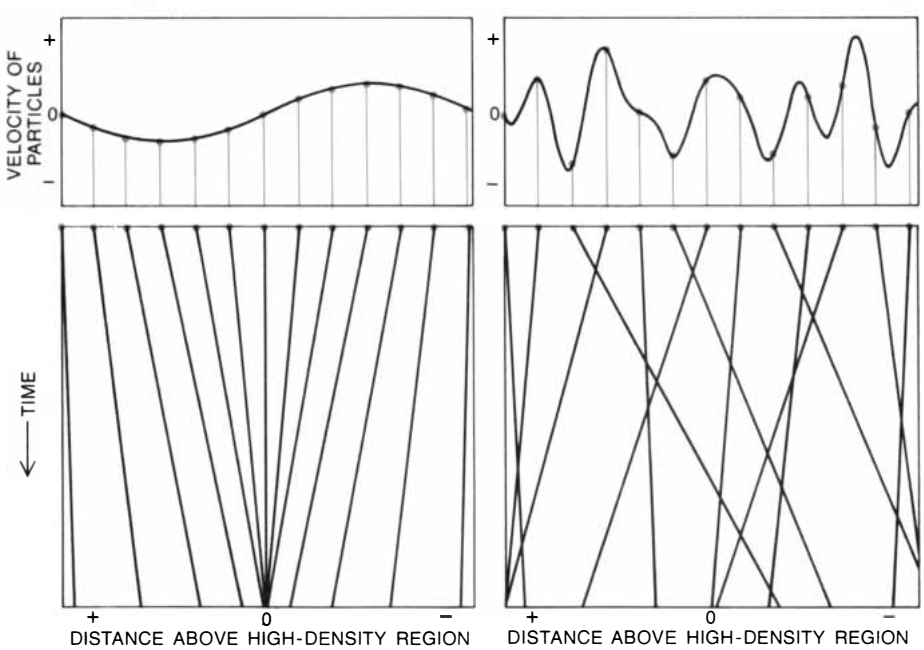
were no greater than the energies typically achieved in small particle accelerators, and so a picture of the early universe emerges when one considers a dense fluid of particles whose individual properties are well known.

By far the most abundant particles in the fluid were the photon, the electron and the three species of neutrino; only relatively small numbers of protons and neutrons were left over from annihilations that took place in an earlier epoch. The electrons and the neutrinos remained in close contact throughout most of the first second and were continuously created and annihilated. Frequent collisions among them guaranteed that energy was distributed randomly throughout the fluid; in other words, the particles were maintained in thermal equilibrium. As the universe expanded, the density of the particles decreased and collisions became less frequent. Because the energy of a photon varies inversely with its wavelength, the average energy of the photons decreased as their wavelengths expanded with the rest of the universe, and so the universe began to cool.

Recent theoretical investigations that have sought to unify the fundamental forces of nature can now peer even farther back than the first millisecond into the history of the universe. The theories are called grand unified theories because they attempt to understand the electromagnetic force, the weak nuclear force and the strong nuclear force as distinct low-energy manifestations of a single, underlying phenomenon. (Gravity, the fourth fundamental force, has not yet been incorporated.) The energy density at which the three forces become indistinct corresponds to the energy density of the universe only 10^{-35} second after the start of the big bang. The early universe has therefore come to be regarded as a laboratory for testing the predictions of grand unified theories.

One prediction of the theories is that if the density of matter must fluctuate in the early stages of expansion, the density of the photons, or radiation, must fluctuate also. Nevertheless, the ratio of the density of matter to the density of radiation must always remain the same. According to the general theory of relativity, energy and matter are equivalent as a source of gravity and determine the geometry of space-time. A fluctuation in the density of mass and energy therefore causes a fluctuation in the gravitational field, which is equivalent to a fluctuation in the curvature of space-time. The comprehensive theory of such fluctuations in the expanding universe, treated within the framework of the general theory of relativity, was developed in 1946 by Eugene M. Lifshitz of the Institute for Physical Problems in Moscow.

It seems reasonable to assume that fluctuations must have existed in the early universe over a wide range of possible scales. We make the assumption primarily for reasons of parsimony: it would seem arbitrary and entirely fortuitous if the initial fluctuations were to single out regions only of, say, galactic scale. There is an upper limit, however, to the size of fluctuation that can be perceived by any observer at a given time. That limit is the spatial horizon of the observer, which is a sphere, centered on the observer, whose radius is equal to the distance light can travel in the time since the start of the big bang. In the standard model of the big bang, however, the initial expansion of space and time from the singular point creates a universe far greater than the spatial horizon of any single observer. On the other hand, because the expansion of the universe is thought to be slowing down, increasing amounts of mass come within any observer's horizon. Fluctuations undetectable in the early universe become detectable later on, because they begin to be encompassed by the observer's ever widening horizon [*see illustration on preceding page*].



SMOOTH DISTRIBUTION OF PARTICLE VELOCITIES arises from a fluctuation with a single wavelength; particles are gravitationally attracted to the regions of highest density, and so the velocity of a particle depends on its distance from such a region, as is shown in the graph at the upper left. In the graph at the lower left the velocity of each particle is given by the slope of the line that represents its trajectory. The trajectories tend to converge and form regions of enhanced density. Thus the smooth fluctuations are amplified. If the fluctuations are random over all the wavelengths (*upper right*), the trajectories do not converge (*lower right*).

Once a fluctuation is within an observer's horizon it is adequately described by classical, or nonrelativistic, gravitational theory. There it takes the form of an observable perturbation in the density of the fluid. There are two competing effects on any parcel of matter and radiation moving together: gravity tends to collapse the parcel, and pressure caused by the chaotic motion of the particles and radiation tends to disperse the parcel in space. On large scales gravity always wins. Pressure cannot resist the collapse, so that particles are attracted to the regions of highest density. Moreover, once gravitational collapse begins, the accreted mass can attract more distant mass and radiation, and so any initial instability is amplified. Matter accumulates in some regions and becomes rarefied in others.

If the soup of particles and radiation that make up the early universe is considered to be an ideal gas, the effects of a density fluctuation superposed on the gas are straightforward. Any local compression in the density over a sufficiently large mass will trigger gravitational instability and lead to incipient collapse. On smaller scales, however, gravity is not strong enough to overcome the increase in the pressure of the gas caused by the increase in density. The compressed parcel of gas will therefore rebound and become rarefied, and the fluctuation will propagate exactly like a sound wave, that is, by the periodic compression and rarefaction of the medium through which it travels.

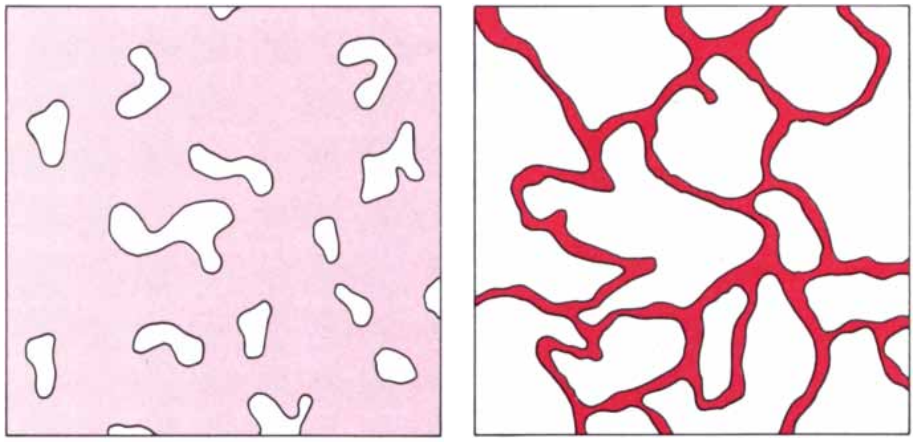
Most sound waves in the air die out in a few tens of meters because the particles that make up the pressure waves are scattered and their coherent motion is dissipated as heat. In a similar way sound waves in the cosmic medium set up by the fluctuations lose their energy and die away at all but the longest wavelengths. Furthermore, the particles and photons in the early universe are much

too densely packed to be treated as an ideal gas. In the first 300,000 years of the big bang the photon radiation was energetic enough to keep all matter ionized. Photons outnumbered electrons by a factor of about 100 million; the free electrons, which would later be bound to atomic nuclei, were therefore under constant bombardment by the photons, freely scattering the photons and being scattered by them. The result was a thick, viscous fluid of electrons and photons in which no particle could travel very far without being scattered.

The scattering of the free electrons by the radiation makes any displacement of the electrons through the radiation much like moving through viscous, cold molasses. The viscosity of the fluid thereby inhibits the growth of gravitational instabilities that might be caused by the accretion of matter alone. Moreover, as in the ideal gas, the large pressure of the radiation keeps matter and radiation from collapsing together under the pull of gravity on all but sufficiently large scales. The remaining fluctuations within the viscous fluid, that is, the ones that survive gravitational collapse, can be regarded as sound waves.

As we have mentioned, grand unified theories require that the ratio of the density of photons to the density of matter remain always the same: in the compression phase of a fluctuation the compression of the photons must therefore match the compression of the particles with mass. If the distance covered by a photon in the time since the start of the big bang is greater than the distance across a compressed region of a fluctuation, however, the photon will in effect not take part in the compression but will instead dissipate its share of the energy of the fluctuation. Since the photons greatly outnumber the particles with mass, they carry almost all the energy of the fluctuations, and so fluctuations on a scale smaller than the average radial displacement of a photon in the time since the start of the big bang are damped out.

The path of a photon can be compared to the path of a drunkard staggering away from a lamppost along any direction with equal probability. In order to wander a distance away from the lamppost that corresponds to N steps when sober, the drunkard must take N^2 steps. Similarly, the photon must be scattered N^2 times in order to travel a radial distance equal to the distance it would travel if it were streaming freely. In spite of their being scattered by the electrons, the photons diffuse radially outward through the medium so fast that they dissipate the energy of all but the largest fluctuations. By the time the universe cools enough for atomic nuclei to capture the free electrons, the photons have diffused through a region of the universe whose mass is about 10^{14} times that of our sun. All initial fluctuations that encompass a mass smaller than this amount are therefore erased.



TOPOLOGICAL STRUCTURE OF THE FLUCTUATIONS that survive filtering in the early stages of the universe is preserved in the structure of galaxy superclusters and voids. At the left the density of the universe is nearly uniform. If the probability of rarefaction caused by a slight fluctuation in the density along any one axis is one-half, the probability that any region is rarefied along all three spatial axes is one-eighth. Such regions are shown in white; they initially occupy only one-eighth of the volume of the universe and include about one-eighth of its mass (*left*). Gravity compresses the colored regions along one or more axes. These regions, which include about seven-eighths of the mass of the universe, collapse to form a cobweb of filaments that eventually fill only one-eighth of the volume of space (*right*). The regions of initial rarefaction expand to make voids that fill the remaining seven-eighths of the universe.

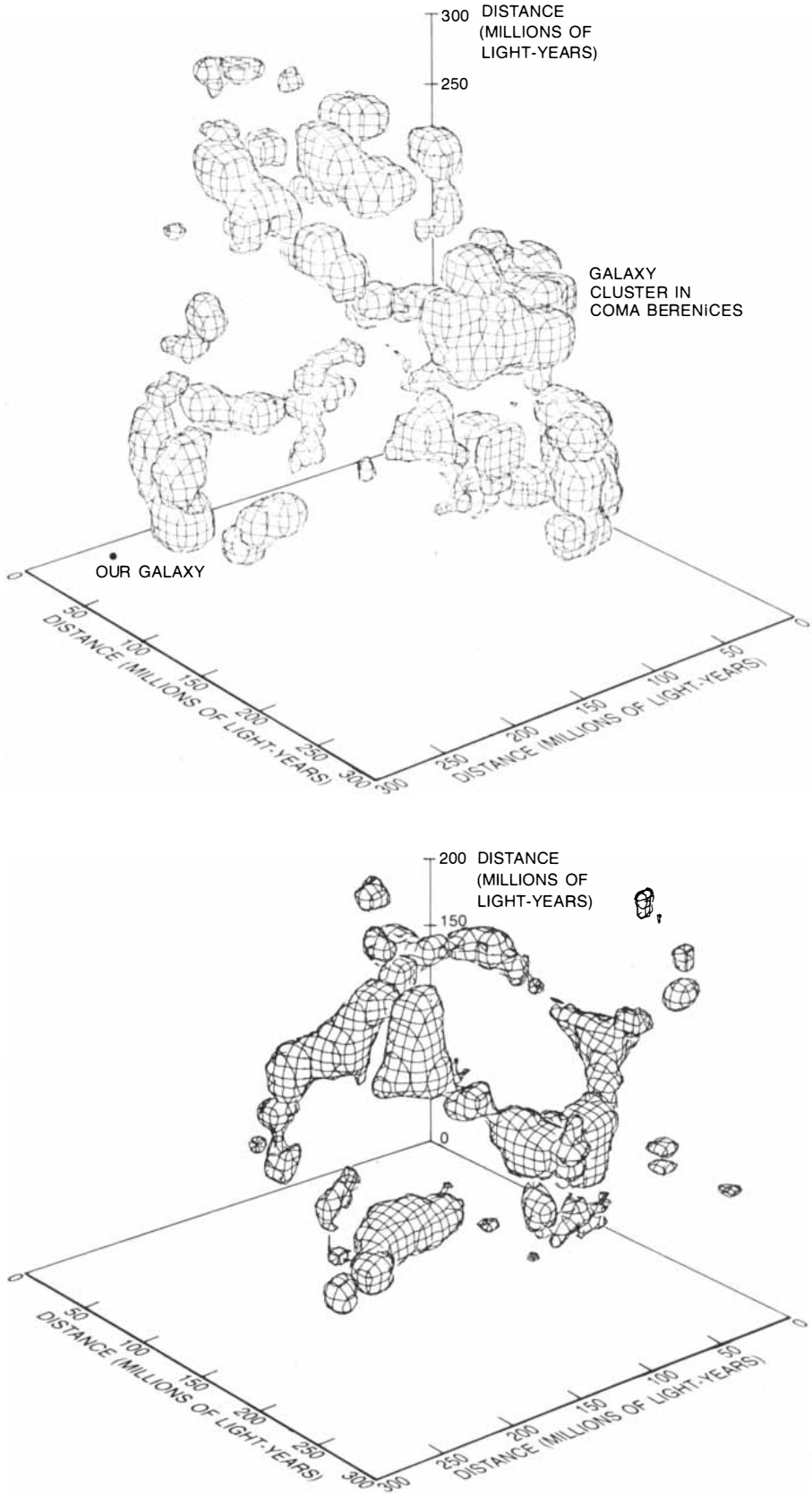
When the electrons finally combine to form atoms, the matter and the radiation cease to interact and the radiation streams off independently of the atoms. The viscosity of the fluid drops abruptly, and the fluctuations that have survived the previous era of radiation-dominated interactions are no longer inhibited from being amplified. Thereafter gravitational instability proceeds with full vigor.

The sudden absence of radiation pressure has a dominant effect in determining the shape and structure of the first objects to form. Thermal pressure always acts isotropically, or equally in all directions, and so if the radiation pressure had remained comparable in strength to gravity, all collapsed objects would have had nearly perfect spherical symmetry. Anisotropies develop because the pressure is completely negligible up to the last moments of collapse.

Because of the lack of pressure to counteract the infall, gravitational instability is highly efficient at sweeping almost all the matter into compressed, high-density regions of space. Consider the following argument. Along any one of the three spatial axes matter can be either compressed or rarefied; assume, for the sake of simplicity, that the probability the matter is compressed along any one axis is one-half. The fraction of the gas that will not be compressed along any axis is the cube of one-half, or one-eighth. This result has immediate implications for the predicted spatial structure following collapse. At an early stage, when the density is still nearly uniform, the regions destined to be compressed include about seven-eighths of all matter. These regions surround smaller bubbles of matter that never collapse; the bubbles are destined to become voids. After the collapse the compressed regions occupy only one-eighth of the volume of space; the small bubbles, which carry one-eighth of the matter, expand to fill the remaining seven-eighths of the volume. The topology of the initial state is preserved. The final outcome is a cellular structure formed by thin walls and filaments of compressed matter that enclose huge voids.

The shape of the compressed regions can be predicted from similar considerations. It is most unlikely that any cubical volume of matter destined for collapse will form a sphere. Such a collapse would require a match of both direction and magnitude of the fluctuations along all three components into which any arbitrary collapse can be resolved. It is much likelier that the cube would collapse first along one randomly selected axis, and it would collapse or expand more slowly along the other two axes. The ensuing distribution of matter is highly anisotropic. Since the mass inside the initial cubical volume does not change as both the thickness and the volume of the cube decrease, the density becomes extremely high and a flat pancake is formed.

At first the pancakes develop in isolated regions, but they soon grow into thin sheets that intersect and form the cellular structure. Numerical simulations of the collapse done with the aid of large computers suggest the universe has only recently acquired a cellular structure. In the future, as larger clumps of matter form, the cellular structure is expected to disappear. Hence it is only during an



CONTOURS OF HIGH DENSITY are plotted in three dimensions for all galaxies brighter than magnitude 14.5 in the northern sky that are within about 250 million light-years of our galaxy (*upper illustration*). The distribution is similar to the one shown in the lower illustration, which is derived by simulating the predictions of the pancake model on a computer. In the model it is assumed the clustering of matter arises from density fluctuations no smaller than the smallest fluctuation to survive the smoothing effects of hypothetical massive neutrinos. The real distribution was constructed by Carlos Frenk and Simon White of the University of California at Berkeley from a map prepared by Marc Davis and his colleagues at Center for Astrophysics of the Harvard College Observatory and the Smithsonian Astrophysical Observatory. Map was based on a survey of 1,801 galaxies. Simulation was done by Frenk, White and Davis.

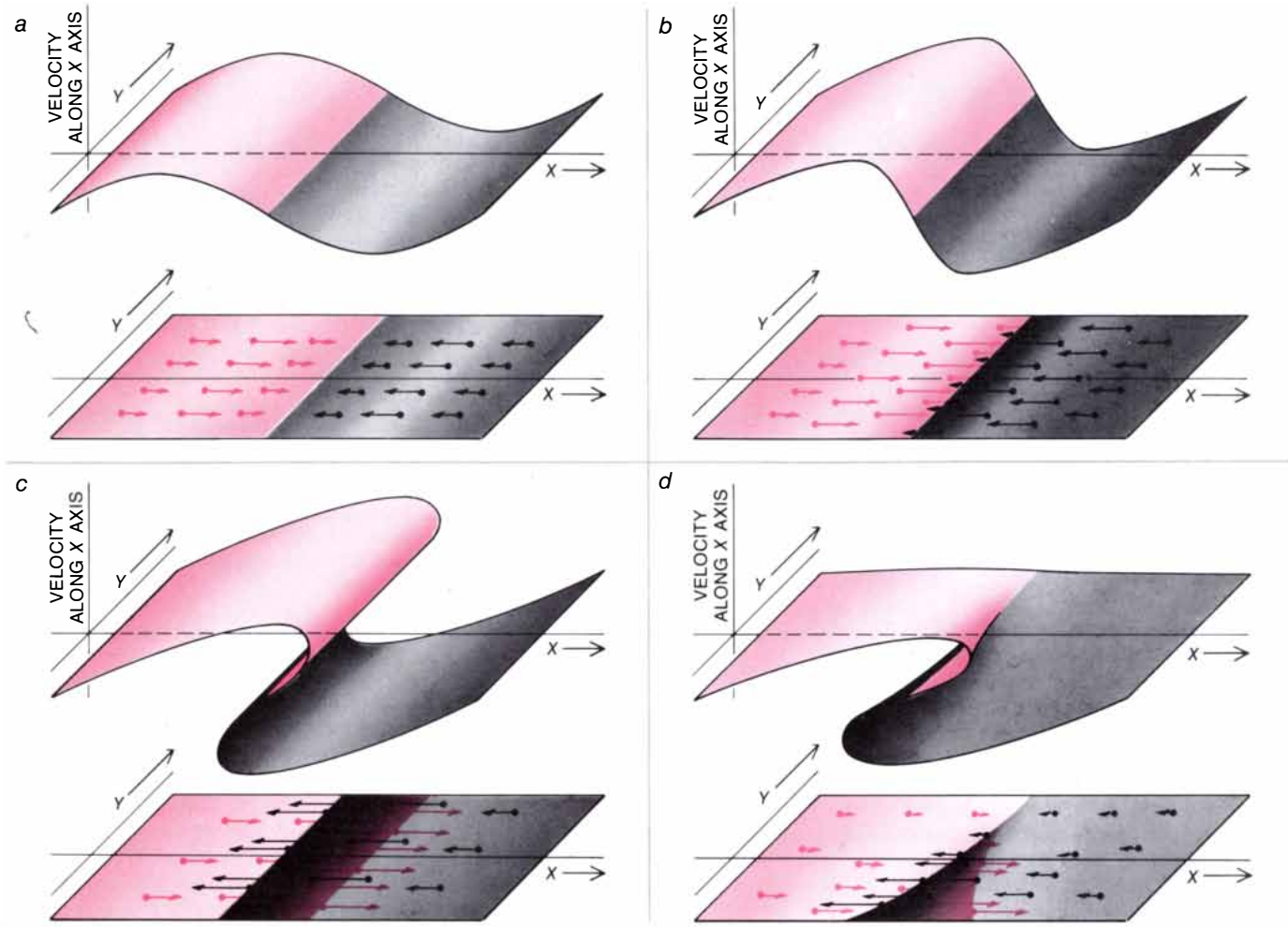
intermediate stage of cosmic evolution that the initial curvature fluctuations are reflected by the structure of matter. The observational evidence shows that from the perspective of the evolution of large-scale structure the universe is neither very young nor very old.

There are two major difficulties with the pancake theory as we have described it so far. First, remember that the smallest fluctuations to survive the radiation era encompass a mass of 10^{14} suns. Structure in the distribution of galaxies, however, exists at much larger scales. Numerical simulations favor a theory in which the smallest fluctuations emerging from the radiation era are on a scale of 10^{15} or 10^{16} suns.

The second difficulty is more serious. Because the microwave background radiation has propagated freely ever since the photons and the electrons ceased to interact, the variation in the temperature of the radiation across the sky reflects primordial inhomogeneities in the distribution of matter. At the time the original pancake theory was formulated the upper bound for the temperature variation over the entire sky was about one part in 1,000. Accordingly it was thought that matter inhomogeneities in the early universe could have been as great as a third of the temperature variation, or one part in 3,000. Recently more stringent limits on the variation of the radiation temperature have been set by Francesco Melchiorri and his co-workers at the University of Florence and the University of Rome, and by Yuri N. Parijskijin of the Pulkovo Observatory in Leningrad. The new upper bound is a variation of less than one part in 30,000 over an angle of six degrees.

The fluctuations required by the original version of the pancake theory were consistent with the earlier estimate of temperature variations, but the agreement with the new estimate is only marginal. Moreover, if the overall density of matter and energy in the universe is so small that the present expansion will continue forever, the agreement is lost. On a cosmic scale the force of gravity would have been so weak in recent epochs that fluctuations must have completed their growth and collapsed at a much earlier time, when the density of matter was much greater than it is today. The amplitude of such fluctuations, however, would have been much too large to be compatible with the uniformity in the microwave background. On the other hand, if the initial fluctuations had been small enough to be compatible with the radiation background, the birth of galaxies would have become practically impossible.

If the universe is dense enough for the amplitude of the fluctuations to be marginally reconciled with the uniformity of the background, another problem

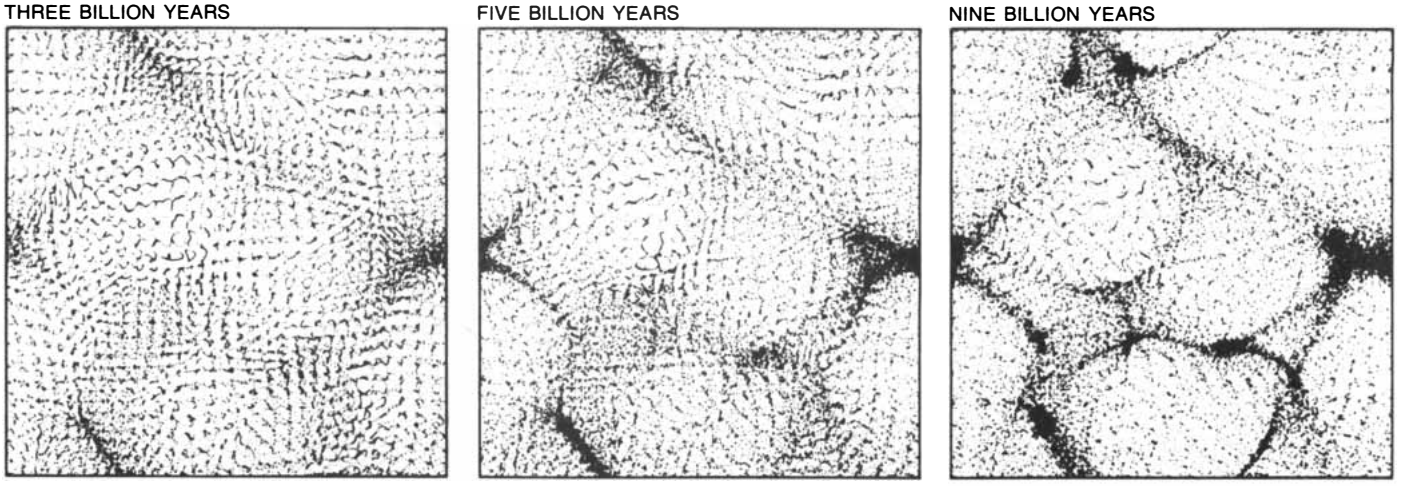


DISCONTINUITIES IN THE DENSITY OF MATTER can result from continuous deformations of the medium during gravitational collapse. In each frame of this schematic sequence the lower plane represents two directions in space; for simplicity only the motions of particles in the plane and parallel to the *x* axis are considered. The particles move toward a central axis of the plane; the length of each arrow indicates the velocity of a particle at the position corresponding to the tail of the arrow (*a, b*). A sheet of particles moving to the right (*colored arrows*) crosses the central axis without colliding with the particles moving to the left (*black arrows*). The motions set up two discontinuities in the density of the medium, one on each side of the central axis (*c*). In almost any real collapse the motions of the two sheets of particles are not exactly symmetrical and the two discontinuities end in a cusp (*d*). The same density distributions can be understood as a special case of a more general phenomenon described by the branch of mathematics called catastrophe theory. If the motions of the particles are plotted in a phase space, that is, in a three-dimensional space where the vertical axis represents the velocity in a direction parallel to the *x* axis, the interaction of the two sheets of particles is represented by a twisting or undulating surface (*upper plane in each frame*). The density of the particles at any point is then given by the "shadow" cast by the deformed surface on the original *x*-*y* plane.

arises. The density cannot then be accounted for solely by the total mass of bright matter, visible as stars, nebulas, galaxies and the like. Instead the universe must be made up predominantly of dark matter. This inference is not a new one. Studies of the rotation of our galaxy and that of other spiral galaxies have shown that the rotational velocities of stars on the periphery of a galaxy are not consistent with Kepler's laws. These laws state that the rotational velocity should decrease with increasing distance from the center of a galaxy, just as the orbital velocity of a planet decreases with its distance from the sun. Peripheral stars, however, do not slow down; their rotational velocities are roughly constant and independent of their distance from the galactic center. P. James E. Peebles and Jeremiah P. Ostriker of Princeton University and Einasto simultaneously suggested the dilemma would be resolved if halos of invisible matter make up the bulk of the mass of spiral galaxies. An indirect argument suggests dark material may be present in even greater quantities within groups and clusters of galaxies. Such systems would fly apart in an unaccountably short time if it were not for the gravitational attraction of dark matter. It is estimated that dark matter may comprise 90 percent of the mass of the universe.

A new component of the universe was badly needed to salvage the pancake theory, and a source of dark matter was needed to account for the motions of galaxies. A natural candidate for both purposes was the neutrino, although certain other exotic but still undetected particles, such as a massive photino or a massive gravitino, might serve the same cosmological function. Theories of elementary particles predict that in the first millisecond of the big bang a wide variety of weakly interacting particles were maintained in thermal equilibrium. Many such particles could still survive, and provided they are stable they could have far-reaching implications for cosmology. Since the neutrino mass can be measured experimentally, in the remainder of this discussion we shall refer to the neutrino. Nevertheless, even if the neutrino turns out to have no mass, the pancake theory is not disproved.

Remember that in the first second of the big bang the primordial soup included an abundance of neutrinos. Even today the ratio of photons to all three varieties of neutrino is only 11 to 9. Neutrinos, unlike protons, electrons and even photons, interact so weakly with other particles that they begin to stream freely through the fluid long before the photons do. Hence the neutrinos, which initially move at the speed of light, can



COMPUTER SIMULATION shows the evolution of large-scale fluctuations in the density of matter and energy with time, assuming the existence of neutrinos that have a nonzero mass. Pancakes and filaments develop as a result of gravitational collapse, and the matter in the remaining regions of space becomes increasingly rarefied. The resulting structure resembles the distribution of superclusters and voids that is currently observed. In several regions there are cusps and other kinds of discontinuity in the density, which can be recognized and classified by means of catastrophe theory. The simulation was done by George Efstathiou of the University of Cambridge.

travel farther than the photons in the early stages of the universe. By the end of the radiation era the neutrinos have dissipated fluctuations on a larger scale than photons alone could have done.

A massive neutrino cannot continue indefinitely moving at the speed of light. When the energy density of the photons falls below the energy that corresponds approximately to the rest mass of the neutrino, the neutrino begins to slow down and move at a speed appropriate to its energy. If the mass of the neutrino is 30 electron volts, the slowdown will begin well before the capture of the free electrons by atomic nuclei. The capture must wait until the background energy is reduced to .1 electron volt, the energy at which hydrogen is ionized by the dense fluid of photons. Although the neutrinos continue to erase the fluctuations as they slow down, they become increasingly susceptible to being trapped by large fluctuations that have not yet been smoothed out. Richard Bond of Stanford University and one of us (Szalay) have estimated the maximum scale over which the neutrinos can freely stream before they are trapped, and consequently the minimum scale over which the fluctuations are not erased. The scale corresponds to a present distance of 100 million light-years and a mass of 10^{15} to 10^{16} suns. The agreement with the size and mass of the galaxy superclusters that are now observed is striking.

How can such fluctuations be compatible with the observed uniformity of the background radiation? The neutrinos cease their erasure of the curvature fluctuations before the end of the radiation era, but unlike the electrons their motions are not inhibited by the viscosity of the fluid. Neutrinos collide so rarely with photons or electrons that they are not subjected to viscous drag. Gravitational instabilities among the neutrinos can accordingly begin to develop before the end of the radiation era, and so they can grow over a much longer time than the fluctuations of ordinary matter can. The initial amplitude of the neutrino fluctuations needed to account for the present inhomogeneities of matter could therefore have been much smaller than the amplitude of the fluctuations needed in a mixture of radiation and ordinary matter. With massive neutrinos the variation in the temperature of the background radiation required to generate the observed aggregations of matter is reduced by an order of magnitude or more. Thus theory and observations can be reconciled.

The new version of the pancake theory leads to a natural explanation for the origin of the dark matter in the universe. The initial collapse of a pancake distributes most of the neutrinos widely because most of them are accelerated by the collapse to large velocities, on the order of 1,000 kilometers per second. Such neutrinos are destined to fill the dark regions of intergalactic space. Other neutrinos, however, move more slowly because they are initially closer to the central plane of the pancake and do not undergo large accelerations. The thin layer of gas in the vicinity of the central plane condenses and breaks up to form protogalaxies. The slow-moving neutrinos are gathered together by aggregates of ordinary matter, and the matter near the center of the protogalaxy continues to condense and form stars. Neutrinos at the periphery of the protogalaxy, however, are gravitationally shared and never condense; they become the dark matter in the galactic halo.

A more detailed theory of galaxy formation within the context of the new pancake theory is now under development. As a pancake collapses, the neutrino component of the collapsing gas passes through the central plane of the pancake without interaction. The density distribution of the neutrinos acquires sharp discontinuities, some of which can be identified with rich clusters of galaxies. Vladimir I. Arnold, a mathematician at Moscow State University, has recently collaborated with astrophysicists on the problem, and he has identified such discontinuities in the overall density distribution with certain elementary structures in the branch of mathematics called catastrophe theory.

The pancake theory, as it has now been modified, offers deep insight into the character and origin of the contemporary structure of the universe. It is based on well-known physical principles and on plausible assumptions about the conditions in the very early universe. As a theory of the origin of large-scale structure it is by no means unique, although it now appears that both theory and observation point in the general direction we have outlined. Nevertheless, there are many important questions that must be resolved before the theory can be considered firmly established.

Given the confirmation of the theory, there are two main lines along which it must be developed. First, one must address the finer structure of the universe, the formation of the first generation of stars from a primordial gas that was totally devoid of the heavy elements. Second, one must ask how the initial conditions assumed by the pancake theory arose from even earlier epochs in the history of the universe. Attempts are now in progress to show how the small-amplitude fluctuations required by the pancake theory could result from earlier and much less well-understood phenomena. These attempts are based on theories not yet settled, but preliminary results leave room for optimism that by the end of the century we shall possess a coherent theory of the universe.

Reshaping the future of film.

From fat to flat. The goal many of us strive for with laborious push-ups and strenuous diets, scientists have achieved in Kodak laboratories. The "bodies" they have streamlined, however, are those of silver halide grains. More than a beauty treatment, this process of reshaping enabled us to position grains for maximum light-catching ability, and expand their sensitizing characteristics. It's this advance in silver halide emulsion technology which made it possible for us to produce a true 1000-speed film with a balance of speed, grain, and sharpness previously unattainable.

The structure of new Kodacolor VR 1000 film is a modification of the inverted-layer format first used in Kodacolor 400 film. This concept places the fastest light-sensitive layers closer to the camera lens. The magenta and cyan layers are repositioned to form a fast-magenta, fast-cyan, slow-magenta, slow-cyan sequence. In the new emulsion, the yellow-filter layer is eliminated, and the protective overcoat and ultraviolet-filter layers are combined into one, without any loss in color quality.

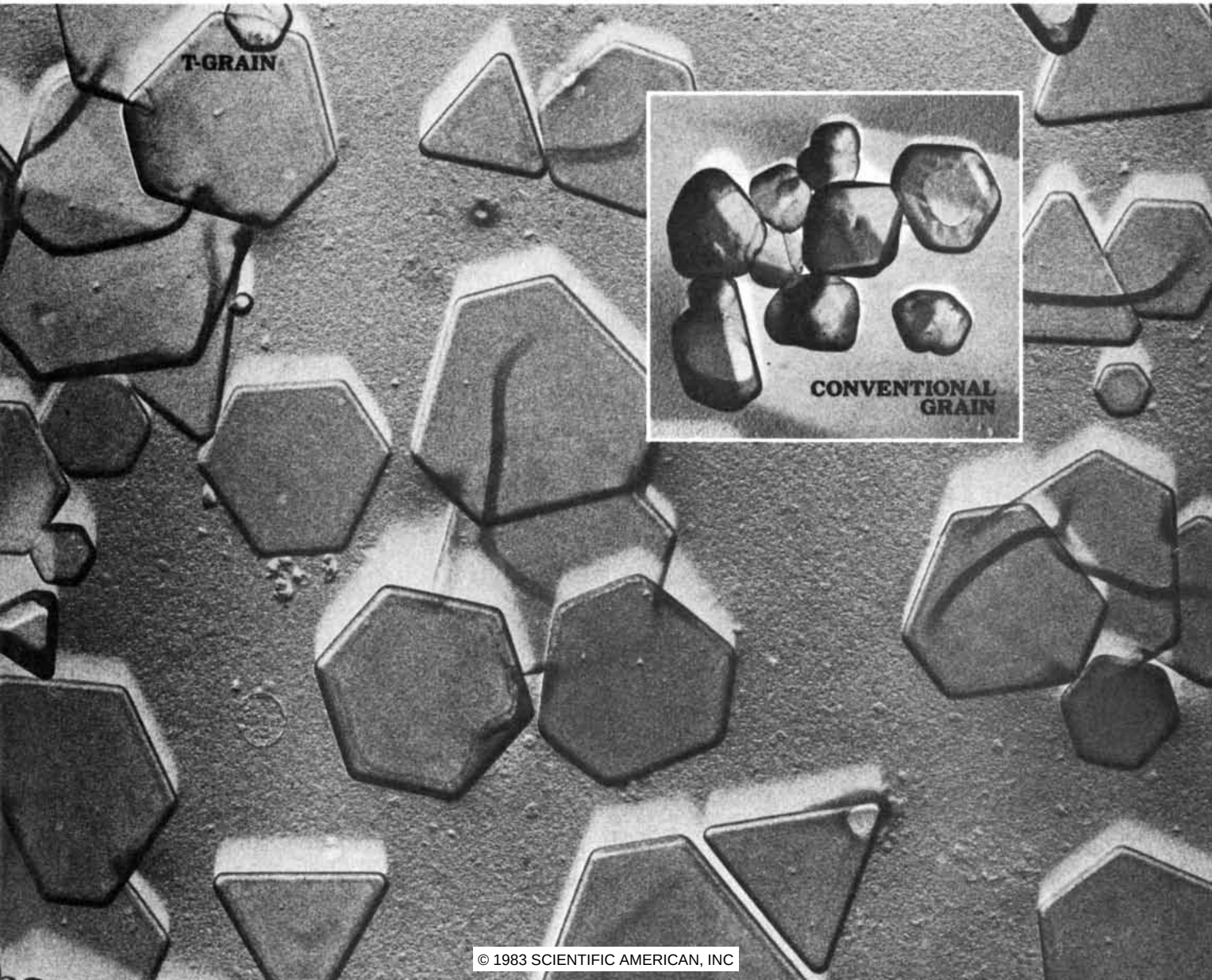
The resultant faster film can be exposed by daylight, electronic flash, or tungsten, which provides photographers with greater picture-taking capability, particularly when recording fast-action scenes or shooting in low-light conditions.

While reshaping the light-sensitive substance of film is a significant accomplishment in itself, we view this new technology as a stepping-stone. It may well reshape the future of film and enable photography to do hundreds of different jobs better than before.

For more information on Kodak's fastest color print film ever and the new emulsion technology behind it...send your request to: Eastman Kodak Company, Department GBSA-8, 343 State St., Rochester, NY 14650.

Kodak

Kodak. Where technology anticipates need.



SCIENCE AND THE CITIZEN

End of the Chain

The worldwide recession that began in 1980 is beginning to ease after three years (making it the longest economic slump since the depression of the 1930's), but one of its legacies has been a serious setback for worldwide development. There is a chain of cause and effect, with the poorest countries at the end of the chain. Recession in the advanced industrial countries has reduced demand for third-world products. It has also increased unemployment, encouraging protectionism and further thwarting developing countries' efforts to export. The terms of trade have turned against the developing countries: inflation has raised the cost of industrial products they need to import while the prices of commodities, their primary exports, have declined. Having turned increasingly to intergovernmental and commercial borrowing as a source of the capital they need, the developing countries have been hit by rising interest rates on the money they owe, a result of the restrictive monetary policies adopted by the industrial countries in an effort to counter inflation.

The foregoing picture is sketched out by the World Bank's *World Development Report* for 1983. According to the report the recession of 1980–82 was the second in less than 10 years. Growth rates of output in the industrial economies and of world trade fell for two years after the oil-price jump of 1973 but recovered rapidly in 1976; the developing countries were not seriously affected. The recent recession has lasted longer, in part because of tightened monetary controls. With monetary restraint accompanied by large fiscal deficits, interest rates rose, reaching a peak in 1981 and prolonging the recession. Unemployment in the industrial countries, which the World Bank considered "high" at about 5 percent after the first recession, climbed to 8 percent in 1982 (and to almost 11 percent in the U.S.). The recession slowed the growth of world trade; exports actually declined in 1982.

The industrial countries influence economic growth in the developing world primarily through international trade and the flow of capital. The recession reduced both total demand and the price of typical third-world exports: foods and industrial raw materials. Adjusted for the inflated cost of manufactured goods the developing countries' import, commodity prices were lower in 1982 than at any time since World War II. Many of the poorest countries, which rely heavily on a single export commodity, were particularly hard hit. Developing countries that had managed to increase their exports of manufactured goods came up against a surge of protectionism in the form of tariffs, import quotas and other restrictive measures. Export earnings of developing countries fell in 1982 to 7 percent below the 1980 level.

The large gap between receipts from exports and the expenditure of foreign exchange for imports and debt servicing is financed in most developing countries largely by official development assistance ("foreign aid") and new borrowing. Development assistance (both loans at low interest rates and grants) comes primarily from the members of the Organization for Economic Cooperation and Development (OECD) and of the Organization of Petroleum Exporting Countries (OPEC). The former have accepted a "target" of .7 percent of their gross national product as their annual contribution to development assistance; few have reached the target. Whereas the Netherlands, Norway and Sweden devoted more than 1 percent of their GNP to such aid in 1982, the percentage was .48 for West Germany, .29 for Japan, .27 for the U.S. and .25 for Switzerland. OPEC has done better, but total development assistance has not increased since 1980.

With exports down, official assistance insufficient and foreign-exchange reserves declining, third-world officials increasingly have turned to private lenders, who are now owed more than 70 percent of the developing countries' total debt. In 1982 developing countries had to pay nearly $50 billion in interest on medium- and long-term debt, 50 percent above the 1980 level. Their total debt came to more than their total earnings from exports; their annual debt-service payments were almost 21 percent of their export earnings.

According to the World Bank's report, sustained world economic growth must begin with vigorous growth in the industrial nations and an expansion of world trade. The report emphasizes that improvement in third-world exports is necessary not only for humanitarian and political reasons but also in the self-interest of the industrial nations. Most obviously, borrowing countries can service their debt only if they earn enough foreign exchange by exporting. Moreover, protectionism "is costly to the protectionist countries themselves." It raises the cost of goods they consume, to the special detriment of their poorest consumers. It hampers needed restructuring of many industrial nations' economies by preserving inefficient industries and postponing investment in new and more appropriate ones. Moreover, by restricting the growth of developing countries protectionism restricts the expansion of what has become a major market for the industrial nations. The U.S., for example, now sells two-fifths of its exports to developing countries.

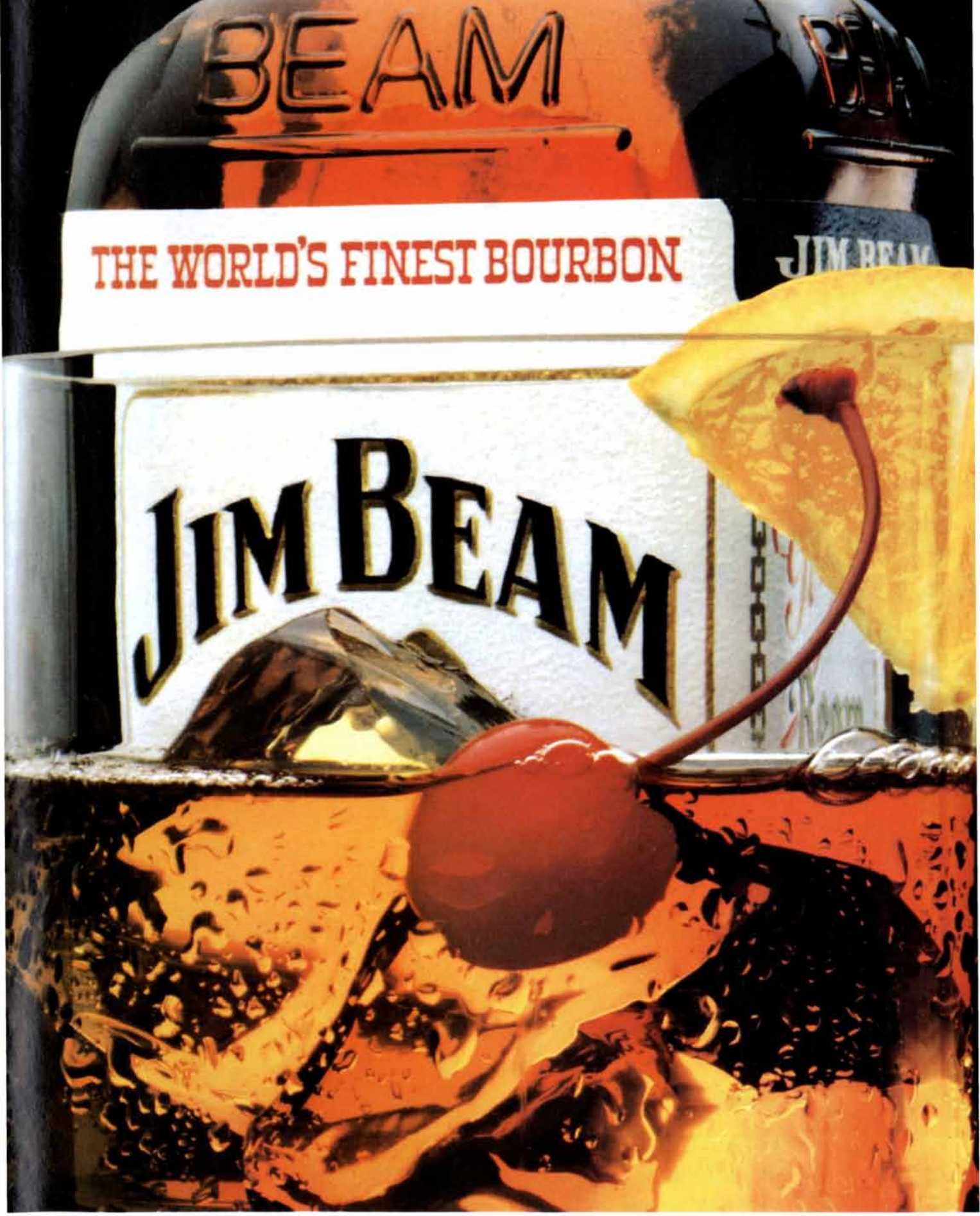
Five-Year Plan

Although the construction of nuclear power plants has slowed considerably in the U.S., the industry is continuing to expand in other countries. France, for example, gets more than 40 percent of its electric power from nuclear energy and plans to reach 85 percent by the end of the century. One country that is known to have a strong commitment to nuclear power but has supplied few details of its program is the U.S.S.R. A rare glimpse of those details has now been provided in *IAEA Bulletin,* a publication of the International Atomic Energy Agency, by B. A. Semenov, a Russian who is deputy director general of the agency and head of its Department of Nuclear Energy and Safety.

Semenov writes that by the end of last year the total installed capacity of the nuclear power plants in the U.S.S.R. exceeded 18,000 megawatts and that in 1981 they generated 86 billion kilowatt-hours of electricity, or 6.5 percent of the electric power. (The Atomic Industrial Forum recently tallied 37 operating reactors in the U.S.S.R. but was unable to ascertain what fraction of the country's power they generated. The U.S. has 72 operating commercial reactors, accounting for 13 percent of the power.)

A sense of the pace of the Russian program is given by Semenov's statement that "during the next five-year period the generation figure will increase more than threefold and will reach 220 billion kilowatt-hours in 1985." (The U.S.S.R.'s current five-year plan for economic development covers the period from the beginning of 1981 to the end of 1985.) Moreover, "since it is planned that the total electric power production in the country will be increased to about 1,500 billion kilowatt-hours, nuclear plants will account for 14 percent of the total electricity production in the entire country by 1985 and for 24 percent in the European region."

Fundamental differences between the European part of the U.S.S.R. and the Asian part constitute one of two reasons cited by Semenov for the nation's decision "to favor nuclear power as a main source of energy." About 80 percent of the country's energy resources are concentrated in the eastern region, whereas 75 percent of the population and the consumers of power are in the European region. As a result the transportation of fuel from east to west constitutes about



Taste is all it takes to switch to Jim Beam.

KENTUCKY STRAIGHT BOURBON WHISKEY. 80 PROOF. DISTILLED AND BOTTLED BY JAMES B. BEAM DISTILLING CO., CLERMONT, BEAM, KY.

CIMARRON '84
THIS ONE'S GOT THE TOUCH.

The Cadillac touch. It's Electronic Fuel Injection, matched by a tenacious Touring Suspension that comes to grips with the road. It's leather-faced front bucket seats with lumbar support behind a leather-trimmed steering wheel that lets you know you're in control. It's new grille and taillight styling. Laser-accurate quality fits. It's Cimarron '84...with something no other car in its class has. The Cadillac touch.

BEST OF ALL...IT'S A CADILLAC.

Let's Get It Together...Buckle Up.

40 percent of the country's rail-freight operations. The second reason is that "nuclear power is less damaging to the environment than conventional power."

Although the U.S.S.R. opened its first nuclear power plant in 1954, the pace of expansion has been most rapid in the past few years. Of the 18,000 megawatts in installed nuclear capacity some 12.5 million kilowatts is supplied by plants put into operation in the period from 1976 to 1982. The rate at which nuclear power was introduced nearly tripled in the last five-year period compared with the preceding one. The rate at which nuclear power plants are being introduced is about 2.5 times higher than the rate of introduction of power plants burning fossil fuels. During the current five-year period the construction of new fossil-fueled plants in the European part of the country "will practically cease," according to Semenov, "and by 1985 almost all the increase of installed capacity will be from nuclear power plants."

The U.S.S.R. also plans to give a good deal of attention to breeder reactors, which are designed to make more nuclear fuel than they consume. (The present program rests on two types of reactor: the WWER pressurized, light-water-moderated-and-cooled reactor and the RBMK light-water-cooled, graphite-moderated channel type.) Breeder reactors have "a special priority," Semenov says, because the U.S.S.R. "clearly recognizes that the solution to long-term nuclear-fuel problems for large-scale nuclear-power programs requires the wide use of breeder reactors."

The Mitochondrion's Message

The concept that aberrant nucleotide sequences in DNA can be passed from parent to child and cause inborn disorders of metabolism is now a familiar one. The nucleotide sequences carry the instructions for making enzymes and other proteins that are essential to the functions of the living cell. Therefore a disruption of the correct nucleotide sequences can lead cells to make abnormal proteins or to make none of a particular protein. In all the familiar instances of inherited human metabolic disorders, such as sickle-cell anemia and beta thalassemia, the incorrect genetic information is in the DNA of the chromosomes in the nucleus. Not all the genetic material of the cell, however, is in the chromosomes. For example, DNA is also found in the mitochondria: the numerous energy-producing organelles in the cytoplasm surrounding the nucleus. In a recent issue of *The New England Journal of Medicine* Joseph Egger and John Wilson of the Hospital for Sick Children in London report the first instance where a metabolic disorder has been shown to be transmitted from parent to child by the mitochondrial DNA.

Each mitochondrion consists of an outer membrane wrapped around an inner one to form a complex, irregular oblong. In the spaces defined by the two membranes are many copies of a large set of enzymes. The enzymes mediate the oxidation of pyruvate, fatty acids and amino acids to carbon dioxide and water. The oxidation is coupled to the synthesis of adenosine triphosphate (ATP), which serves as the fuel for many cellular reactions.

In order to carry out its function of making ATP each mitochondrion needs a full complement of enzymes. The genetic information required to make the proteins is divided between the DNA in the nucleus and the DNA in the mitochondrion. The code for most of the enzyme components is carried by the chromosomes. The code for the rest of the enzyme components is carried by the genetic material of the mitochondrion: a double-strand DNA circle that in human cells is a few thousand nucleotides long. The chromosomally coded proteins are made on ribosomes in the cytoplasm and transported into the mitochondrion. The mitochondrially coded proteins are made on ribosomes within the mitochondrion.

Since some enzymes are coded in the nucleus whereas others are coded in the mitochondrion, a genetic disorder of the organelle could have its origin in the nuclear DNA or in the mitochondrial DNA. The nuclear and mitochondrial forms of inheritance can give rise to quite different patterns of transmission.

The nuclear pattern is Mendelian inheritance. Each trait that shows such inheritance is determined by at least two genes, one on each member of a pair of chromosomes. Each gamete (sperm or egg) includes only one of the pair of chromosomes. As a result the child does not necessarily inherit the trait: it appears in a complex pattern in the next generation, with some children inheriting it and others not inheriting it. The pattern is called segregation, and if it is known whether the trait is dominant or recessive, the probability of inheritance can be calculated with considerable precision. It can readily be seen that a Mendelian trait can be inherited from either the mother or the father, because the zygote (fertilized egg) contains one set of chromosomes from each parent.

The traits coded by mitochondrial genes, however, are transmitted by a quite different mechanism. Almost all the mitochondria in the zygote come from the mother. The sperm contributes very little cytoplasm to the zygote and therefore contributes few cytoplasmic organelles or none. Hence the mitochondrial DNA comes almost exclusively from the mother.

Egger and Wilson noted the appearance of the syndrome called mitochondrial cytopathy in successive generations of 30 families; in each family the disorder was known to be present in at least two generations. Mitochondrial cytopathy entails defects in the shape of the mitochondria and in the structure of several mitochondrial enzymes. The symptoms of the disease include reduced height, muscular weakness and many malfunctions of specific organs.

In 27 of the 30 families the disease was exclusively transmitted through the mother. Fifty-one mothers and only three fathers had passed the disease to their children. Of the 130 siblings of definitely diagnosed victims of mitochondrial cytopathy, 89 showed symptoms of the disease. This is a much higher ratio than would be expected if Mendelian segregation were at work.

Egger and Wilson conclude that mitochondrial cytopathy is transmitted by the DNA of the mitochondrion. In accounting for the fact that mitochondrial cytopathy was transmitted by the father in a few cases, they propose that occasionally a mitochondrial gene could be taken up into the nuclear genome (the full complement of genetic information in the nucleus). Once inserted into a chromosome the gene would be transmitted according to the rules of Mendelian inheritance.

If all the mother's mitochondrial DNA had the same defective nucleotide sequences and the gamete got copies of all the maternal mitochondrial genes, then the children of a woman suffering from the disease would all have the syndrome with the same degree of severity. In Egger and Wilson's observations, however, there was considerable variation in the severity of the symptoms, and some children escaped the disease completely. It could be that not all of the mother's mitochondria contain the abnormal nucleotide sequences. When the gamete is formed, copies of the mitochondrial genes are parceled out to the egg according to non-Mendelian rules of distribution. The number of copies of the aberrant genes could vary from egg to egg, and hence the severity of the disease would vary among offspring.

Quantum Evaporation

Albert Einstein's explanation of the photoelectric effect, in which an electron is ejected from the surface of a metal by light or some other form of electromagnetic radiation, was a decisive step in convincing many physicists that Max Planck's hypothetical quanta, or discrete packets of energy, are physically real. One of the most straightforward analogues of the photoelectric effect is the evaporation of atoms or molecules from the surface of a liquid. Under normal circumstances, however, such a large number of atoms or molecules are ejected from the evaporating surface that the presumed quantization of

the thermal energy causing the evaporation is smoothed out. Now three experimental physicists at the University of Exeter, M. J. Baird, F. R. Hope and A. F. G. Wyatt, have designed a sensitive apparatus that enables them to observe quantum evaporation under extreme physical conditions. In quantum evaporation a single atom is ejected from the surface of a liquid by a single, quantized thermal excitation of the liquid. The work is reported in *Nature*.

The investigators point out that ordinary evaporation remains far too complex to be explained from the first principles of the quantum theory. The difficulty is to understand how atoms acquire the energy needed to overcome the forces binding them to the surface of the liquid, an energy that is often far in excess of the average kinetic energy of an atom in thermal equilibrium with the rest of the atoms in the liquid. Hence in order to demonstrate quantum evaporation the complex interactions that give rise to ordinary evaporation had to be eliminated; experimental conditions were imposed in which the mechanism of evaporation would match, as closely as possible, the mechanism proposed by Einstein to explain the photoemission of electrons.

The quantum nature of the photoelectric effect is evident in the frequency threshold that must be crossed before any electrons are emitted. Furthermore, above the threshold frequency the kinetic energy of the emitted electrons varies directly with the frequency of the incident radiation. A change in the intensity, or amplitude, of the incident radiation, however, is inconsequential because an electron can gain energy only in the discrete amount carried by a single photon, or quantum of radiation. The energy content of a photon varies directly with its frequency, and so only photons of sufficiently high frequency can eject electrons from a metal. The kinetic energy of the emitted electron is equal to the difference between the energy transmitted to it by the incident photon and the binding energy the electron must overcome in order to escape from the metal.

The quantum-mechanical analogue of the photon for thermal excitations is the phonon. As early as 1912 Peter J. W. Debye (and almost simultaneously Max Born and Theodor von Kármán) recognized that phonons, very-high-frequency pressure waves, could transmit thermal energy through a liquid or a solid. Although from a classical (non-quantum-mechanical) point of view phonons are merely distortions of the atomic medium, quantum mechanics implies that the phonon must also be understood as a particle that moves through the medium with a certain wavelength and carrying a discrete amount of energy.

The major difficulty overcome by the Exeter workers was in demonstrating that the evaporation of an atom can be caused by a single incident phonon and not by some more complex interaction. In many liquids the mean free path of a phonon, that is, the average length of the path before the phonon is scattered or attenuated, decreases sharply with an increase in the phonon's energy. If a phonon with sufficient energy to evaporate an atom were experimentally introduced into such a liquid, its mean free path would be so short that by the time it reached the surface of the liquid its integrity could no longer be guaranteed. If evaporation were to take place, a mechanism for the evaporation analogous to that for the photoelectric effect could not be inferred. In a liquid consisting of the isotope helium 4, however, the mean free path of a phonon becomes quite large for a range of phonon frequencies above a critical value; the critical frequency is greater than the frequency required to eject atoms from the liquid-helium surface.

Baird, Hope and Wyatt submerged a small heater in a bath of liquid helium 4 cooled to within a tenth of a degree Celsius of absolute zero. The heater was

connected by a rigid bar to a bolometer above the surface of the helium that could detect helium atoms emitted from the surface. The bar was fixed to a carriage, and so the entire apparatus could be moved up or down with respect to the surface of the liquid helium. The distance between the heater and the bolometer was measured, and the time between the emission of a pulse of energy from the heater and the first detection of helium atoms at the bolometer was recorded for numerous vertical positions of the heater.

The pulse of energy at the heater introduces phonons of many different frequencies into the liquid helium. The velocity of the phonons through the liquid varies inversely with their wavelength, so that the low-frequency phonons arrive at the surface of the liquid first. On the other hand, for phonons that are energetic enough to evaporate atoms from the surface, the higher the frequency of the phonon, the greater the velocity of the emitted atom and the smaller the time of flight of the atom from the surface of the liquid to the bolometer. Hence for a given depth of the heater in the liquid there is a characteristic interval between the heating of the liquid and the arrival of helium atoms at the bolometer, provided the phonon excitations travel unimpeded through the liquid. The measured times for many different depths agree well with the predicted values, and so the experimenters conclude that the energy required for evaporation is transmitted by individual phonons. They write: "Liquid helium 4, therefore, is the first liquid in which we can understand evaporation at the atomic level."

Dynamic Proteins

Every textbook of molecular biology includes dozens of drawings of molecules. In some of them balls representing atoms are joined rigidly by sticks representing bond lengths and angles; in others rigid three-dimensional forms represent the volume of influence of each atom's electrons. In a way the drawings are misleading: they show only the average form of the molecule over a long period of time. In actuality the molecules of importance in molecular biology tend to be fluid. For example, globular proteins, which consist of compact, serpentine chains of amino acids, are flexible: the bonds that link the succession of amino acids can rotate, so that over times on the order of 10^{-13} second "the motion of individual groups" in the protein is "similar to that of small molecules in a liquid. The groups jiggle about as a result of frequent collisions with the surrounding 'cage' atoms" in the liquid. Over longer periods "larger regions in the protein molecule" make "slower elastic movements."

The above quotations are from a discussion of the fluid motions of globular proteins by J. Andrew McCammon of the University of Houston and Martin Karplus of Harvard University. In an article in *Accounts of Chemical Research* McCammon and Karplus treat the subject as a new theoretical science. The first step, they write, is to devise a mathematical description of the potential energy of a protein as a function of the positions of its atoms. The description includes terms depending on bond lengths and bond angles. Additional terms represent interactions between atoms in the protein that are not bonded to each other. Such interactions are "important in globular proteins because of the dense packing of atoms in these molecules." Indeed, the "close-packed nature of globular proteins" makes their short-term properties similar to those of a "simple liquid" in which "molecules are composed of hard sphere atoms; that is, the structure is one that optimizes the packing of such molecules, and the molecular motion reflects the frequency of collisions between them." The completed description of the potential energy of the protein readily yields a

mathematical description of the forces acting on each atom, and then, by Newtonian equations, the description of the forces yields a description of how the molecule moves over time.

Slower motions in the protein require different methods. In one method the motion of "a group of side-chain atoms in a protein" is taken to be analogous to the diffusion of a molecule through a liquid or a solid. "It is therefore a temperature-dependent quantity and typically becomes softer, or more permissive, as the mobility of neighboring groups increases." Again the interactions between atoms that are not bonded to each other prove to be important. "These interactions produce randomly varying forces that act to speed or slow the motion of the group in a given direction." The motion itself entails a certain degree of friction between the group and its surroundings, and that too must be taken into account.

The dynamics of certain parts of certain proteins have already been modeled in detail. Bovine pancreatic trypsin inhibitor (BPTI) is an example. The atoms in BPTI turn out to fluctuate about their average positions by distances comparable to the radii of the atoms. The fluctuations "increase markedly near the protein surface." The 21st amino acid in the chain of BPTI is tyrosine, which is notable for a ring of carbon atoms projecting outward from the backbone of the chain. The ring turns out to twist about its bond to the backbone; "the motion is analogous to the rotation of a benzene [ring] about an axis passing through two atoms at opposite vertices of the ring." In BPTI the time-averaged amplitude of the twisting (about 12 degrees) is limited by "hindrance between atoms in the ring and those in the cage surrounding the ring," but "large-scale distortions of the protein produce small changes in the overall shape of the cage, with a concomitant alteration of the ring orientation." Sometimes the ring flips: it twists 180 degrees. The theoretical studies suggest that the flip requires only .5 to 1 picosecond and that it occurs "not as the result of a particularly energetic collision with some cage atom but as the result of a transient decrease in frequency and intensity of collisions that would drive the ring away" from having the energy a flip requires.

McCammon and Karplus suggest that "the dynamical nature of protein molecules is essential to much of their biological activity. Indeed, it is reasonable to suppose that the internal flexibility of proteins and some of their dynamical characteristics have been shaped by evolution to allow efficient expression of protein function." It is known that the protein myoglobin, which binds oxygen molecules in muscle cells, has "no channel for oxygen entry." The entry "is dependent on transient structural fluctuations." On larger scales the hinged motion of parts of a protein may modulate the rate at which the protein acts, say, as an enzyme, that is, as a catalyst. The theoretical study of protein dynamics should make it possible to predict such rates "before the end of this century," and the predictive ability "will ultimately be of practical use in connection with genetic engineering and industrial enzyme technology."

Star Grazers

Two workers at the Lunar and Planetary Institute in Houston studying the images from the 1976 Viking mission to Mars noticed something funny about the craters that pit the Martian surface. Too many of the craters were elongated rather than circular, and the direction of the major axis of the elongated craters seemed to vary systematically with their age. A catalogue of 176 such craters confirmed this impression and led Peter H. Schultz and Anne B. Lutz-Garihan to some startling conclusions about the bodies that produced the craters and the reason for the variation in the axis of the craters. They present them in a recent issue of *Journal of Geophysical Research.*

Most impact craters on the moon, Mars and Mercury are relatively circular and are surrounded by a symmetrical pattern of ejecta. An elongated crater with a butterfly-wing pattern of ejecta perpendicular to the long axis of the crater is produced only by a grazing impact. Laboratory experiments have shown that the angle of impact must be less than five degrees to make craters with both these identifying characteristics. For objects in orbit around the sun, such as asteroids or comets, the most probable angle of impact with another body is 45 degrees. The probability of impact at angles less than five degrees is .7 percent. On the maria (lava plains) of the moon there is only one grazing-impact crater larger than three kilometers, a frequency consistent with the theoretical probability of grazing collisions between heliocentric objects and the moon. On the lava plains of Mars, however, about 5 percent of the craters are grazers, a frequency 10 times higher than collisions with heliocentric bodies should have produced.

When the 176 Martian grazers were grouped according to their age (determined on the basis of the degree to which they had been eroded), it became apparent that the major axes of craters of roughly the same age often fall on the same great circle and that the great circles traced by the axes of older craters are increasingly inclined toward the Martian equator. In other words, the axes of newer craters are roughly east-west with respect to the Martian geographic poles and the axes of older craters are increasingly north-south with respect to the poles.

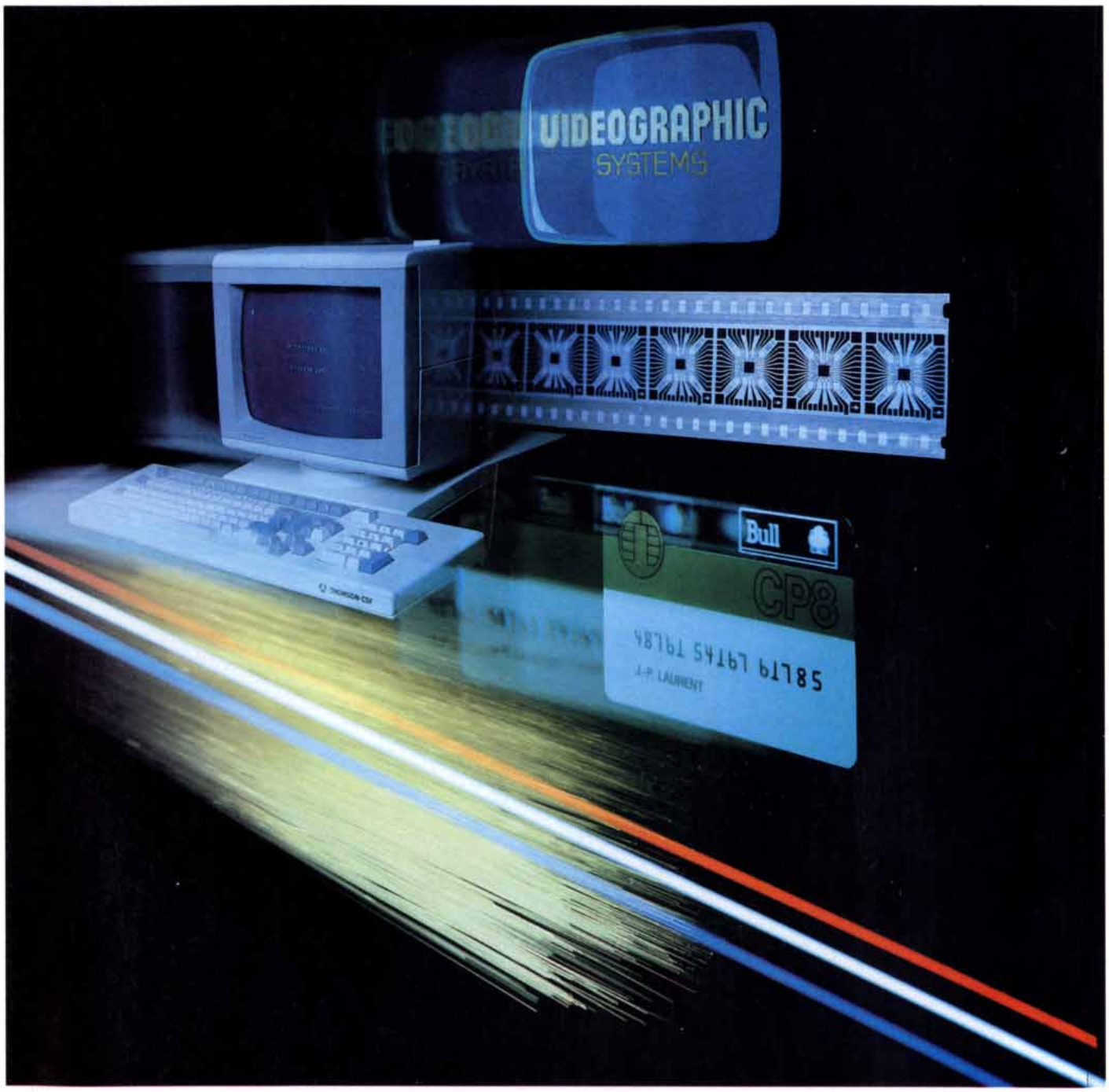
After considering several possible interpretations of the evidence Schultz and Lutz-Garihan conclude that the grazers were produced not by heliocentric bodies but by areocentric ones: a large family of Martian satellites whose orbits decayed over time. The consistency of the orientation of the axes of impact indicates that at any given time the satellites had orbits with nearly the same inclination. This suggests that a swarm of smaller satellites may have been created by a process such as the incomplete accretion of one large satellite, at least 225 kilometers in diameter. The tiny Martian moons Phobos (which will collide with Mars in about 10 million years) and Deimos may be the last members of this large family.

Schultz and Lutz-Garihan also consider two possible explanations for the variation of the axis of cratering with time. They conclude that the axis changed not because the inclination of the orbits of the satellites changed but because the Martian crust moved. Any of several processes causing substantial changes in the moment of inertia of the planet (the distribution of mass with respect to the spin axis) could have caused the crust to migrate. For example, the orientation of the long axes of the grazing craters shifted from north-south to east-west at about the same time as the first major epoch of Martian volcanism began. The volcanic and tectonic processes that formed a large uncompensated mass such as the Tharsis province on the surface of the planet and the upwelling of dense mantle material that may have accompanied the formation of the mass would have significantly changed the moment of inertia. Centrifugal force would then have caused the mass to migrate toward the equator (outward) until the greatest mass (the principal moment of inertia) coincided with the equator and the smallest mass (the minimum moment of inertia) coincided with the planet's pole or spin axis. The orientation of the axes of the Martian grazers provides a clear record of the redistribution of mass with respect to the spin axis caused by the migration of the crust.

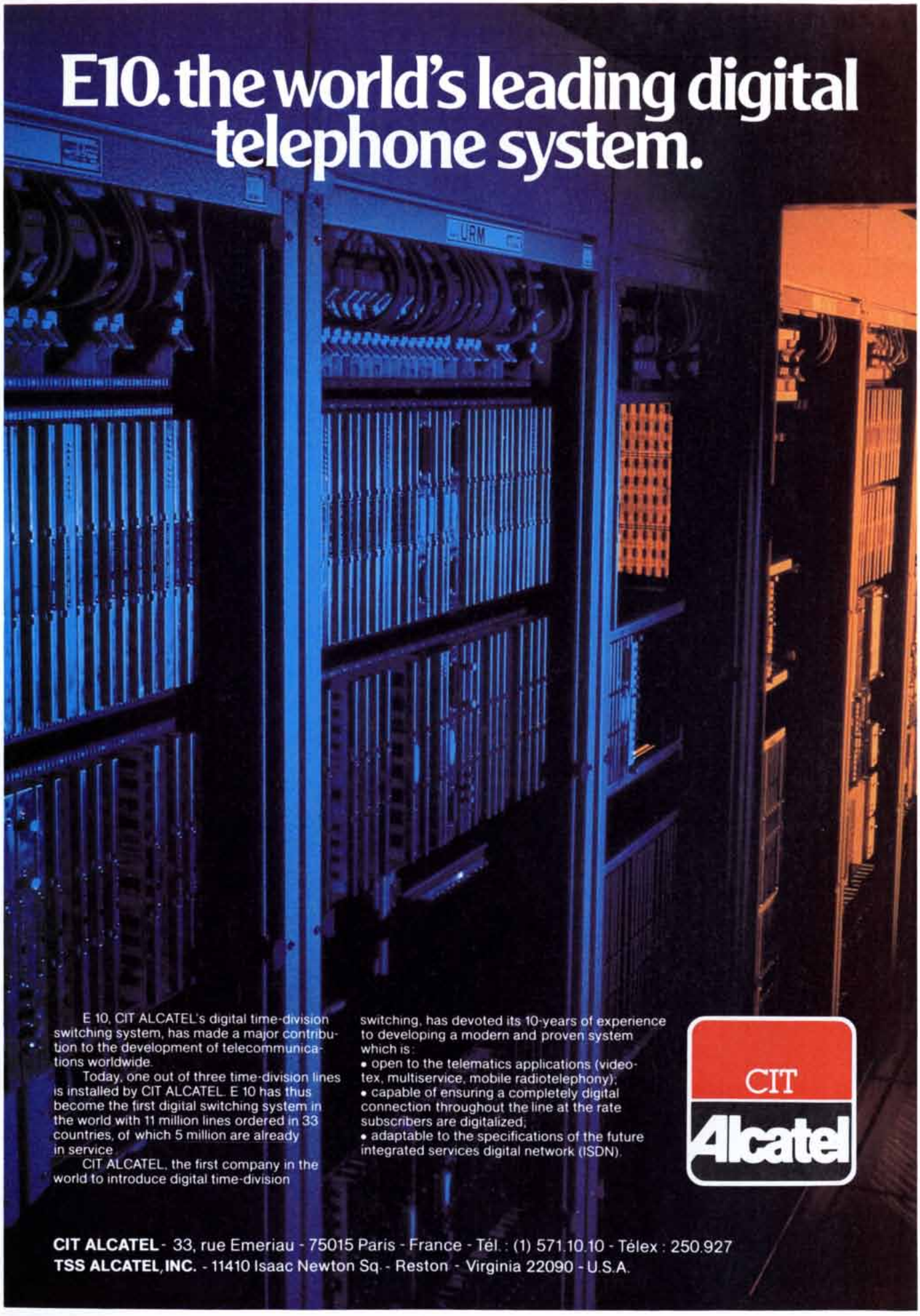
It can be shown on this basis that the points on the Martian surface that are now the geographic poles were once at much lower latitudes. In general the variation of the axis of cratering records the wandering of the Martian geographic poles much as the alignment of magnetic grains in the rocks of the earth's crust records the wandering of the earth's magnetic poles. The Martian grazers might thus serve as the basis for reconstructions of the past geography of Mars just as remanent magnetism serves as the basis for reconstructions of the past distribution of the continents of the earth.

French Communications: Exporting Technical Expertise

This special report on French communications was written by Joel Stratte-McClure following visits to public and private research facilities, government agencies and industrial companies throughout France.



E10. the world's leading digital telephone system.



E 10, CIT ALCATEL's digital time-division switching system, has made a major contribution to the development of telecommunications worldwide.

Today, one out of three time-division lines is installed by CIT ALCATEL. E 10 has thus become the first digital switching system in the world with 11 million lines ordered in 33 countries, of which 5 million are already in service.

CIT ALCATEL, the first company in the world to introduce digital time-division switching, has devoted its 10-years of experience to developing a modern and proven system which is:

- open to the telematics applications (videotex, multiservice, mobile radiotelephony);
- capable of ensuring a completely digital connection throughout the line at the rate subscribers are digitalized;
- adaptable to the specifications of the future integrated services digital network (ISDN).

CIT Alcatel

CIT ALCATEL - 33, rue Emeriau - 75015 Paris - France - Tél. : (1) 571.10.10 - Télex : 250.927
TSS ALCATEL, INC. - 11410 Isaac Newton Sq. - Reston - Virginia 22090 - U.S.A.

CREATING A DOMESTIC INFRASTRUCTURE

One of the cornerstones of the French government's ambitious attempt to become a global force in high technology (see "French Telecommunications Digital Technology and the Télématique Program" and "French Technology: Preparing for the 21st Century," in the September 1980 and November 1982 issues of this magazine, respectively) is to enhance the lead it has established in numerous sectors of military and civilian communications. During the past decade France has developed and created a number of advanced products and systems, introduced a wide range of domestic communications services, launched a variety of long-term research and development (R&D) projects, contributed to international standards and penetrated the international marketplace.

The transition in French communications began in 1975, when the modernization of the domestic telephone network became a priority of the country's seventh five-year plan. $30 billion was initially allocated to improve the internal telecommunications network and increase the number of subscriber lines from 6.2 million in 1974 to over 20 million in 1983.

The technical emphasis was on the development and introduction of electronic time division multiplex (tdm) switching (the world's first electronic tdm switching center was operating in France in 1970), digital pulse code modulation (pcm) transmission, a packet-switched data network and a multiservice domestic satellite system. Government and industrial R&D concentrated on microelectronics, optoelectronics, intelligent terminals and networks, optical and satellite communication systems, computer and microprocessor assistance to network function and new communication concepts.

In the late 1970's, the French launched the *télématique* (a word formed by combining *télécommunications* and *informatique*, which means data processing) program. *Télématique* integrates numerous compatible products and services into a harmonious network permitting data and other forms of information to be transferred speedily using pcm transmission and tdm switching techniques. Today the emphasis in French communications is on utilizing the country's semi-digital network infrastructure to create easy-to-use low-cost *télématique* services for companies, community organizations and individuals. *Télématique* transforms the public switch telephone network (pstn) into a multifunctional tool that answers a variety of communication requirements.

In 1986, it will be possible for French subscribers to have an all-digital dialing network with a 64 kilobits per second (kbit/s) transmission rate providing access to a fuller range of new services. Digitization of the network to the subscriber level will produce a digital synergy merging terminations, private branch exchanges (pbxs), cellular radio and satellite services with new forms of transmission—primarily satellite, fiber optics and packet switching. The result will be the concurrent storage, processing and transmission of text, data and voice on a single carrier.

In addition, the government recently decided to complement this integrated telephone and data network (itdn) with a nationwide fiber-optical videocommunications network—which will pave the way for the implementation of a wide-band integrated services digital network (isdn). The French are gambling on its also enabling them to leapfrog their competitors on the technological front and further exploit export markets.

PTT: PROVIDING THE DIRECTION

The French communications effort is controlled by the PTT—the Ministry of Postes, Télécommunications and Télédiffusion—which owns, regulates and operates the national telecommunications network. The PTT directs and executes telecommunications, television and postal policy and is responsible for the pace of technical change, the type of equipment permitted on the market and the services available.

The Direction Générale des Télécommunications (DGT) is the telecommunications arm of the PTT and implements telecommunications policy. Within the DGT are the Direction of Industrial and International Affairs (DAII), the National Telecommunications Research Center (CNET) and other affiliates responsible for overseeing the effort.

While some PTT's are moving towards deregulation, there is no intention of further liberalizing telecommunications policy in France. In 1982, the government—continuing a process begun in the mid-1970's, when some foreign firms were forced to sell their telecommunications operations in France to local companies—nationalized major telecommunications, data processing and electronics firms.

"Nationalization will permit more collaboration, promote efficiency and provide a unified effort," says Louis Mexandeau, Minister of the PTT. "It helps France avoid duplication of R&D and speeds up development. In addition, industry will remain tightly regulated because the alternative leads to an absence of any global planning and guidance—often resulting in higher charges and deteriorating service."

Although the current French economic austerity program has led to budget reductions throughout the public sector, the PTT remains a major innovative force in the country's development.

"Our charter provides that the budget will remain at 27 billion French Francs (FF)* for the next four years," says Mexandeau. "The primary expenditures will be development of the regular telephone network, *télématique* services and wide-band cable technology."

Jacques Dondoux, the Director General of Telecommunications, contends "France has introduced *télématique* products and we intend to make *télématique* profitable, establish a competitive fiber optic industry, launch our domestic satellite and increase telephone traffic."

THE EMPHASIS ON ELECTRONICS

The electronics industry, with 1,700 companies and a workforce of 490,000, is the keystone of the French industrial program. As part of a government plan, 140 billion FF is slated to be invested in electronics by the state and industry during the next five years, with 80 billion FF earmarked for telecommunications and professional electronics.

The key goal is to reduce the negative trade balance in electronics products, which rose from 6 billion FF in 1981 to 12 billion FF in 1982. Another aspect of the plan is to create a strong domestic industry and boost the French presence in export markets. France represents about 5 percent of the world electronics market, but 52 percent of the French electronics and telecommunication markets is controlled by foreign companies—primarily from the U.S. (22 percent), Japan (7 percent), West Germany (7 percent), and Holland (6 percent). Excluding their domestic market, the French have only 1.4 percent of the world electronics market—and only 0.3 percent of the U.S. electronics market and less than 2 percent of the U.S. telecommunications market. The electronics effort is meant to alter this situation.

"The solid structure of French telecommunications will bring a dynamism to other electronics sectors," predicts Mexandeau.

Critics contend that the French elec-

*At the time of writing, 1 U.S. dollar equals approximately 8 FF.

tronics plan, much of which is under the supervision of the PTT, is too vast and financially unrealistic. But most observers agree that France has a technical lead in telecommunications that can be exploited.

THE INDUSTRIAL STRUCTURE

The French want to have at least two domestic suppliers in most areas of telecommunications rather than create a nationalized "Telephone de France." Although some foreign companies have participated in the development of French telecommunications, most of the effort is allocated to domestic companies.

Five companies, nationalized or partly owned by the French state as part of President François Mitterrand's Socialist program following his election in May 1981, are the prime industrial movers behind the communications effort: Bull, Compagnie Générale de Constructions Téléphoniques (CGCT), CIT Alcatel, Matra and Thomson-CSF.

CIT Alcatel is a subsidiary of the Compagnie Générale d'Electricité, (CGE), the fifth largest company in France, and has always conducted a strategic concertation with the government.

"The nationalization has had a favorable influence because it provides the long-term outlook needed in the telecommunications industry," says Pierre Chavance, CIT Alcatel's director general.

Today CIT Alcatel is a leading manufacturer of tdm switching systems (30 percent of the world market), 30-channel pcm equipment, submarine telephone systems and electronic pbxs. Its affiliate Alcatel Electronique is a specialist in mail handling, peripheral telecommunications equipment, radiocommunications and electronic telex terminals. SESA, in which CIT Alcatel has a 55 percent stake, is the leading French company in the area of packet switching networks, and its affiliate Câbles de Lyon is France's largest manufacturer of telecommunications cables.

Thomson-CSF—part of the Thomson group and a leading exporter of detection systems, microwave equipment, satellite earth stations and radio/TV transmitters—has about 40 percent of the French tdm public telephone switching market and 21 percent of the private telephone market. Thomson has recently restructured its telecommunications activities, placing a priority on forming more international agreements and penetrating the U.S. market.

"We have synthesized the wide range of our activities in communications to provide customers with complete turnkey systems in numerous areas," says Jacques Darmon, the head of Thomson-CSF's communications branch.

The Thomson-CSF communications branch includes public telecommunications, radio communications, business communications, knowledge information processing systems and software.

Matra—a diversified defense, electronics and communications group—is consolidating its telecommunications industrial base for increased development of pbxs and terminals. Participation by the French state in Matra has not altered the company's ambitious diversification philosophy, which has led to numerous international joint ventures.

"The French government has not replaced our management as it has with other newly nationalized companies," says Maurice Remy, director of Matra's telecommunications branch.

CGCT, a former subsidiary of ITT, previously manufactured space division electronic switching systems. After two years of government debate, however, it has been given a license to manufacture the Thomson-CSF range of digital switching systems. CGCT also specializes in private telephone sets and systems and manufactures a range of pbxs, telephone and *télématique* terminals, teletex equipment, decoders and local area networks.

"We needed both government money and the decision to manufacture a digital switching system in order to survive," says CGCT president Pierre Lestrade.

Bull (formerly Cii-Honeywell Bull) is the second largest European vendor of data processing equipment. The French government has signed a comprehensive agreement with Bull to develop a complete range of data processing products, including software, components, mini- and microcomputers, office automation networks and medium-sized and large computer systems. Honeywell retains just under 20 percent of Bull and has renewed an existing technology and marketing agreement for ten years.

"Our task is to integrate our wide scope of activities and participate in the rapid developments taking place in French communications," says Claude Boulle, director of Bull's networks and communications group.

The group G3S includes CSEE (Compagnie de Signaux et d'Enterprises Electriques), SAGEM (Société d'Applications Générales d'Electricité et de Mécanique) and SAT (Sociéte Anonyme de Télécommunications). Forty-three percent of G3S activity is in telecommunications and data processing areas, including local and long-distance cables, microwave radio links, transmission equipment, teleprinters and teletex, facsimile transmission equipment, telephone and telegraph electronic switching, telemetry, telephone networks, cable TV, automatic postal sorting equipment and disk and bubble memories.

"Although there was initially concern that the government would primarily support nationalized companies, we are still getting our fair share of work from the PTT," says Francois Le Menestrel, chief executive officer of SAT. "We've maintained our market share in cables, transmission and microwave activites and export 30 percent of our turnover."

Jeumont-Schneider, part of the Empain Schneider group, produces components and software, markets a line of electronic pbxs and manufactures a rural tdm switching system.

TRT (Télécommunications Radioélectriques et Téléphoniques), an affiliate of Philips, is active in microwave radio systems, radio communications, data communications and switching, telephone transmission, *télématique* terminals and integrated digital systems.

INDUSTRIAL DEVELOPMENTS

Though the list of French communications projects is extensive, it is worthwhile surveying some of the more important activities.

INTEGRATED CIRCUITS: French companies have licensed chip-making technology and basic chip design from abroad, creating joint ventures and technology cross-licensing agreements with American firms. Following an expensive five-year integrated circuit plan, France has reorganized its components industry around two industrial poles, Thomson-CSF Components and Matra-Harris Semiconducteurs.

In 1982, French manufacturers accounted for only 5 percent of the domestic microprocessor and MOS memory markets (45 percent if foreign groups are included) but the French government will spend 4.5 billion FF on the integrated circuit industry from 1983 to 1986 in an effort to equalize the trade deficit.

SOFTWARE: France, Europe's largest supplier of software, developed the ADA language, powerful software for tdm switching (which requires about 1.2 million instructions) and software for *télématique* and videocommunication applications.

"France is effectively disseminating

the use of computers that will encourage more software advances," says Michel Jalabert, vice president of corporate development at information engineering services company Cap Gemini Sogeti.

Cap Gemini Sogeti and Steria have provided most of the software for the country's *télématique* videotex experiments; France Câbles & Radio subsidiary Télésystems plays an active role in data processing and produces software for electronic mail, network engineering, applications software and videotex; Sligos has developed software packages for the smart card; and Bull is expanding its range of sophisticated software for its data processing products and systems.

DIGITAL SWITCHING: The last electromechanical telephone exchanges in France were ordered in 1981, and the PTT continues to invest heavily in semi-digital and digital exchanges for cost-effective expansion (tdm is 30 percent less expensive than space division switching) and modernization of the telephone network. In 1983, more than 90 percent of the DGT's orders for switching equipment will be tdm, and more than 3 million digital lines are already in service.

The results of digital switching are numerous—better service, simplified engineering because of its modular structure, sophisticated administration and maintenance, and enhanced features—and the PTT is now ordering second-generation systems from CIT Alcatel (E10 B local exchanges and E 12 transit centers) and Thomson-CSF (MT 20 transit centers and MT 25 local exchanges).

CIT Alcatel, whose E 10 switching system has been ordered by 34 countries, has a technological and commercial lead on Thomson-CSF, whose MT range of tdm exchanges has been ordered by 16 countries. CIT Alcatel's E 10 all-electronic telephone exchanges won 50 percent of the orders from the PTT last year against 35 percent for Thomson-CSF and 15 percent for CGCT. But both companies must now concentrate on the international marketplace, where the real marketing battle is being waged.

French industry has also developed modular, medium-capacity digital systems for telephone and *télématique* applications, including the E 10 S from CIT Alcatel and the MT 35 from Thomson-CSF. Jeumont-Schneider's JISCOS electronic public switching exchange has been designed for low- and medium-density population areas, and SAT manufactures the TC 300 digital public switching system with a capacity of over 8,000 subscribers for rural

or medium-density zone telephone networks.

French companies are examining the evolution of digital switching equipment. "There will be a definition of new products based on applications such as animated images," says Jean-Claude Grynberg, head of the industrial switching group at the DGT. "Once manufactured, systems will then be tailored to individual needs."

"Industry is moving towards decentralized systems of autonomous subscriber connection units," adds Jacques Hauri, product planning manager of Thomson-CSF's public switching division. "There will be an integration of services with a more flexible system."

CABLE AND TRANSMISSION: Accompanying the introduction of tdm switching is the corresponding pcm digital transmission supporting environment. The French are converting the transmission system from analog to digital techniques that use hierarchical operating channels to transmit over coaxial cable, microwave radio relay and optical fibers. Digital transmission reduces the required amount of coding and multiplexing equipment, permits more circuits to be established on existing cables and facilitates transmission of new services.

The three primary cable manufacturers are CIT Alcatel, SAT, and Thomson-CSF subsidiary LTT (Lignes Télégraphiques et Téléphoniques). In addition, SAT, Thomson-CSF, and TRT compete for the microwave market; TRT and SAT are leaders in the modem market; and multiplexer and amplifier suppliers are CIT Alcatel, SAT and LTT. For several years, the DGT orders for transmission systems have been for digital equipment.

The major effort in the transmission field is to equip France with fiber-optical networks, including interurban links, wide-band links to subscribers, submarine cable and optical fibers for video telephone and video teleconferences. Most manufacturers provide cable and optical fiber telecommunications equipment, including long-haul analog and digital transmission systems for land links; cable for local networks and subscriber connection; equipment for *télématique* transmission, including the connection of professional terminals, facsimiles and data transmission equipment; and optoelectronic components.

PRIVATE TELEPHONY: Numerous French companies—CGCT, CIT Alcatel, Jeumont-Schneider, Matra, SAT and Thomson-CSF—are producing multifunctional pbxs with digital technology that save space and improve reliability. They include the basic components of a controller with sophisticated software, a switch matrix, a number of interface modules and transmission at 64 kbit/s. Sales of digital pbx equipment are expected to surpass analog in 1984—simultaneously creating a large market for vlsi chips, coder-decoders and subscriber line interface circuits (slics).

"There is a competitive, open market for pbx equipment in France, but the return is not great because the cost per line is much less than in the U.S.," says Jeumont-Schneider's commercial director Jacques T. Darmon. "We believe there is a great role in the office for the multiservice pbx as a local area network."

A number of companies are marketing the T 83, the new electronic telephone set available to French subscribers, as well as a variety of terminals for domestic use and export.

"The leadership for requirements and needs in private telephony comes from the U.S., but the market is worldwide," says François Dufaux, director of Thomson-CSF's private telephone division.

VIDEOTEX: Two French videotex systems are operating today. The Télétel interactive videotex uses the telephone line to transmit requested information, and the ANTIOPE (Numerical Acquisition and Televising of Images Organized in Pages of Writing) teletext broadcasts information repetitively in the blanking interval between frames

FRENCH COMMUNICATIONS:

SMALL COMPANIES ARE PROSPERING

While nationalized and large private companies in France handle a substantial amount of telecommunications activity, a number of smaller firms are also making considerable technical breakthroughs and creating an international commercial impact.

"We are trying to find the best synergy possible between the investment and research capabilities of nationalized firms and the innovative capacity of smaller companies," says the DGT's Jacques Dondoux. "Innovations range from products associated with digital and packet switching to the *télématique* arena and private telephony."

Some examples:

—Barphone, located in Saumur in the Loire Valley, has established a worldwide commercial network to market its telephone terminals and accessories, which include fully electronic key sets.

—BOGA, with manufacturing facilities in the Normandy town of Fécamp, specializes in equipment for the interface between subscribers and the automatic telephone exchange.

FIET

Numerous small French companies are active in telecommunications. This portable minitel terminal is manufactured by FIET.

—FIET (France Informatique Eléctronique & Télématique), with a plant at Chateaugiron in Brittany, manufactures a 26-pound portable terminal that houses a 5.5-inch pop-up black-and-white CRT screen, a full alphanumeric keyboard and a 40 character per line matrix printer.

—Tekélec has developed an X.25 software package for its TE 92 packet switching analyzer simulator that has become a model for diagnostic software for public and private networks. Its pcm and data transmission testing instruments are manufactured in Pessac, near Bordeaux.

—Visioptronic in Paris manufactures videophones and other products for video communications systems, including wide-band intercoms, cables and connectors.

—XCom in Grenoble is working on a variety of *télématique* products and applications, including computer translation. The company has developed a system for speech synthesis from text, using a program designed to calculate the intonations of sentences and phrases from their punctuation marks. The S-100 card, employing a system of diphones, is based on a CNET speech synthesis coding circuit and an 8085 microprocessor. The card could be used for distribution of messages from a data bank, creation of public service messages, man-machine dialogue and industrial processes.

The important role of small companies in telecommunications cannot be emphasized enough," says Dondoux. "They are the inspiration for the industry."

on the television channel.

One aspect of the Télétel videotex system is the electronic telephone directory, inaugurated in Britanny last February and progressively available in most other French cities. The electronic directory program could be considered the largest conversational data processing system in the world. Six hundred thousand minitel interactive terminals (minitel is the generic name for a range of stand-alone interactive videotex terminals) have been ordered by the PTT, and approximately 140,000 terminals will be in service by the end of 1983. By 1990, the PTT says, every Frenchman will be able to exchange the telephone book for a free minitel. This volume provides for relatively low-cost terminals compatible with other videotex services.

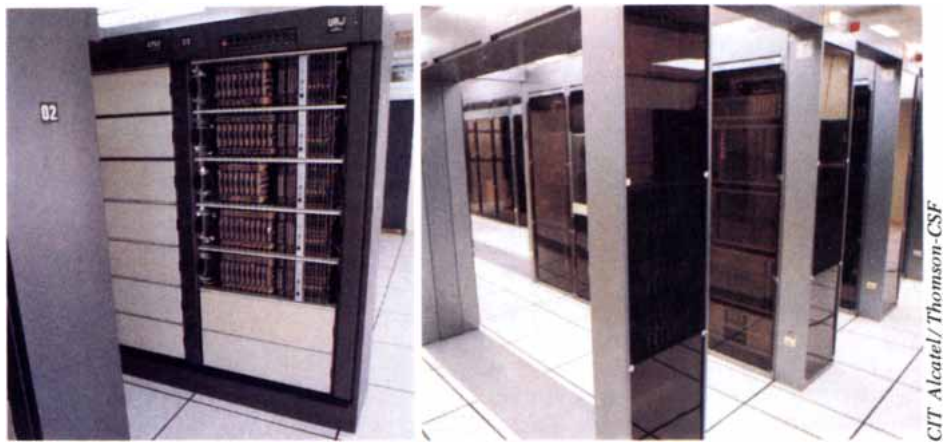
Cap Gemini Sogeti, Matra, TRT and Bull are developing one system, while Bull, CIT Alcatel, SESA and SINTRA Alcatel are producing a second. The extension on a national basis will be the responsibility of Cap Gemini Sogeti, SESA and CIT Alcatel. SESA and IBM are also working with the PTT on a computerized directory service for operators.

"The directory, which will enable the user to obtain telephone numbers throughout France, is not a goal in itself but a means of communications opening the way for other *télématique* services," says Jean-Paul Maury, head of the project at the DGT.

Télétel, which combines the electronic directory with other interactive services, was tested in 2,241 households near Paris and included timetables, news, teleshopping, stock quotations and information from other data banks provided by 190 service suppliers. A study of users indicated that the average consultation lasted 14.5 minutes, accessed 3.6 data bases and involved transmission of about 47 television frames of information.

Some French firms are using portable videotex terminals to provide sales representatives wih instant two-way access to computerized records. The towns of Grenoble and Nantes are running municipal videotex systems, and the Crédit Mutuel de Bretagne is using the minitel for home banking services.

THE SMART CARD: The smart card is an intelligent plastic credit card containing an imbedded integrated circuit capable of storing information and conducting numerous transactions without costly interfaces or communication with a central computer. It can be employed as an electronic checkbook for point-of-sale purchases, a telepayment card to conduct financial services over a videotex system, a high-security au-



CIT Alcatel/Thomson-CSF

The latest generations of digital switching exchanges manufactured by CIT Alcatel and Thomson-CSF are the E 10 (left) and the MT 20, photographed respectively in Lebanon and Jordan.

FRENCH COMMUNICATIONS:

SUBMARINE CABLE

Although satellites are obviously an important factor in the future of telecommunications transmission, numerous countries will continue installing submarine cable systems during the 1980's. France helped spearhead underwater links in 1957 using coaxial cable, and over 40,000 kilometers of French-manufactured submarine links are in service. Manufacturers are proposing systems with capacities ranging from 500 to 5,000 channels.

Submarine transmission is ideal for conveying traffic requiring large circuit capacities over short and medium-distance point-to-point links. Existing high-performance capacity submarine cable systems have improved transmission quality and reliability and reduced maintenance. And while capacity has increased, the cost of submarine circuits has decreased. The price per kilometer of circuit for a transatlantic telephone channel has declined from $140 in the 1950's to $9 today.

One important project currently taking advantage of these improvements is the largest analog submarine cable ever installed. The SEA-ME-WE (Southeast Asia-Middle East-Western Europe) cable will be 14,000 kilometers in length and link France with Singapore when it is completed in 1985.

The introduction of fiber-optical submarine transmission will meet increased intercontinental traffic demands and play an important role in establishing networks capable of various teleprocessing applications. Numerous government and commercial studies are under way in France to extend digital transmission on optical fibers. An optical fiber cable has been laid on the French Riviera, and a submarine fiber-optic link between Corsica and France with a flow rate of 2×140 Mbit/s is scheduled to come into service in 1985.

The French have played a major role in the evolution of submarine cable technology—aimed at improving transmission quality, reducing costs and increasing traffic-handling capacity. Their effort has resulted in substantial improvements in the manufacture of cable components—including the cable itself, repeaters, equalizers and cable-laying equipment.

R&D on submarine cable is geared towards decreasing attenuation by improving the quality of the structures and materials used for conductors. Repeaters, the submerged units used to amplify signals, have increased gains and passbands, broadband transistors have been developed, and automatic gain regulation systems have been introduced. Improved equalizers permit the remote control of characteristic frequencies from terminal stations and allow reliable remote monitoring and fault locating.

Submarcom, a joint venture of CIT Alcatel and Câbles de Lyons, bid for a role in the $300 million contract for the first transatlantic cable (TAT-8) using optical fibers. The cable, slated for deployment in early 1988, will handle 40,000 calls simultaneously and double the amount of voice and data traffic that can now be transmitted between Europe and North America. Other French companies, such as PTT affiliate France Câbles et Radio, provide cable-laying ships and equipment.

thorization and access card, a portable file card, a prepaid card for pay telephones, or a billing method for computer time sharing, pay television programs, or other electronic services.

The French launched three ongoing large-scale field trials with 120,000 cards and 650 point-of-sale terminals in three cities—Lyon, Blois, and Caen—as part of a 50 million FF test being financed by a syndicate of French banks. In addition, 300 users employed the smart card for teleidentification and telepayment during the Télétel tests.

Three French companies—Bull, Flonic Schlumberger and Philips Data Systems—are developing the card in collaboration with in-house or external software firms. Sligos, a systems house, has been contracted to operate the central clearing systems between banks. Although each firm has a different technical approach, an international association (INTAMIC) has been formed to monitor common standards for the smart card.

In addition, the U.S. Department of Defense is testing the smart card, with Army personnel using it to gain admittance to hospital and commissary facilities, while the Department of Agriculture is considering a test in which the card will replace food stamps.

The use of credit cards for electronic funds transfer and point-of-sale purchases is also expanding in France. Magnetic cards and multiservice terminals designed by Electronique Serge Dassault are being used in a 30-month trial in Saint-Etienne for instantaneous point-of-sale transactions. The system was designed by SG2 (Société Générale de Service et de Gestion) and the voice-over data equipment was produced by SECRE. An off-line test with magnetic cards is underway in Aix en Provence, using terminals manufactured by Electronique Serge Dassault and CSEE.

"The future card will combine the smart card and magnetic strip and have multiple functions with more than one microprocessor," predicts François Salle, group vice president for research and technology at Bull.

The PTT, which to date has ordered 450,000 smart cards, has also awarded development contracts for 200 public telephone booths to accept the smart card and bank credit cards—for billing through the user's post office or bank account. Prototypes of the booths were put into service last June. An additional 2,000 telephones using cards will be installed in 1984, and 10,000 are scheduled for introduction in 1985. There are currently over 150,000 public telephones in France; use of cards will prevent fraud, enable prepaid calls and reduce the cost of collecting 16,500 tons of coins.

"The expanding growth of applications will result in a reasonable price for the smart card," says Jean-Louis Marchand at the DGT's smart card delegation. "It should decline from 65 FF today to about 30 FF in 1986."

TELETEX: Teletex combines text typing and processing with directory-

FRENCH COMMUNICATIONS:

THE WORLD'S LARGEST X.25 PACKET-SWITCHED NETWORK

The French public packet-switched data network has substantially promoted the use of distributed data processing by providing access to computers from remote terminals—with tariffs independent of distance. The Transpac network, which is connected through the international transit node to the European Economic Community network (Euronet) and data networks in 20 other countries, has transparent features allowing users anywhere to be connected to the data storage and processing capabilities of large machines.

Almost any remote processing need can be met by Transpac. Its uses cover inquiries, updating files, time sharing and on-line data transaction processing. It can also handle off-line data collection with deferred transmission. Consequently, Transpac is an important factor in the expansion of videotex, teletex, high-speed facsimile, point-of-sale transactions and electronic mail. The videotex national network, for example, is based on Transpac and uses distributed gateways throughout France. Transpac is also the link between host computers in the electronic directory system and is used as the transmission vehicle for the point-of-sale tests in Saint-Etienne.

The Transpac packet-switched data network, with its operational center in Rennes, provides access to computers from remote terminals with tariffs independent of distance.

Transpac, providing the circuit between a customer's terminal equipment and the network, is articulated around data concentrating and switching processors. Information is submitted to the transmission network in the form of "packets," with network nodes forwarding the packets as they are received. The switching nodes are interconnected by a highly meshed network of fast data channels with at least two 72 kbit/s links between each pair of switches. Operation of the network is supervised by a national management center.

Transpac entered service at the end of 1978 with twelve switching centers and a capacity of 1,500 subscribers. Today there are over 11,000 direct subscribers and 22 switching centers in 20 cities, and transmission potential has been increased from 50 bit/s to 48 kbit/s. Eleven hundred additional users access the system through the pstn and telex networks, from 300 bit/s to 1200 bit/s.

A new type of switch, SESA's DPS 25, has been introduced to accomodate growth in network connections and traffic. It permits the installation of small satellite switches, a gradual increase in the number of main nodes and specialization of certain switches as transit nodes.

The Transpac network involves the participation of a number of French companies. Network designer SESA, TRT and Bull subsidiary SEMS are responsible for the switching system, SAT supplies the multiplexers, and CIT Alcatel, Thomson-CSF, SAT and TRT provide various categories of modem.

Two-thirds of direct connections to Transpac employ the X.25 protocol (the standard software interface for access), making it the world's largest X.25 network. Transpac transmits about 40 billion bits and treats 100,000 calls a day—and during peak hours handles 5,000 simultaneous communications. Transpac, managed by the PTT, will invest 300 million FF in 1983 to increase the capacity of existing concentrators and integrate new inter-nodes. The PTT estimates that with investments of 2 billion FF between 1983 and 1990, there will be 100,000 subscribers in 1990.

FRENCH COMMUNICATIONS: THE EVOLUTIONARY CAPABILITY OF THE E 10 DIGITAL SWITCHING SYSTEM

CIT Alcatel has been active in the communications business for over 100 years and manufactured the world's first electronic tdm switching system in 1970. Since then France's leading telecommunications company has installed its family of E 10 switching exchanges in 34 countries. In addition, the group has utilized its experience in digital switching to expand its line of switching systems to meet its customers' changing technical and commercial demands.

In an interview at CIT Alcatel's Paris headquarters, Christian Fayard, general manager of the public telecommunications division, discussed the E 10 switching system.

Scientific American: Why was a French company the first to develop an electronic tdm switching system?

Fayard: The R&D program we initiated with the PTT in 1965 was predicated on the belief that there would ultimately be a fully integrated electronic telecommunications network—combining digital pcm transmission with tdm switching techniques to increase efficiency, decrease costs and augment the communications capabilities of the telephone system. This was due to the increasing use of computers and microprocessors to perform data processing services—including call processing, circuit control and fault finding.

Our choice initially met with a great deal of skepticism. Most telecommunications specialists felt digital technology was applicable only in transit switching centers and were surprised when we began applying digital techniques to rural subscriber networks. Our first tdm switching system, the E 10, immediately illustrated the advantages of digital techniques over outmoded analog methods: better protection against noise, easier maintenance, improved fault detection and significant space savings.

Today, of course, tdm is the technology selected by most telephone administrations, and our international competitors are introducing switching equipment using this technique.

Scientitic American: What were the major achievements of the first E 10 system?

Fayard: The E 10 was the foundation for the rapid transition in France from an underdeveloped telephone network to one of the best in the world.Today France has an expanding modern network with 4.3 million E 10 lines in service.

Equally significant is the E 10's flexibility. The E 10 can be used to construct central office or transit exchanges. But it is an open-ended system and has been expanded to cope with the modernization of the French network in areas such as the electronic directory, direct satellite communication and cellular mobile radio telephone networks. For example, the E 10-Videotex is used as the access interface between the telephone network and the national videotex network. The E 10-Multiservice, used for the terrestrial switching centers of Télécom 1, incorporates the hardware and software modules required for processing the various terminal access protocols. It integrates the voice and data network by providing each subscriber with a high-speed data channel (up to 2 Mbit/s) that permits videoconference and other services. The E 10-Radiotelephone is used for a cellular mobile radio telephone network.

A CIT Alcatel minitel videotex terminal in the foreground of the E 10-Videotex switching system is an example of the adaptability of the E 10 to new telecommunications requirements. The unit provides the interface between the subscriber and the data bank, controls the connection, and handles format, transmission speed, and signaling conversions.

Scientific American: Hasn't the E 10 system become obsolete as the competition introduces new technology?

Fayard: No, because we have always kept the E 10 updated and upgraded by extending capacities and incorporating new components, such as vlsi microchips, 64 kbit dynamic RAM microprocessors and gate arrays. We are also introducing the international signaling code (CCITT No. 7) and common channel signaling.

It's been said that the E 10 is not a fully digital system, but it is in the American version, the E 10 Five, and will be in its 30-channel version with the introduction of CSN (the digital subscriber connection unit) in 1985. CSN is not only a single-channel codec but also the subscriber connection unit of tomorrow's isdn. However, the most important point is the system's total efficiency and reliability. Since its inception the E 10 has been function-dedicated, and today we remain the only distributed system operating on a large scale.

Scientific American: What are the emphases in R&D?

Fayard: The major R&D theme is the introduction of wide-band multiservice techniques. We are also studying the feasibility of optical switching units and are developing logic machines for software.

Software represents over half the development costs of a digital switching system (about 60 percent of the software is for operation and maintenance instructions and the remainder for function requirements), and we are aiming for the development of independent modular software that can be interlinked with processors using symbolic addressing. We do not believe there will be a new generation of switching systems but rather a continual evolution—a philosophy that is ideal for the E 10's modularity and distributed architecture.

Scientific American: How important is your international commercial presence, and what kind of contracts are necessary today?

Fayard: We have sold the E 10 system and transferred technology throughout the world. It is now manufactured in six countries, and our approach to future markets is typified by the large-scale project we are developing in India, which involves a complete transfer of technology and manufacturing know-how.

The E 10 is a very flexible system and can be used in most telephone networks. The E 10 Five, for example, has been adapted for the U.S. market as a central subscriber office.

based switched communications, which establishes a high-speed real-time connection between teletex-compatible terminals, word processors or electronic typewriters. Operating at a transmission speed of 2.4 kbit/s, it is 50 times faster than telex and produces documents in standard office letter format. Building on international standards, the French are preparing to launch a teletex service in 1984 to use the pstn and Transpac. It will capitalize on the French experience in teleprinter devices and the installed telex base in France, which includes over 100,000 subscribers.

The French are supporting international standardization of a mixed-mode teletex that incorporates digital facsimile capabilities. DGT officials argue that limited graphics are required so that texts can carry a signature and charts can be transmitted. Two firms, SINTRA Alcatel and SAGEM, are piloting the mixed-mode terminal applications, and a gateway to handle code, data rate and procedure conversions between teletex and telex networks should be operating by 1984.

"We are definitely pioneering standards in this area and are technically ahead in terminal identity procedures and the safeguarding of received information," says Philippe Leger, associate director of SAGEM, the world's second largest producer of telex terminals. "We will have a system that enables the transfer of graphics and terminal-to-terminal editing."

"France will develop a multimode teletex capable of transmitting written text and graphics on numerous data, telephone and telex networks," adds Roger Chaste, director of the telecommunications department at SINTRA Alcatel and a specialist in French telex display terminals and teleprinters.

The PTT is also studying electronic mail and electronic funds transfer within the postal system. One example of an existing service is Missive, marketed by France Câbles & Radio. Using a terminal connected to the telecommunications network, any subscriber can access a personal electronic mailbox through which he can prepare, exchange and file messages of all types to and from other subscribers.

VIDEOCOMMUNICATIONS: The government plans to order equipment for 1.4 million homes to be cabled in three years (100,000 in 1983, 300,000 in 1984, and one million in 1985) with a star system using multiservice fiber-optical local network transmitting images and sound. The cost is estimated at seven billion FF from 1983 to 1985, and manufacturers bidding for the work, scheduled to be contracted in late 1983, include CGCT, CIT Alcatel, SAT, Thomson-CSF and several smaller firms.

A second phase in 1986 will involve the expansion of the service to one million homes annually, and it is anticipated that one in every two French families could be connected to an optical fiber cable network in 1995. At that time the local networks will be interconnected through the high-speed national monomode transmission system.

"The goal is a multiservice wideband network with interactive characteristics employing fiber optics and a star structure," says Mexandeau. "The cable network, using the same architecture as the pstn, will increase capacity for existing services and promote videoconferencing, distributed data processing and distributed office automation."

In addition to the national plan, two tests are under way. In Biarritz at the

end of 1983, 1,500 subscribers will have access to 12 FM stereo channels, 15 TV channels and switched services that include videophone, videotex and data banks with image. SAT is the primary contractor and defined the system, and Thomson-CSF is an important subcontractor. In Lille, development of a local fiber-optical cable television system is under way for 50 subscribers, increasing to 3,000 in the 1984–85 period.

Mexandeau calls the French effort a "technically advanced, integrated, modular system that will rapidly become more competitive than conventional toll center distribution and telephone systems."

POSTAL SERVICES: The French have traditionally had an excellent postal service. During the next five years there will be increasing automation of the 17,200 post offices through the installation of microcomputers and minitel terminals. The PTT, which handles 14 billion pieces of mail a year, is studying money transfer, telecopying and new postage treatment centers. CIT Alcatel, Electronique Serge Dassault, SAT and other companies produce mail handling equipment, postage meters, automatic mail processing machines and electronic scales.

NETWORKS: France's nationwide 64 kbit/s digital network with end-to-end connections for transmission of speech, data and new services will soon create an itdn that will ultimately evolve towards the wide-band isdn—when the digital network will handle all services, including the transmission of moving pictures. The French are advanced in defining network architecture, network interface characteristics, user/machine access methods and net-

FRENCH COMMUNICATIONS:

TELECOM 1

The PTT uses INTELSAT, EUTELSAT and INMARSAT satellites for telecommunications, but the French also plan to launch their domestic satellite, Télécom 1, in April 1984. Matra is the prime contractor and is responsible for final integration of the satellite with the payload (including repeaters, transponders and antennas), being supplied by Thomson-CSF. Thomson-CSF and CIT Alcatel, through their joint venture Telspace, will supply earth stations, while Matra has a contract with the PTT for video transmission earth stations.

Télécom 1 is one of the key facets of the French multiservice communications system and will provide France with a spatial telecommunications network for the public and private sectors. While handling telephone traffic between France and its overseas territories and supporting video and defense communications, Télécom 1 will primarily guarantee efficient internal digital communications for French and European business traffic.

The business portion of the network, expected to have approximately 3,000 users, will utilize a maximum of 320 earth stations—with approximately 150 rural and 40 urban earth stations located in France. The quality, speed and cost-effectiveness of Télécom 1 has also led to the installation of additional earth stations in Switzerland, West Germany, Belgium and the United Kingdom in the framework of the European Telecommunications Satellite Organization (Eutelsat). Eutelsat will use part of the capacity of Télécom 1 for specialized intra-European services, while West Germany's Bundespost has contracted to use Télécom 1 to satisfy the digital private line needs of its national customers.

The applications payload of Télécom 1 permits the establishment of digital links of variable speed, from 2.4 kbit/s (i.e., text teleprocessing) to 2 Mbit/s (i.e., teleconferencing or high rate data transfers), between distant locations. This high-speed link, permitting numerous forms of transmission and processing of a wide variety and intensity of traffic, will assist the development of new types of communication requiring large bandwidths—such as video teleconferencing, electronic mail and fast-file data transmission between computers.

Télécom 1 offers the speedy installation of links, using earth stations with small-diameter antennae (3.5 meters), and an excellent adaptability to traffic growth. Most important, however, it provides a substantial degree of flexibility resulting from the utilization of the time division multiplex access (tdma) method of communication.

Tdma permits real-time demand allocation of digital channels and transmission capacity and allows users access to the satellite only when it is required, with the utilized capacity adapted to the service desired. The method is advantageous because the digitized signal can be regenerated on board the satellite, improving link quality, and the satellite transponder is used at maximum power, improving transmitter performance.

In the tdma access mode, each ground station transmits to the satellite on a common frequency occupying the totality of transponder capacity. Transmission ensures that blocks of digital data from different stations reach the satellite in sequence. This contrasts with the frequency division multiple access (fdma) technique, in which each station occupies part of the transponder capacity on a permanent basis.

A high-reliability central reference earth station located in Mulhouse in eastern France is used to control the network and on-request capacity assignment (the clock and frame synchronization) of traffic. This centralized intelligence will reduce the costs of tdma terminals in ordinary stations.

Matra

Télécom 1, the French multiservice domestic satellite, is being integrated at Matra's European test facilities. It is scheduled to be launched by the European Space Agency's Ariane launcher in April 1984.

Tdma experiments have been run with the Symphonie and OTS satellites, and the European ECS network will use this method exclusively. Specifications for the Télécom 1 system were prepared by the CNET with equipment supplied by a Thomson-CSF, CIT Alcatel and SAT consortium. The management of the Télécom 1 business system, designed by PTT affiliate France Câbles & Radio, will permit customers to have detailed records and information on communications expenditure.

France is also manufacturing TDF 1, a broadcasting satellite expected to be launched in the spring of 1985. The program involves a similar satellite for Germany; development and construction have been entrusted to Eurosatellite, in which Thomson-CSF and Aerospatiale are the French shareholders.

"There is an exciting future for digital business communcations," says Yves Fargette, president of France Câbles & Radio. "Télécom 1 will provide us with the know-how to expand our technology beyond France."

work control and management mechanisms.

In addition, CGCT has developed a fiber-optical multiservice local network for business offices, with an experimental version of the system installed at CNET research laboratories in Rennes. "Carthage" interconnects with the public telephone networks and, using the existing pbx, connects 600 telephone terminals, 400 terminals, and three computers, permitting the transmission of video, text, data and voice on one network.

French companies have also developed their own networks, such as Omeganet at SAGEM and Gixinet at Compagnie Internationale de Services en Informatique (CISI). Bull's Distributed System Architecture (DSA) is the central feature of its product strategy, and SESA is also studying the future approach to networking.

Some other interesting industrial developments:

—Audioconferencing has existed in France since 1976, and there are currently 100 public studios, known as *télécenters*, interconnected through the Caducée network.

—Telewriting permits the simultaneous transmission of written material using multiplexing techniques that allow input from a pressure-sensitive graphic table to be conveyed in the segment of the speech bandwidth between 1550 and 1950 Hz. France Câbles et Radio assembles the equipment, which is made by an affiliate of Télémechanique.

—Videoconferencing, achieved by transmission on a standardized 2048 Mbit/s channel on the telecommunications network, is under way in France, with 10 demonstration units throughout the country.

—SAT, SAGEM, SINTRA Alcatel, Thomson-CSF, TRT and other French and Belgian companies have developed the automatic integrated transmission network (RITA) for tactical military communications.

—A *Téléalarme* service, which is a home alarm system for elderly persons, has been inaugurated in Pau with ten alarm centers and 10,000 transmitters ordered from Thomson-CSF.

—Videotransmission permits the two-way projection of sound and images on large screens using microwave or satellite transmission. A network exists linking 13 large French cities, and mobile installations are also available.

RESEARCH AND DEVELOPMENT

The R&D effort in telecommunications technology is basically conducted under the auspices of the CNET, which particularly influences industrial development of telecommunications by preparing specifications, participating in consultations, monitoring market studies and standardizing new equipment.

CNET's total budget in 1983 was 685 million FF, with 3,827 persons working at six administratively decentralized research centers. General networks, optoelectronics and intercontinental links are studied in two Paris laboratories; local networks, switching, enhanced services, components and digital transmission are studied in two research centers in Lannion; new services and terminals are developed in Rennes at the CCETT (Common Center for Television and Telecommunications Research), and micro-electronics are studied at the Norbert Segard Microelectronics Laboratory in Grenoble. Research at CNET is largely responsible for tdm switching and pcm transmission, the tdma system for Télécom 1, the packet-switched data network and numerous *télématique* developments. Breakthroughs also include developments in solid-state physics, signal processing, radio communications and network design.

"Our work stops at the demonstration of feasibility, at which point industry takes over; our efforts today include a modernization of the current network to isdn, videocommunications and cable networking and research associated with the national electronics effort," says CNET director Jean-Pierre Poitevin. "We are digitizing the line to the subscriber, expanding the use of fiber optics with low-priced components, exploring new *télématique* orientations (such as voice recognition), improving submarine cables and conducting research on submicron micro-electronics."

Other research areas include future generation architecture and software for digital switching, liquid crystal display flat screens, second-generation videotex terminals, III-V semiconductor material, artificial intelligence and computer-aided design and manufacturing (cad/cam).

The CNET laboratory in Grenoble, for example, is developing a CMOS technology for telecommunications with the objective of producing chips using a 1-micrometer geometry by 1986. The laboratory is also working on strategic circuits for switching matrices, codec-filters and other applications related to videocommunication.

In Paris, network planning is being conducted at all levels (private, international, packet, telephone, videocommunication) to generate specifications for industry.

"We have a good lead in telephone and packet-switched networks, but not in data processing, which means that for local area networks (lan) France must often import a solution," says Jean-Marc Chaduc, director of the Paris A laboratory. "The most important aspect of any future network will be protocols."

"Our priorities are videocommunications, new electronic switching applications and the related software," adds Jean-Noel Mereur, director of the Lannion A laboratory. "We are digitizing the lan with combined data/voice communications and working on voice recognition and synthesis. In the latter area, we are advanced in algorithms but lack the necessary microelectronic components to create revolutionary developments."

CNET's network studies are leading to the digitization of a network integrating numerous transport options through the use of modular software.

"We look forward to basic specifications for the software to ensure adaptability for integrated systems that must support applications that are still not defined," says Daniel Hardy, whose R&D group in Lannion has an experimental multiservice switching system, known as Palme, under development as part of its general work on isdn.

The CNET is also conducting the Concerto software project aimed at demonstrating the possibility of a software workshop integrating the necessary tools for all software engineering activity—including design, development, documentation, qualification, maintenance and production.

"We are trying to construct models that provide the base and rationale for the next architecture of electronic switching systems," says Concerto project director Edouard André.

The CNET laboratory in Lannion began its R&D in fiber optics in 1970 and has since joined industry in installing numerous fiber-optical links throughout France. Today the CNET is using grooved cylindrical cable structures and establishing different multimode and monomode optoelectronic systems. The long-distance optical fiber link between Le Mans, La Fleche and Angers, for example, will employ both monomode and multimode fibers with a transmission rate of 140 Mbit/s, repeaters at 25 kilometers, and lasers emitting at the 1.3 μm wavelength. An advanced 42-kilometer monomode fiber link being tested in Brittany uses a 1.55 μm wavelength and has a rate of 4×140 Mbit/s.

"Like the rest of the world, we are leaning towards monomode networks," says Remy Bouillie, head of the optical networks division at Lannion B.

FRENCH COMMUNICATIONS: THOMSON-CSF CONSOLIDATES ITS COMMUNICATIONS ACTIVITIES

The Thomson group, France's largest electronics company, with 82,000 employees and sales of 47 billion francs (45 percent in export markets) in 1982, has integrated the full range of its numerous communications activities. Thomson-CSF, the group's professional electronics affiliate, has formed a comprehensive communications branch to provide a complete approach to communications technology. Today Thomson-CSF is capable of handling all aspects of the acquisition, storage, processing, management and transmission of information in any form—voice, image or data.

The communications branch accounts for 25 percent of Thomson-CSF's activities, has 33,400 employees, exports 32 percent of its sales and allocates a substantial 14 percent of its revenue to R&D. It is involved in all aspects of telecommunications and electronics (components development, telecommunications, radio communications, satellite communications, office automation, networking and software), which form the foundation for the eventual integrated services digital networks. It develops thoroughly integrated products and guarantees the conception, manufacturing, installation and maintenance of turnkey networks and systems.

Thomson-CSF is France's complete communications technology company, with activities that include public switching, satellites, videocommuncations and business and military communications products and networks.

• Thomson-CSF is one of two French public switching equipment manufacturers and has 5 percent of the world market, with 20 million lines installed or on order in 20 countries (3.6 million digital lines to 16 countries). It has designed, developed, manufactured and installed exchanges based on electromechanical, space division electronic and time division multiplex (tdm) technology. The company now concentrates on its fully digital MT range of tdm switching equipment, which is one of the newest exchanges on the world market and can respond to the demands of a number of different public telephone requirements—urban, inter-urban, national, and international, with small, medium or large capacities.

Thomson-CSF has supplied turnkey telecommunications networks to clients including Chile, Egypt and Iraq and also encourages the transfer of technology. In the Soviet Union, for example, manufacturing facilities were constructed to produce one million MT lines per year. In addition, Thomson-CSF produces a full range of electronic pbxs, terminals and telephone sets.

• Thomson-CSF services the entire spectrum of satellite communications needs, with experience dating back 20 years to the first French and European scientific satellites. It has participated in virtually every European and several international satellite programs, is a member of the worldwide team working on Intelsat V advanced commercial communications satellites (providing transmitters, receivers and antennas) and will participate in Intelsat VI in collaboration with Hughes Aircraft Co. To date, Thomson-CSF has helped equip over 50 satellites and is the world's second leading supplier of earth stations.

Thomson-CSF is capable of manufacturing most spatial and terrestrial equipment for integrated state-of-the-art communications networks and systems. Its space-oriented activities range from components and traveling wave tubes to satellite payloads, onboard and terrestrial telecommunications equipment, and earth stations.

• Thomson-CSF is a major participant in the full range of transmission activities and is playing a key role in Biarritz, where France is introducing its first multiservice fiber-optical network. It is also installing the fiber-optical network in Lille and expects to participate in the national fiber-optical videocommunications program.

During the past 10 years Thomson-CSF has cut over a number of fiber-optical systems between public telephone centers, computers and railway stations for communication and surveillance requirements. It is capable of producing the full range of components required for a fiber-optical network—from cables to connectors.

Thomson-CSF's R&D activities embrace public switching, satellite communications and videocommunications, as well as a wide range of other disciplines in electronics and telecommunications. The group's R&D effort includes 18,000 persons, with 640 patents filed in 1982. In addition, Thomson has established specialized units to train foreign personnel and arrange technology transfers to other countries.

The company's current thrust is in the United States market, where it intends to expand its operations. GTE is selling Thomson-CSF communications terminals, 3M is marketing the Thomson-CSF desktop facsimile, and NBC and CBS are using Thomson-CSF's videotex know-how. With manufacturing subsidiaries or representatives in over 100 countries, Thomson CSF is playing a substantial role in telecommunications throughout the world.

THOMSON-CSF

173 BOULEVARD HAUSSMANN/75379 PARIS CEDEX 08/FRANCE TEL. (1)561.96.00/TELEX: ELIHU PARIS 650143. TCSF 204780F


PTT


TRT


Thomson-CSF

The minitel terminal is being used in numerous businesses and homes in France and has been adapted to other languages for export sales. Thomson-CSF has sold its communication terminal to GTE in the United States.

"We are also testing the feasibility of plastic fiber, optical switching and a local optical network."

The prototype of the CNET's local optical network—including transmission, signal processing and switching—employs a single multimode fiber to offer bidirectional service.

THE FOREIGN PRESENCE

Not all foreign companies can be expected to be pleased with French policies. ITT's French subsidiary was nationalized, and National Semiconductor sold its stake in Eurotechnique to Thomson-CSF "for a symbolic one franc." But numerous foreign firms operate in France, including IBM, Philips, ITT, Motorola, Hewlett Packard, SGS Ates, Texas Instruments, Wang and Tektronix.

IBM is the major participant, and its telecommunications products include pbxs, modems, multiplexers, telex software, and special adapters for packet-switched networks. Its international telecommunications research center is located at La Gaude, near Nice.

"Our major concern about France is the threat of protectionism and the direction of the economy," says Hervé Caron, assistant general manager of IBM France. "Although we certainly don't depend on the French government for our general strategy, we are an integral part of French electronics efforts and are reasonably confident about our future."

American firms feel they should take advantage of the French position in telecommunications.

"We gained tremendous insight into packet-switched data networks, videotex, fiber optics and the trend toward isdn because of our presence in Grenoble," says Wim Roelandts, R&D manager for Hewlett Packard's information products group. "There has recently been a much more open attitude by the government to establish joint R&D projects with us."

"We are pleased with our agreement with Matra, which continues to have the government's blessing," adds Jean-Claude Rivet, Intel's assistant general manager for Europe. "We do not have enough design resources in the U.S., and that joint venture provides us with European expertise."

TRT, in which the Dutch Philips group has a 45.6 percent stake, uses that link to market French innovations on a worldwide basis.

"Obviously we will use the Philips distribution network to sell the electronic directory in Europe," says TRT commercial director Marc Houery.

Other foreign companies are rapidly expanding in France. The world's first commercial Wangnet has been installed in the Citibank headquarters in La Défense, and Wang may construct manufacturing facilities in Normandy. Apple Computer has reopened negotiations with the French government to locate its European software center in France and may also distribute French-manufactured hardware in the U.S.

COOPERATION

The French are playing a role in mounting a European challenge to American and Japanese predominance in electronics and telecommunications, and the PTT is attempting to establish pan-European technical and commercial ties.

"We recognize the importance of IBM in our industry," says Mexandeau. "Yet at the same time we must fortify our European connections if we are to adequately compete with Japan and the U.S."

Obviously, a European solution could brighten the future of French electronics and telecommunications. The 10 European Economic Community (EEC) countries represent 30 percent of the world market for information technology, but manufacture only 15 percent of the products. Cooperation would provide a larger home market, standardized products and more export clout. One French-supported venture in this direction is the European Strategic Program of Research and Development in Information Technology (ESPRIT), which has a goal of tripling the part of the EEC in world markets by 1990.

There is also a possible pan-European collaboration to develop future switching equipment, and Bull is discussing joint research programs in the data processing field with West German and British companies.

"We have defended our local market against foreign penetration without protectionist measures and have proven our technical and commercial strengths abroad," says CIT Alcatel's Chavance. "We still hope that we can reach important agreements with European partners."

EXPORTING FRENCH PRODUCTS

France is the fifth largest telecommunications exporter behind West Germany, Japan, the United States and Sweden. Orders for telecommunications equipment increased from 5.4 billion FF in 1981 to 6.3 billion FF in 1982, with exports representing 24 percent of total sales. The main export sectors were switching (36 percent) and transmission equipment (27 percent), and the principal markets were the Middle East (29 percent), Africa (27 percent), Europe (27 percent) and Latin America (7 percent).

The government acts as a vanguard for the promotion of most French products abroad. France Câbles & Radio, for example, has subsidiaries in numerous countries to construct submarine cable systems and manage international telecommunications activities. More important, when French President Mitterrand and officials travel, telecommunications is often on the agenda during high-level discussions, and French banks are extremely cooperative in financing PTT-backed export projects.

"We have a variety of products and services that are capable of penetrating international markets, and it is our job to promote good French equip-

FRENCH COMMUNICATIONS: SPEARHEADING ELECTRONIC FUNDS TRANSFER

The French PTT, banks and industrial companies have united to launch an on-line point-of-sale system (OLPOSS) that has the potential to penetrate export markets, thanks to its economy, flexibility, security and simplicity. The project combines data processing, telecommunications and financial networks to create state-of-the-art electronic funds transfer (EFT).

The installed system allows a complete financial transaction, including authorization and recording of data, to take place in only a few seconds. It makes it unnecessary to transmit *any* additional information between the customer, the retailer and the bank. The one-step process involves magnetic stripe credit cards supplied by French banks and a multiservice terminal connected to a central computer.

An initial 30-month test in Saint-Etienne, known as the Point Rubis trial and estimated to cost 30 million FF (including design, research, investment and operating costs), is being financed by a consortium of French banks, the PTT and retailers. Saint-Etienne was selected because it is a large regional center (population 220,000) with an extensive business infrastructure.

Jacques Mayoux, chairman of Société Générale, the world's ninth largest bank, which is coordinating the project, contends that "the experiment has been successful because of the cooperation between oft-competing financial institutions, retailers and industrial partners."

The on-line procedure includes entry and validation of transaction data, transmission, data checking and data recording. Once a user's credit card is inserted into the terminal card reader and purchases are totaled, the user employs a hand-held key pad to enter the required confidential authorization information—a personal identification code (PIN). The terminal then establishes communications with the Interbank Network Management Center to verify the PIN, accept or deny the transaction and record the data needed to credit the retailer's account and debit the customer's account.

Data is sent from retailers' terminals to either a local concentrator or a public switch concentrator installed in a telephone exchange. The concentrator acts as a packet assembler/disassembler for transmission to the central computer via Transpac, the French public packet-switched data network.

The public point-of-sale test in Saint-Etienne uses a multiservice terminal and credit cards with magnetic stripes to interact in real time with a central computer over the French packet-switched data network. The user is providing the system with her personal identification code.

The clearing of payment between banks, crediting of retailers' accounts, debiting of customers' accounts and transmission of daily transaction statements to retailers are handled in batch mode from the central processing unit.

The prime contractor for the system is Société Générale's software engineering and information services company, SG2 (Société Générale de Service et de Gestion). SG2 has provided software for a number of financial networks and systems and is responsible for all the software, codes and algorithms in the central computer.

Terminals and concentrators were designed and manufactured by Electronique Serge Dassault, which is a specialist in producing financial and control terminals. The 5-kilogram terminal for Saint-Etienne includes a half-duplex modem, a magnetic track reader, a keyboard and display unit for the retailer, a printer (for the customer's charge slip and the retailer's records) and a keyboard and auxiliary display unit for the customer.

"There was a successful synergy between the talents of a software house and a hardware house to produce a fusion of systems," says Serge Dassault.

Electronique Serge Dassault and SG2 are commercializing the EFT system through the joint venture company OLPOSS. They believe there is a significant export market, since the system is easily transportable and can be delivered as a turnkey network in less than two months. Software can be modified to suit local requirements, and the system can be adapted for numerous other uses—such as purchasing transport and parking tickets or paying highway tolls.

The benefits of OLPOSS are numerous. For retailers the system provides speed and security while eliminating paper and the risk of unpaid bills. For banks, the cost per transaction is about five times less than with checks and half that of a regular credit card transaction. While OLPOSS is not expected to eliminate traditional payment methods, it is expected to stabilize the use of checks in France. An adapted system will be used for home banking and telepurchasing applications in conjunction with domestic videotex terminals.

"The key to the system is the security of transmission, the rapidity of interrogation, and the efficient routing of information," says Philippe Tournaud, associate director of SG2. "In addition, the system can easily be expanded to take new types of cards—such as smart cards or cards employing holographics."

Numerous foreign banks and financial companies have expressed interest in the system, which is also available in an off-line mode. More important, French banks, public authorities and industry have developed a common strategy that will spearhead the implementation of EFT and establish a French lead in this high-growth technology.

ment," says Jacques Dondoux.

To facilitate export of the French videotex products, the French are adapting to local market requirements. The database consultation dialogue of the electronic directory, for example, has been translated into English, German, Spanish and Arabic, and videotex systems have been sold in Brazil, Kuwait, Italy, Australia, New Zealand, the United States and Greece.

Naturally, the large, expanding U.S. telecommunications market is important terrain for the French.

"No French company has an excellent base in the U.S., which is where the most important marketing battles will be fought in many areas of telecommunications," says SAT's Le Menestrel. "It's the number one priority for every French company."

SAT, like most French companies, has established a variety of agreements and ventures with U.S. firms. For example, it took a stake in IPC Communications to market its pbx equipment and has a joint venture with General Optronics for fiber-optical products.

CIT Alcatel has numerous joint programs and cooperative ventures. Lynch Communications System, in which CIT Alcatel has a 25 percent share, has given it a U.S. base for marketing the E 10 switching exchanges and the electronic directory. CIT Alcatel recently won a major contract in India and will build two local plants to manufacture E 10 digital switching exchanges, each with an initial capacity of 500,000 lines.

"The Indian agreement is an ideal transfer of technology," says Mexandeau. "It is the type of exemplary agreement we would like to pursue in selling French products."

Thomson-CSF is active throughout the world, with major contracts in Russia, Iraq, Lebanon and the Gulf states. Its U.S. activities are conducted by Thomson-CSF Communications Inc. "We will be very active in the U.S.

FRENCH COMMUNICATIONS:

SUPPLYING ENGINEERING EXPERTISE WORLDWIDE

Exporting French telecommunications expertise and engineering techniques is a government priority that has been underlined as a result of the wide range of advanced products and programs recently introduced in France. French telecommunications experts offer their know-how in telephone network design, maintenance and operation methods to public administrations and companies throughout the world.

The DGT also assists foreign administrations in developing and expanding their training facilities. One third of all DGT experts sent abroad do so within the framework of technical cooperation. Foreign technicians visiting France are provided with the training—in the DGT's engineering schools, in specialized training centers or in specific seminars—required to become acquainted with French techniques and equipment. And the CNET organizes numerous scientific and technical exchanges between foreign research institutes in all fields of advanced or applied research. The result is a two-way street in the transfer of technology between France and developed and developing countries.

Another important participant in this international role is SOFRECOM (Société Francaise d'Etudes et de Réalisations d'Equipments de Télécommunications). Established in 1966, it provides consulting and engineering services throughout the world and is independent of any industrial or commercial group. The PTT has a 32.8 percent stake in SOFRECOM (the remaining shareholders are seven French banks). SOFRECOM's revenue has increased from 23.5 million FF in 1979 to 55 million in 1982—with over 80 million FF forecast for 1983.

The organization has over 300 contracts in more than 40 countries following international bidding competition between major consulting firms. It is approved by the International Telecommunications Union and major international and regional development banks.

SOFRECOM provides four types of services: planning (from demand forecast to network planning); engineering at all stages of design; technical assistance for operation and maintenance; and management consulting. SOFRECOM's staff of 90 (40 of whom are engineers) are specialists in all the required switching, transmission, power and data processing areas associated with telecommunications. Most of the experts have been active in the PTT, where they gained firsthand experience in the implementation and operation of telecommunications equipment.

An example of SOFRECOM's role in international technical cooperation is the general assistance it is providing for the modernization of India's telephone network. SOFRECOM assists the Indian telecommunications administration in mastering the introduction of digital exchanges in an analog network with the help of management methods and tools developed by the French administration. The contract involves training in France and India and the supply of engineering, testing, operation, maintenance and managing methods.

SOFRECOM also provides consultancy services for a complete regional transmission network, including traffic studies, cable and microwave route surveys, drafts of specifications, tender evaluations, assistance during contracting and acceptance testing.

In addition to SOFRECOM's activity, France Câbles & Radio acts as a consultant in international telephony for public telecommunications networks, satellite communications, radio communications, teleconferencing, submarine systems, computer systems and data transmission networks, private networks and office automation. It also forms operating companies for international telecommunications and submarine systems in association with foreign governments. Its affiliate Intelmatique is the French promotional and marketing organization for the smart card and videotex products, and another subsidiary, France Telecom, promotes French telecommunications in New York, Singapore and Caracas.

French companies have exported their communications equipment throughout the world. Thomson-CSF installed a complete turnkey microwave network in Zaire, and SOFRECOM was responsible for the design of a microwave network in the Middle East.

during late 1983 and throughout 1984 in capital risk, financial participation, joint ventures and other forms of collaboration," says Jacques Darmon.

Matra is a major exporter and is often associated with other important international companies: TRW and British Aerospace for space projects, Harris Semiconductors and Intel for integrated circuits and Datapoint for data processing. Matra and Tymshare, the California-based computer services company, have formed Tymshare-Matra Corporation (TMC) to distribute 560,000 Scanset terminals in North America. Tandy's TRS 80 Model III minicomputers are being manufactured in Colmar as part of the agreement with Matra.

SESA is creating Auspak, the X.25 public packet network operated by Telecom Australia, with the same DPS 25 packet switch that it is using for public networks in Brazil, Luxembourg, New Zealand, the U.S. and Europe.

"We obtain 50 percent of the contracts awarded for packet-switching data transmission networks throughout the world," says SESA president Jacques Arnould.

TRT has recently received contracts for microwave networks in the Congo, Saudi Arabia, Nigeria, the Ivory Coast, Zaire, Jordan, Lebanon and Tunisia. It also recently won a contract to supply one hundred IRT 1500 stations throughout New Zealand for the rural telephone system.

Exports account for 28 percent of Jeumont-Schneider's telecommunications revenue, and the JISCOS switching equipment and range of pbxs have been exported to 30 countries. TIE Communications Inc. distributes Jeumont-Schneider products in the United States, and the company is developing new products for the U.S. market.

The French also hope to catapult their software expertise into an international presence. CISI took over the Wharton Econometric Forecasting Associates as part of its long-term strategy to develop an international data processing network. Steria has been asked by an American bank to develop new services for its videotex system, including integration of the smart card, which has considerable export potential.

Videographic Systems of America (VSA) has been formed by Thomson-CSF (51 percent), Cap Gemini Sogeti (13 percent), Steria, and other French companies (government organizations hold 16 percent of the capital) to penetrate the U.S. market. CIT Alcatel has formed a marketing agreement with SESA and Cap Gemini Sogeti, and Matra and Télésystems have created a

A researcher at the CNET laboratory in Lannion in western France is using Mastermind to test voice recognition techniques (left) and can also instruct the system to draw lines (right) connecting various French cities. CNET.

joint venture for the exportation of interactive videotex systems.

"The French products come from the same environment; thus uniting to make the technical and commercial adaptations for the American market is extremely sensible," says Bernard Joseph, president of VSA.

"VSA has produced a general awareness of the French presence in this area and shows that the French, like the Japanese, can adapt their products to American standards," adds Gregory Harper, vice president of VSA. "The joint venture also reveals that the French realize a group approach is sometimes necessary to penetrate the U.S. market."

However, "We don't need a French 'get together' just to sell the electronic directory in the U.S.," counters CIT Alcatel's Chavance.

MARKETING FRENCH EQUIPMENT

Although the French have technical leads in some sectors, there are a number of hurdles to overcome before they can be considered masters of international telecommunications. The serious economic situation in France could retard ambitious national programs and the resulting introduction of low-priced products on international markets. New projects, such as the fiber-optical cabling of France, are extremely ambitious in an era when financing is limited and the technology is untried.

There are also some ingrained difficulties. In measuring equipment and instrumentation, for example, there is what one government official calls "the traditional *need* to buy American." And the French have been attempting to create a solid computer industry since the 1960's without much success.

"We have not performed well in the past because there hasn't been a coherent long-term plan," contends Jacques Stern, president of Bull. "We now have that plan, we will implement it, and it will succeed."

Such assertions notwithstanding, the French must become more realistic. Their ambitious electronics plan is too expansive and too expensive in its present format.

Most French companies also lack effective worldwide commercial strategies, and the government sometimes seems more intent on boosting domestic employment than on increasing exports. The emphasis should be reversed, and the French should move quickly to establish a greater international presence.

Although the French have alienated some potential multinational partners as a result of their nationalization program, they are wise to support more cooperative ventures—in Europe, the U.S., Japan and the Third World. Future bilateral and multinational agreements could provide the commercial backbone that would enable French companies to profit from their established technological lead. Collaborative ventures are definitely required if the French are to penetrate newly deregulated European markets—something they have been slow to do in the past—and the transformed American marketplace.

"Telecommunications in France is a relatively new industry, and we still don't have the commercial astuteness of some of our competitors," says Mexandeau. "But we are initiating new products far ahead of the competition and must capitalize on our lead by selling throughout the world. Our results are good in general; however, we are virtually still on square one in some markets."

To offset their lack of commercial acumen, the French nationalized banks do deserve credit for financing large export projects supported by the PTT. This financial element is extremely important in international telecommunications, particularly when the client is a government administration, and the French have the grudging admiration of their competitors in formulating attractive financing packages.

Nevertheless, they cannot rely on a captive domestic market and the supportive banking industry. They understand that innovative marketing strategies, including more commercial agreements, are required to sell their telecommunications equipment on an international scale. One indication that they are improving their commercial role is that their national exhibition at the quadriannual "Telecom 83" in Geneva in late October is seven times larger than it was in 1979.

"We must start moving faster than the Japanese," concludes CIT Alcatel's Chavance.

Front Page Photograph. The French government and industry have initiated a number of new communications products, systems and services, including microchips, low-cost terminals, fiber-optical networks and smart cards. Credit: GILBERT LEGAY

FRENCH COMMUNICATIONS:
BULL: THE INTERNATIONAL INFORMATION SYSTEMS GROUP

France is concentrating its expertise and resources in the area of information processing systems around Bull, a group which has been internationally active in the data processing industry for fifty years and today successfully markets its products and systems in over 75 countries. Bull, with 25,000 employees and a 1982 revenue of 10 billion FF, is a key element in the French *télématique* industry. The group has long acknowledged and supported the evolving integration of telecommunications and data processing techniques. It is playing a major part in the country's long-term thrust in information technology.

Bull, majority-owned by the French government, has announced its technical and commercial strategy for the coming years designed to strengthen its position notably in distributed data processing, business communications and office automation. The group now includes Cii Honeywell Bull, minicomputer manufacturer SEMS, distributed data processing company Transac and microcomputer producer R2E. New divisions have been formed with full responsibility for planning, development and manufacturing: medium and large mainframe systems (Bull Systèmes), minicomputers (Bull Sems), peripheral equipment (Bull Périphériques) and office automation and microcomputers (Bull Transac). All products and systems are marketed internationally through a single sales organization.

Increased capital investment will enable the group to realize its goals. Bull will also benefit from its mainframe and networking experience and develop, at the international level, new applications and activities in distributed data processing.

The French government, assuming its responsibility as main shareholder, invested 1.5 billion FF in Bull during 1983—thus providing the resources to balance the insufficient capital investment of the last five years and implement the group's new strategy. The group projects an annual growth rate of about 16% concentrating on four major market sectors:

1. Bull is consolidating and developing its installed base in medium and large data processing systems.
2. Bull is penetrating the distributed data processing market with a range of minicomputers, microcomputers, office automation equipment and terminals based on a global systems and networks approach. The interweaving of the traditional fields of office equipment, telecommunications and data processing and the overlapping of microcomputers, minicomputers and mainframe systems are key elements in the group's approach.
3. To support these two lines of action, Bull is cooperating with software houses and users to expand the supply of services, such as software packages (specific applications software aimed at specific market segments), technical assistance, education and training.
4. Bull is also expanding its computer peripheral activities on the OEM market in areas including compact disk drives and non-impact magnetographic high-speed printers.

Bull will also capitalize on its established position in rapidly expanding areas such as networking. Distributed Systems Architecture (DSA)—the Bull network which offers a unified, coherent approach to data communications within a distributed system—implements all internationally agreed protocols and allows Bull products to connect directly to most existing public and private networks. DSA is an "open" architecture which enables the group's products to cooperate with products from other suppliers operating in other types of network such as SNA. DSA enables Bull to meet expanding demand in this market and, to ensure a solid marketing position in the future, development projects are underway to extend this architecture to local area networks and electronic message and mail applications.

While Bull will naturally develop its current product lines and use them as a springboard for expansion, it is also active in innovative areas.

The Bull CP8 smart card, for example, is a plastic card which contains a self-programmable microprocessor and memory chip. It can be used as a means of payment, an access key, or a portable file of personal information. Bull is making a considerable research effort in this field and possesses a technological lead due to pioneering R&D and experimentation with new applications. Bull's CP8 smart cards are being used in numerous pilot projects in Europe and throughout the world for point-of-sale payment, remote purchasing/payment, home banking, public payphone operations and personal record keeping.

Other examples of innovation can be found in such widely differing hardware and software domains as non-impact printer technology and program language development. The MP non-impact high-speed printer uses a new magnetographic technology developed in-house to combine reliability and high quality with low cost. The ADA programming language, developed by the group for the US Department of Defense as a replacement for the many incompatible languages now in use, is gaining wide industry acceptance.

Bull's relatively ambitious strategy relies on the continued strengthening of worldwide technical and commercial cooperation. Bull has built up one of the largest international marketing networks in the computer industry—an asset that will facilitate future growth. In France, Bull has increased its systematic cooperation with French universities, public research bodies and industrial companies. For many years, Bull has cooperated closely with Honeywell, which holds a minority stake in the French group. This association, which has resulted in common product lines, was extended last year with a new set of long-term technical and marketing agreements. As part of its policy to promote cooperation, Bull also acquired a minority stake in the capital stock of Trilogy when that computer company was founded by Dr. Gene Amdahl in 1981. The group also has commercial and technical agreements with other American companies such as MPI and Convergent Technologies. It also collaborates with European companies and research organizations in a variety of areas.

R&D is an important sector with a 1983 budget of 1 billion French francs. While the group is making headway in augmenting the capacities and capabilities of its existing products, it is also conducting basic researh into magnetic storage and non-impact printer technologies, fiber optics to create high-performance communication channels between computers, artificial intelligence, software engineering, logic machines and the development of new integrated circuits using custom vlsi technology.

These combined activities make Bull a strong international information systems group which guarantees advanced technology and continuity in the development of an integrated range of computer and communications products for today and tomorrow.

HOW CAN YOU FIND OUT MORE ABOUT THE SMART CARD AND VIDEO TEX PRODUCTS?

Just ask Intelmatique. We're the international promotional, marketing and consultancy company for *télématique* products. In fact, we're the ones responsible for coining the phrase "smart card" and launching a number of Teletel videotex projects internationally.

As the official representative of the French Telecommunications Administration, we're in a unique position. We not only monitor *télématique* activities throughout the world but are in constant contact with French *télématique* programs, research projects and industrial developments. We can provide you with details about proven applications and technical specifications for the smart card and other products. Why? Because we've overseen the introduction of the smart card for numerous user trials from Fort Lee to Oslo and studied the consumer and banking reaction to point-of-sale experiments.

The smart card is used for telepayment or teleshopping simply by inserting it into a minitel terminal. The home user places the card—with a microprocessor and memory embedded in it—into an add-on card reader/processor and, after typing a personal identificaton number, the memory written into the card by the issuing authority identifies the user, indicates the money value or banking power of the card and automatically dates and records information within the integrated circuit. The card can be used for a variety of other banking and business applications.

We also can supply you with the know-how gained from six years of international experience in the videotex field. We've held seminars on the smart card and videotex from Chicago (where we've opened a public videotex demonstration and support center in conjunction with Honeywell) to Australia. We've helped install videotex trial systems in Kuwait, Sao Paulo and Minneapolis. We've put videotex terminals on executives' desks, in middle size businesses, in bank branches and in living rooms. Perhaps you haven't heard about the French range of low cost terminals (minitels) which can handle information while interfacing with your own system. These inexpensive terminals could be the answer to your in-house communication needs and can be used in conjunction with the smart card.

If you are ready to evaluate the smart card or other videotex products let us open the doors. Intelmatique—the international promotional and marketing arm of the French PTT—has stimulated interest in many countries and our widespread experience can help you. We can show you the technology available today and planned for tomorrow. We are also able to offer professional consulting in most parts of the world if your need is for expert assistance in developing a business strategy.

To join the smart set and make the link with télématique simply mail us this card. We'll send you additional information.

Yes, I'd like to receive additional documentation on

The smart card ☐ or videotex ☐.

Name .....

Position .....

Company .....

Address .....

City .....

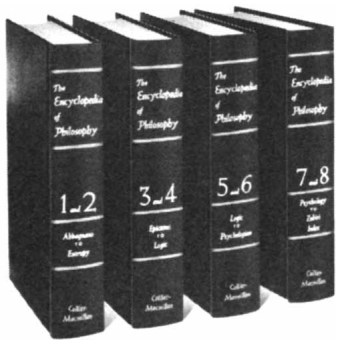
Country .....

Intelmatique
FRANCE

THE ORGANIZATION FOR THE INTERNATIONAL PROMOTION OF TELEMATIQUE
98, rue de Sèvres 75007 PARIS. Tél. : (33) 1 306.16.36, Télex 203185 TELEMAT. F.

or call our representatives in U.S.A. · (203) 834.11.43; Australia : (61)2.27 21 81; New Zealand : (04) 844.870; West Germany : (49) 611.683271; Greece : (30) 1.9228.735.

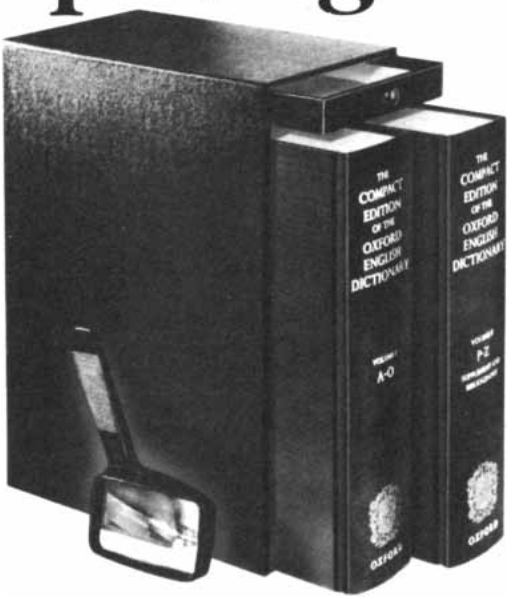
Sets of permanent value at surprising savings.



The Encyclopedia of Philosophy

for **$24.95** (Pub price $175)

The most comprehensive encyclopedia of philosophy ever published, this set traces ancient, medieval, modern, Eastern and Western thought. An essential and rewarding reference source for home libraries.



The Compact Edition of The Oxford English Dictionary

for **$24.95** (Pub price $150)

The "most complete, most scholarly dictionary of the English language"—*The Christian Science Monitor*. Through photoreduction, the original 13-volume set has been reproduced in this two-volume *Compact Edition*. Magnifying glass included.

The Nine Beethoven Symphonies & The Five Piano Concertos/Ashkenazy

for **$19.95** (List prices total $115.74)

Two of the most celebrated recordings of Beethoven's works. Sir Georg Solti conducts the Chicago Symphony in the nine-record set of Beethoven's complete symphonies. "A glorious musical combustion"—*Time*. In collaboration with soloist Vladimir Ashkenazy, Solti and the Chicago Symphony perform Beethoven's five concertos. "A major addition to the Beethoven discography"—*High Fidelity*. Available in 13 records or 8 cassettes.

The Decline and Fall of the Roman Empire by Edward Gibbon. Edited by J. B. Bury

for **$24.95** (Pub price $300)

The definitive Bury edition of the most acclaimed history of all. Gibbon evokes a world of grandeur and decadence, masterfully tracing its collapse under emperors noble and ignoble. Seven-volume set, newly available with maps and illustrations on long-lasting, acid-free paper quarter-bound in leather.

The Story of Civilization by Will and Ariel Durant

for **$29.95** (Pub prices total $335.45)

For almost half a century Will and Ariel Durant traced the continuity of world history—the religions and philosophies, the political and economic tides, the arts and sciences, the customs and conquests—to show the foundations of society today. A Book-of-the-Month Club exclusive for almost 50 years, the Durants' illustrated masterwork is history come alive.

Choose one of these five sets and save up to $305.50

You simply agree to buy 4 books within the next two years.

Facts about Membership. As a member you will receive the *Book-of-the-Month Club News*® 15 times a year (about every 3½ weeks). Every issue reviews a Selection and 150 other books that we call Alternates, which are carefully chosen by our editors. If you want the Selection, do nothing. It will be shipped to you automatically. If you want one or more Alternates—or no book at all—indicate your decision on the Reply Form and return it by the specified date. *Return Privilege*: If the *News* is delayed and you receive the Selection without having had 10 days to notify us, you may return it for credit at our expense. *Cancellations*: Membership may be discontinued, either by you or by the Club, at any time after you have bought four additional books. Join today. With savings and choices like these, no wonder Book-of-the-Month Club is America's Bookstore.

BOOK-OF-THE-MONTH CLUB

America's Bookstore® since 1926.

Book-of-the-Month Club, Inc., Camp Hill, Pennsylvania 17012 A170-10

Check one box only.

- ☐ 912. Compact OED **$24.95**
- ☐ 913. The Story of Civ. **$29.95**
- ☐ 917. Ency. of Philosophy **$24.95**
- ☐ 932. Beethoven (13 Records) **$19.95**
- ☐ 933. Beethoven (8 Cassettes) **$19.95**
- ☐ 951. Decline and Fall of the Roman Empire **$24.95**

Please enroll me as a member of Book-of-the-Month Club and send me the set I have checked at left, billing me for the appropriate amount, plus shipping and handling charges. I agree to buy four books during the next two years. A shipping and handling charge is added to each shipment.

Name_____ 3-64
(Please print plainly)

Address_____ Apt._____

City_____

State_____ Zip_____

Prices shown are U.S. prices. Outside the U.S., prices are generally higher.

The Processing of RNA

DNA is transcribed into messenger RNA, which is then translated into protein. In cells that have a nucleus, including human cells, a lot happens to the RNA between transcription and translation

by James E. Darnell, Jr.

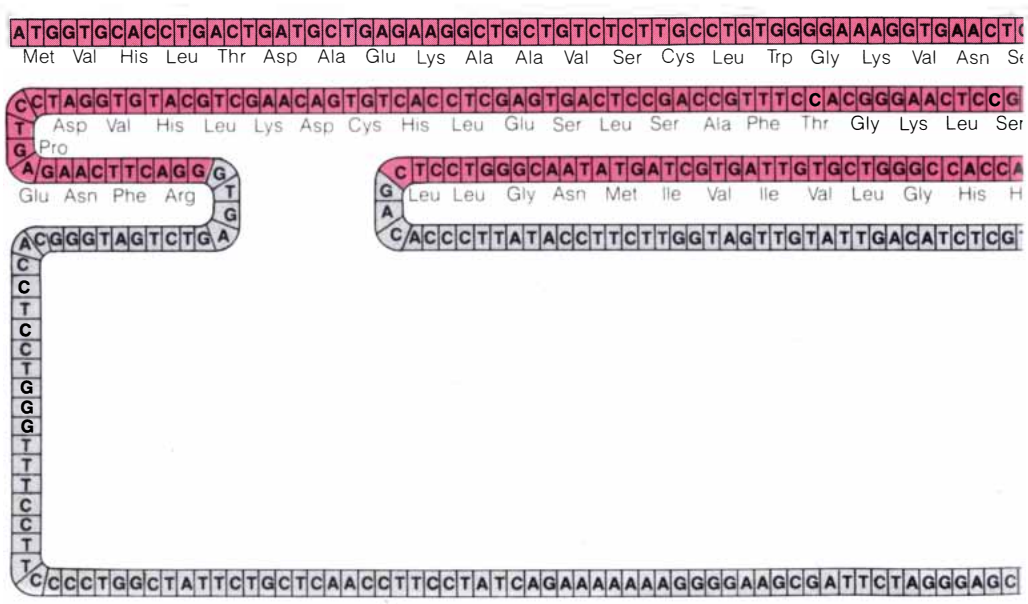
One of the central problems of molecular biology is to discover how two cells with the same set of genes can each make a different array of proteins. It is probable that with a few exceptions all the cells in a multicellular organism have the same genetic information encoded in the chains of nucleotide bases that make up their DNA. The sequence of nucleotides in the DNA chain serves as the instructions for the assembly of the proteins that engineer all cell functions. Hence it might seem that all the cells of a multicellular organism should manufacture the same proteins. In actuality, of course, each kind of cell makes only a characteristic subset of all the proteins encoded in its DNA. How is the genetic apparatus controlled so that each kind of cell manufactures a specific array of proteins and in the right amounts?

The cells of multicellular organisms are eukaryotic: they have a well-defined nucleus. In such cells the sequence of nucleotides in a gene, the stretch of DNA that codes for a single protein, is transcribed into a molecule of RNA in the nucleus. The RNA then moves out of the nucleus into the surrounding cytoplasm, where it is translated into the protein. Thus in the eukaryotic cell several levels of genetic regulation are possible. Control could be exerted over which stretches of DNA are transcribed into RNA, over which transcribed sequences are transported to the cytoplasm and over the rate at which a particular RNA is translated. It has long been assumed that the control of transcription and the control of translation play a part in the regulation of eukaryotic genes. As recently as 1975, however, knowledge of what happens to the RNA between transcription and translation was quite sketchy.

In the late 1970's it became clear that it takes several significant operations to transform the primary, or newly formed, RNA transcript into the mature messenger RNA (mRNA) needed for translation. Different structures are added to the two ends of the RNA chain. Certain nucleotides in the chain are chemically modified. Most intriguing, however, was the discovery that the transcript is frequently cut and spliced to yield an mRNA shorter than the primary transcript. In some instances the transcript can be cut and spliced in more than one way, yielding different mRNA's and hence different proteins. Such differential cutting and splicing could be a form of genetic control, and in a few instances it has been shown to be one. It is likely that posttranscription processing is necessary in many mRNA's but that it is a form of regulation in only a few. The discovery of mRNA processing has nonetheless added a new dimension to the picture of gene expression, which is in itself a significant advance. Moreover, it has given rise to intriguing hypotheses on the very early history of genes and cells.

The Transcription of DNA

Like DNA, RNA is a polymer chain whose monomer units are nucleotides. In RNA the four nucleotides are adenine, cytosine, guanine and uracil, abbreviated *A, C, G* and *U*. (In DNA the place of *U* is taken by thymine, *T*.) Each nucleotide is made up of a nitrogenous base and a five-carbon sugar. The five carbons of the sugar are generally designated by numbers. Each pair of adjacent nucleotides is linked by a phosphate group that makes a bond between the 5′ carbon on the sugar unit of one nucleo-



GENE CODING FOR A PROTEIN is a sequence of nucleotides (*A, C, G, T*) in DNA. The sequence shown here is the gene in the mouse for beta globin: one of the two chains of amino acids in the protein hemoglobin. The actual coding sequence of the DNA is interrupted by two "introns" (*gray*). The three stretches of coding sequence are "exons" (*color*). The amino acids of the beta-globin chain are shown next to the corresponding nucleotides. In order for the ge-

tide and the 3′ carbon on the sugar unit of the adjacent nucleotide. Thus the RNA molecule has directionality: one end is the 5′ end and the other is the 3′.

The transcription of DNA into RNA is accomplished by an RNA polymerase, one of three types of such enzymes in a eukaryotic cell. The enzyme binds to the DNA at a correct "start" site for RNA and selects the first nucleotide, which becomes the 5′ end of the RNA chain. It then moves rapidly down the DNA chain, adding the correct nucleotides to the RNA chain. The RNA separates from the DNA as it is assembled; the 5′ end comes off first, and the RNA molecule as a whole does not come off until the 3′ end is formed.

When the RNA polymerase copies a region of one strand of the DNA, the nucleotide that is added to the RNA is complementary to the one on the DNA. Because of the molecular structure of the nucleotides, each nucleotide can form hydrogen bonds with only one of the other three. Thus *C* and *G* can form hydrogen bonds only with each other, and *A* and *U* (or *T*) can form hydrogen bonds only with each other. It is the hydrogen bonds between complementary bases that enable two strands of DNA to form a double helix. By the same token a piece of RNA can form a double-strand molecule with a piece of DNA if the bases on the two strands are complementary.

The transcribed RNA is therefore complementary to the stretch of DNA from which it comes. Since it conserves the information from that part of the genome (the full complement of genetic information), the RNA can embody the code for the chain of amino acid units that constitutes a protein. The code is read from the RNA three nucleotides at a time, and each triplet of nucleotides, which codes for one of the 20 different amino acids, is called a codon. In the process of translation the reading of the codon results in the addition of the corresponding amino acid to the protein chain being assembled.

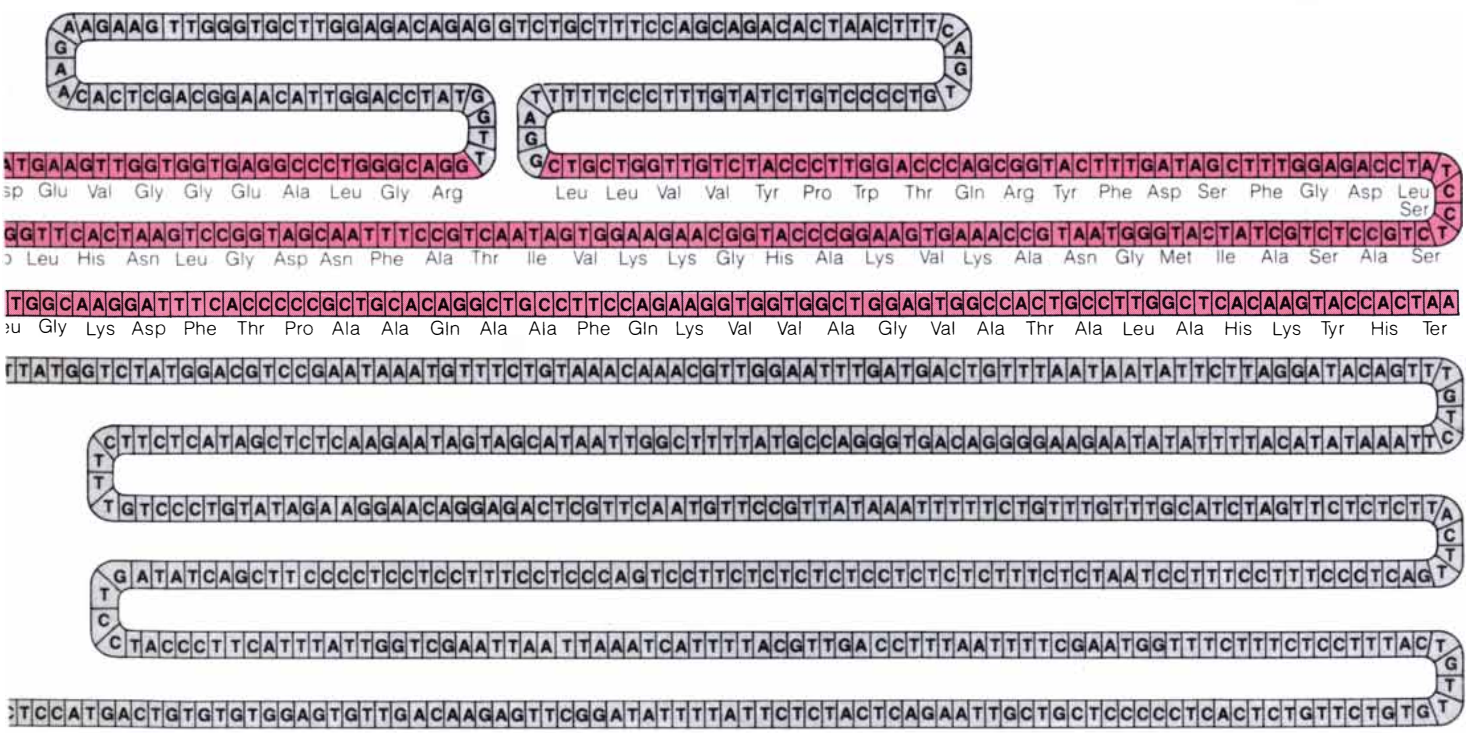
The Three RNA's

Messenger RNA, the RNA with the protein-coding function, is not the only kind of RNA. There are at least two other major kinds, each of which has a significant role in protein synthesis. Ribosomal RNA (rRNA) is a component of the ribosome, the cytoplasmic organelle that acts as a platform for translation. The ribosome is made up of two subunits, designated large and small; each subunit incorporates one rRNA molecule and between 25 and 50 protein molecules. Transfer RNA (tRNA) functions as a molecular hook to put the next amino acid on the end of a protein chain; each of the many different tRNA's recognizes a particular amino acid.

On the ribosome the transfer RNA is brought together with the messenger RNA and the enzymes whose function is to connect the right amino acid to the protein chain and to advance the apparatus to read the next codon. Thus in the synthesis of a protein, tRNA and rRNA have repetitive roles that are carried out under the instructions of the mRNA. In human cells there are about a million copies of each kind of tRNA and about five million copies of each of the two main kinds of rRNA: one for each ribosome in the cell.

Because of their abundance the transfer RNA's and the ribosomal RNA's are easier to study than the messenger RNA's, and they had been intensively investigated before much was known about mRNA. Indeed, the first example of RNA processing was found in ribosomal RNA. In 1961 Klaus Scherrer and Harriet Latham joined me in a new animal-cell and animal-virus laboratory at the Massachusetts Institute of Technology. We undertook to examine the RNA of human cells grown in a culture medium. We wanted in particular to compare the newly transcribed RNA's in the cell with the abundant kinds of stable RNA: the tRNA's and the two kinds of rRNA.

Bacteria are prokaryotic: their cells have no well-defined nucleus. In such a cell transcription and translation are carried out simultaneously: the messenger RNA begins to be translated while it is still being transcribed from the DNA. Like eukaryotic cells, however, bacterial cells rely on ribosomes and tRNA's; therefore much of the early work on the three stable kinds of RNA was done with bacterial cells.



netic message to be translated into the chain of amino acids in the protein, RNA must be transcribed from the DNA. The intron sequences must then be removed in order for the messenger RNA (mRNA) to have the correct coding sequence. Introns are characteristic of genes in eukaryotic cells: cells that unlike bacterial cells have a well-defined nucleus. The nucleotides *ATG* at the beginning of the sequence (*upper left*) are the signal for the initiation of protein synthesis. The nucleotides *TAA* at the end of the sequence are the signal for the end of protein synthesis. The nucleotide sequence was worked out by Philip Leder and his colleagues at the Harvard Medical School.

The three types of stable, abundant RNA's can be distinguished on the basis of their size. The tRNA's are all fairly small: about 80 nucleotides long. The two main kinds of ribosomal RNA are substantially larger. The size of an RNA molecule is often measured according to how fast the molecule sinks when it is spun at high speed in a centrifuge. The method is called zonal sedimentation analysis, and the sedimentation rate is expressed as the Svedberg number, abbreviated *S*. The longer the RNA, the larger its *S* is. The two major forms of rRNA in eukaryotic cells are designated 18*S* and 28*S*.

In our first experiments Scherrer, Latham and I sought to find out whether the initial products in the transcription of RNA are the same size as the abundant kinds of RNA, or alternatively whether the RNA is transcribed in units that are longer or shorter than the abundant molecules. Nucleosides, the precursors of nucleotide bases, can be labeled with various radioactive atoms. If growing cells are supplied with radioactive nucleosides, the labeled subunits will enter the pools of nucleotides that provide the building material for RNA chains. The radioactive molecules will then be added to new RNA chains by the RNA polymerases. The label provides a means of identifying the newly constructed RNA. After the labeled RNA's are extracted from the cell they can be separated according to their size by sedimentation analysis and compared with the previously existing unlabeled RNA in the cell.

The Processing of rRNA and tRNA

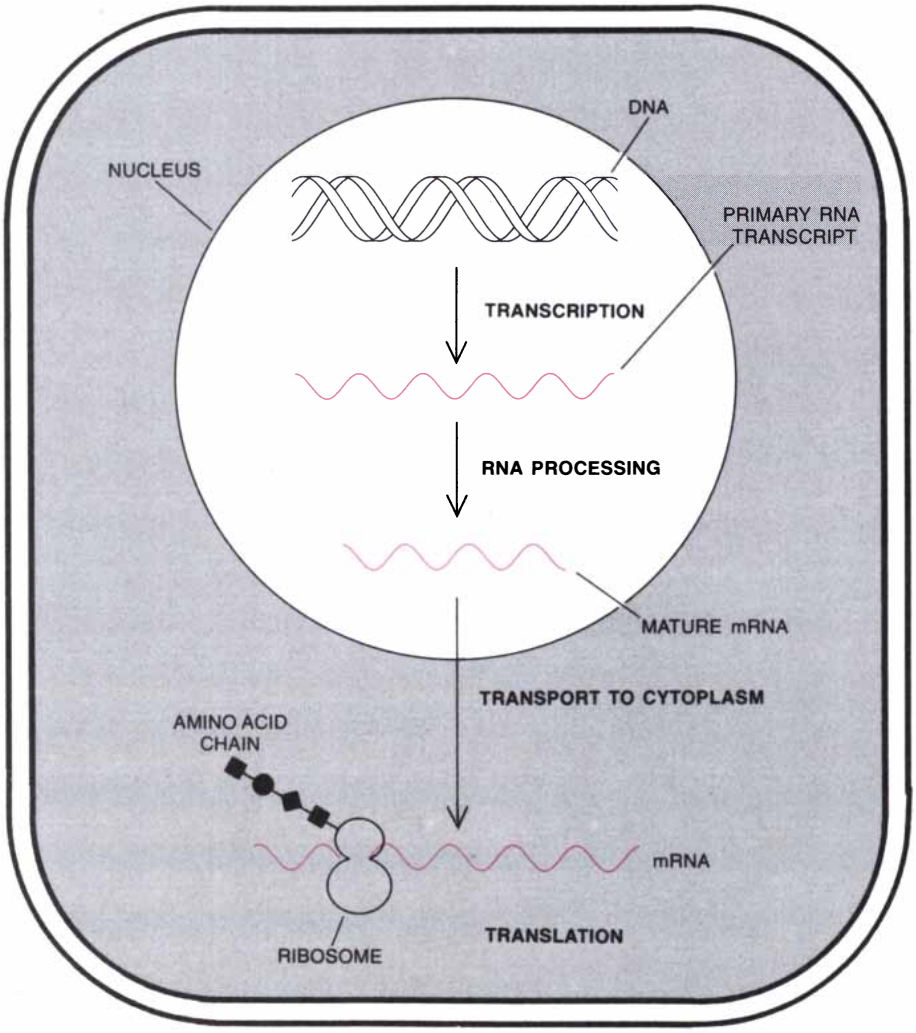
The cells were initially supplied with the labeled nucleosides for only five minutes. When this was done, the radioactivity did not appear in the RNA with sizes corresponding to the three preexisting stable kinds. Instead it appeared in the nucleus of the cells in an assortment of molecules with a wide range of sizes. Many of the labeled molecules were much longer than even the longest ribosomal RNA, which is 5,000 nucleotides long. As we shall see, such large, rapidly labeled molecules turned out to be of great significance in the work on messenger RNA. The transcription products that were labeled after five minutes were of so many different sizes that they could not be put into a few categories on the basis of their size. When the time during which the labeled nucleosides were supplied to the cell was increased from five minutes to 60 minutes, however, distinct groups of labeled molecules having different sizes became evident. One of the largest molecules, which appeared after 25 to 30 minutes of labeling, had a sedimentation value of 45*S*.

The base composition of the 45*S* RNA (the relative abundances of *A, C, G* and *U*) was very similar to that of the 18*S* and 28*S* RNA's. The 45*S* molecule was soon found to be related to the ribosomal RNA's in another and most interesting way. Transcription can be interrupted quickly by the antibiotic actinomycin, which binds tightly to DNA. We supplied actinomycin to the cells after the label had already been taken up into the 45*S* molecule. After the antibiotic had been supplied no more RNA was transcribed from DNA; hence any label was in molecules that had been transcribed earlier. Shortly after the actinomycin was supplied the label disappeared from the 45*S* molecules and reappeared in the 18*S* and 28*S* RNA's.

We hypothesized that the 45*S* RNA is a long primary transcription product that is cut to yield the two finished ribosomal RNA's. The hypothesis has since been borne out by many experiments. Improved methods of nucleotide sequencing have made it possible to determine the sequence of bases in both the genes for the ribosomal RNA and the rRNA's themselves. It is now clear that a long rRNA precursor is cut up to yield shorter finished molecules in many types of eukaryotic cells, including those of yeast, plants, frogs and mice. Recent experiments have shown that it is so even in bacteria.

Moreover, in the late 1960's Roy H. Burdon of the University of Glasgow and Deborah Bernhardt in my laboratory at M.I.T. found that transfer RNA is also formed by processing. In tRNA, however, the difference in length between the primary transcript and the finished molecule is only between 20 and 30 bases: a precursor about 100 nucleotides long is shortened to yield the 80-nucleotide finished product.

By the early 1970's the processing of ribosomal RNA and transfer RNA had been conclusively established in many



GENETIC REGULATION in a eukaryotic cell has several levels. In the nucleus of such a cell the DNA is first transcribed into a primary RNA transcript, which is a complementary copy of a stretch of DNA. The primary transcript is processed into mature mRNA: messenger RNA with the noncoding sequences removed. The mRNA is then transported from the nucleus to the cytoplasm, where it is translated by ribosomes into the amino acid chain of a protein. The expression of the genes can be controlled during transcription and processing in the nucleus, during translation in the cytoplasm and during transport from the nucleus to the cytoplasm.

types of cell. The question then arose of whether messenger RNA was processed in a similar way. It seemed unlikely that mRNA could be processed in prokaryotic cells, since in prokaryotes ribosomes translate the mRNA while it is still being transcribed. In eukaryotic cells, on the other hand, where transcription and translation are separated in time and space, mRNA processing was a distinct and interesting possibility.

RNA's in the Polyribosome

Much more had to be found out about messenger RNA, however, before the question of its processing could be approached directly. When the processing of ribosomal RNA was discovered in the 1960's, the mRNA of eukaryotic cells had not even been isolated. It had been shown quite early that amino acids are added to proteins in polyribosomes: clusters of ribosomes in the cytoplasm. It was therefore assumed that the messenger was in the polyribosomes, but it had not been proved.

In an attempt to find the putative messenger Sheldon Penman, Yechiel Becker and Scherrer in my laboratory at M.I.T. grew the human tumor cells called HeLa cells in the presence of labeled nucleosides. The nucleosides were incorporated into RNA; later labeled RNA was extracted from the polyribosomes. Some of the extracted RNA was of course ribosomal RNA, but the rRNA had not been labeled after a brief exposure to the radioactive precursors. There was, however, another group of RNA molecules in the polyribosomes that had been rapidly labeled, and these molecules had a base composition quite different from that of rRNA. The polyribosomal RNA's, as they were called, were from 500 to 3,000 nucleotides long. We hypothesized that the polyribosomal RNA included an assortment of all the messenger RNA's in the cell.

The base composition of the polyribosomal RNA's was compared with that of the long molecules that had been found in the nucleus in the course of the work on ribosomal-RNA processing. The assortment of rapidly labeled nonribosomal RNA's had been named heterogeneous nuclear RNA (hnRNA). It was readily shown that the hnRNA had a base composition much like that of the briefly labeled polyribosomal RNA. Hence it appeared that hnRNA could be a precursor of the messenger molecule that was utilized in translation in the polyribosomes.

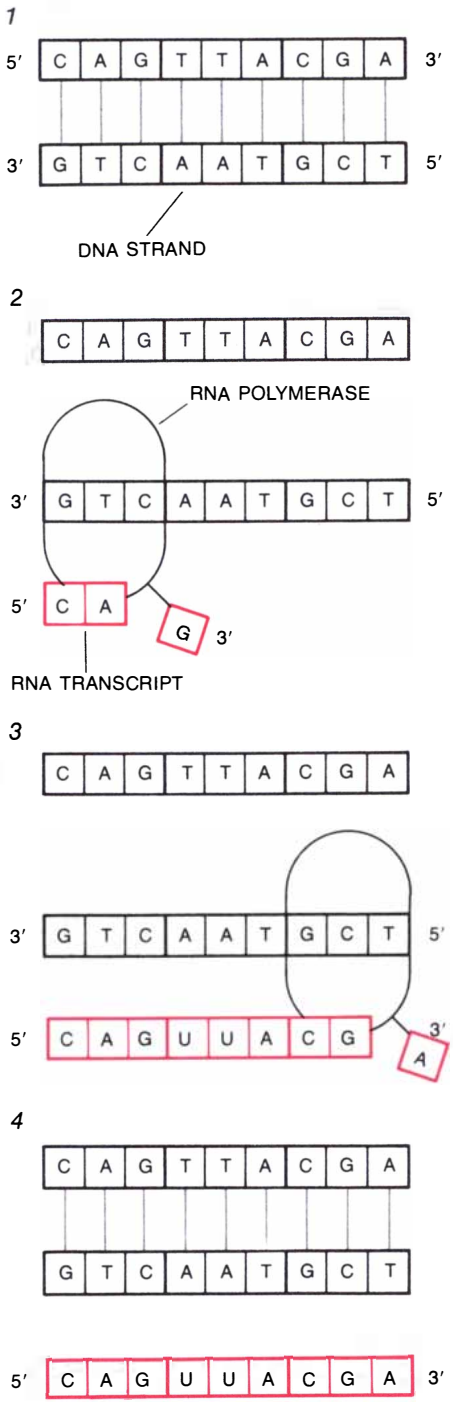
The trouble with the hypothesis was that some of the hnRNA's were 5,000 nucleotides long or longer, whereas the longest polyribosomal RNA's were only 3,000 nucleotides long. With the example of tRNA and rRNA processing in mind, we suggested that the hnRNA is shortened in a processing operation in the nucleus before being transported into the cytoplasm. It was not feasible for some years, however, to test this possibility in a direct way. The reason is that eukaryotic cells manufacture thousands of kinds of messenger RNA. Since no single mRNA had been isolated, it was not possible to observe the synthesis of an mRNA molecule to tell whether or not it is processed.

One way of circumventing the difficulty is to take advantage of the simplicity of organisms much less highly organized than cells: viruses. We therefore turned to the study of virus-infected eukaryotic cells. The infection of an animal cell by a virus turned out to be an excellent experimental system for studying the biochemical properties of messenger RNA and ultimately its synthesis. The genome of a virus, which is contained in the core of the virus particle, is a molecule of DNA or RNA. When the viral genome enters the host cell, it usurps the cell's synthetic apparatus so that the cell manufactures viral nucleic acids and proteins. At the end of the process of infection new viral molecules combine into virus particles that can infect other cells. Compared with the mammalian host cell the virus has few proteins and therefore few messenger RNA's. This simplifies matters. Since the viral mRNA must be translated by the host's ribosomes and tRNA's, the viral mRNA can be examined almost as if it were the mRNA of a eukaryotic cell. Furthermore, some DNA viruses enter the cell nucleus, where enzymes make viral mRNA; hence the steps in RNA manufacture can also be studied by means of a virus.

The Virus as a Tool

The simplicity of the virus was initially exploited to show that the briefly labeled polyribosomal RNA is the messenger. Penman and Becker in my laboratory found that in cells infected with the virus of poliomyelitis, an RNA virus, the viral RNA took the place of the briefly labeled cellular RNA in the ribosomes. Several investigators then utilized a second method to show that the viral mRNA enters the polyribosomes. The method is the one called molecular hybridization, which was first applied to DNA viruses that infect bacteria by Sol Spiegelman and Benjamin D. Hall of the University of Illinois. Molecular hybridization relies on the fact that strands of RNA and DNA can hybridize, or form a double-strand structure, only if their nucleotide sequences are complementary. If a hybrid is formed, it can be inferred that the RNA was originally transcribed from the DNA.

RNA extracted from the polyribosomes of cells infected with DNA viruses was mixed with the DNA of the virus and the host cell. When this was



TRANSCRIPTION of DNA into RNA preserves the genetic information encoded in the DNA. Each DNA nucleotide can form hydrogen bonds with only one other nucleotide: *A* (adenine) pairs with *T* (thymine) and *C* (cytosine) pairs with *G* (guanine). The nucleotides that can form hydrogen bonds are said to be complementary; the DNA helix is made up of two complementary DNA chains held together by such bonds (*1*). RNA is a single chain of nucleotides in which thymine is replaced by uracil (*U*). Both DNA and RNA chains are directional: one end is designated 5′ and the other 3′. One strand of DNA is transcribed into RNA by the enzyme RNA polymerase (*2*). The enzyme moves along one strand of the DNA, reading the nucleotides in turn and adding the complementary nucleotide to an RNA chain growing from 5′ to 3′ (*3*). When the 3′ end of the RNA is formed, the new RNA transcript separates from the DNA (*4*).

done, the polyribosomal RNA hybridized with the DNA of the infecting virus but not with the DNA of the mammalian host or that of other viruses. Brian R. McAuslan of Princeton University went on to show that the core structure of the vaccinia virus, a large DNA virus, can synthesize RNA from nucleotide precursors. Molecular hybridization was employed to demonstrate that the RNA synthesized by the virus core was the same as the polyribosomal RNA in cells infected with vaccinia virus. The polyribosomal RNA had therefore unquestionably been identified as the messenger: it was known to be present at the site of translation and it had been matched with the complementary stretches of DNA in the viral genome.

The identification of the messenger was a decisive advance. By studying viral mRNA's it was possible to follow the synthesis of specific messenger molecules to see what operations are performed on the transcript. Several significant types of messenger-RNA processing were soon found. Joseph R. Kates of the University of Colorado at Boulder noted that a segment of each mRNA synthesized by the vaccinia virus is rich in adenine nucleotides (*A*). By chemical analysis Kates showed that the adenine-rich segment is at the 3′ end of the messenger. Soon four groups led by Kates, Mary Edmonds of the University of Pittsburgh, George Brawerman of Tufts University and me independently demonstrated that almost all polyribosomal mRNA's from animal cells have a sequence of from 150 to 200 *A*'s attached to their 3′ end. The sequence is not found, however, in transfer or ribosomal RNA's.

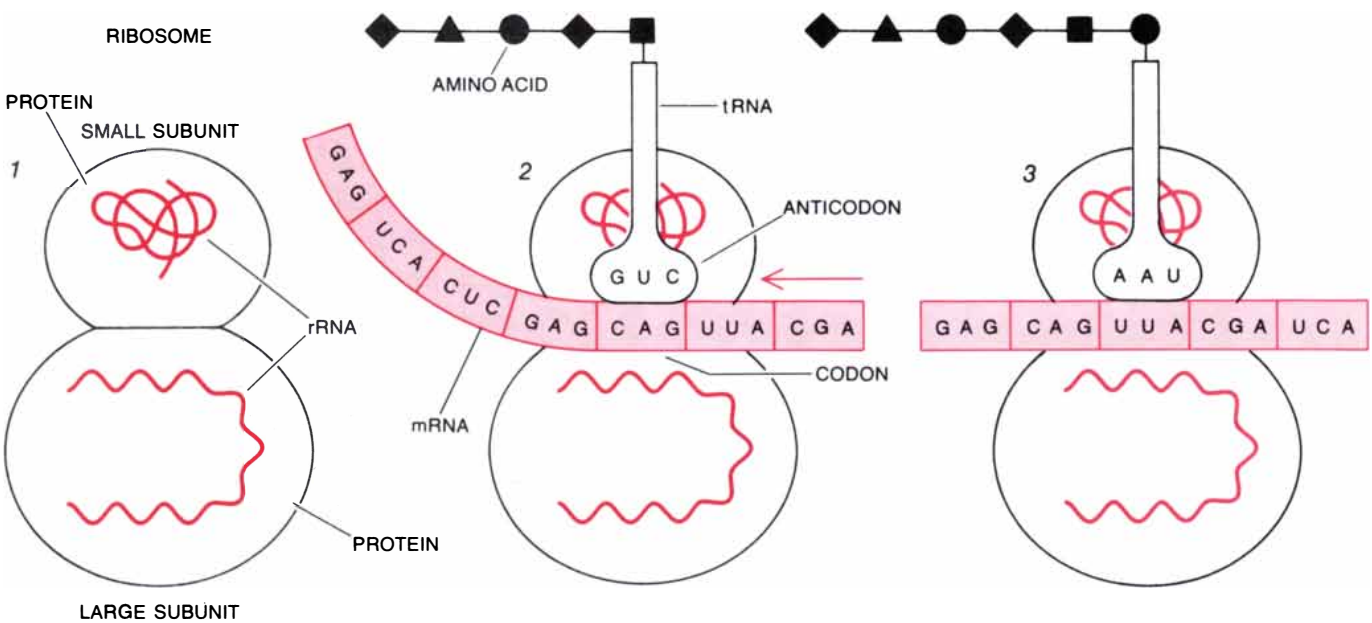
The 3′ "tail" of adenine nucleotides on the messenger RNA has been named the poly(*A*) sequence, and the process whereby poly(*A*) is added is called polyadenylation. It is now known that the tail is added to hnRNA in the cell nucleus by an enzyme almost immediately after the hnRNA is transcribed. Although the sequence of molecular events in polyadenylation has not been reconstructed in the test tube, it has now been established that the RNA polymerase proceeds far past the poly(*A*) site: the place on the DNA that corresponds to the 3′ end of the hnRNA where the tail is added. The RNA chain is cut about 20 nucleotides past a signal sequence; part of the signal is the group *AAUAAA*, which has been found in more than 100 mRNA's in plants and animals. The free 3′ end is then elongated by the addition of about 200 *A*'s. The addition is done by an enzyme discovered by Edmonds.

Tails and Caps

Almost all messenger RNA's that are transported to the cytoplasm have a poly(*A*) tail. An mRNA, however, need not have a poly(*A*) tail in order to be translated. The function of the tail appears to be to protect the mRNA from breakdown by enzymes in the cytoplasm. Messenger RNA's without the poly(*A*) tail last only a few minutes in the cytoplasm, whereas those with the tail can be stable for hours or days. The only known mRNA's that enter the cytoplasm without a poly(*A*) tail are the ones for the small proteins called histones, which bind to DNA. These histone mRNA's, designated poly(*A*)$^-$, last less than 30 minutes in the cytoplasm.

In addition to its theoretical interest the poly(*A*) sequence was of great practical benefit to the work on messenger-RNA processing. The reason is that an mRNA molecule can be caught by its poly(*A*) tail. This is done by synthesizing a polynucleotide homopolymer: a chain consisting of only one type of nucleotide. A vertical glass column is filled with paper fibers that have such a polymer adhering to them; a homopolymer consisting of all *T*'s or all *U*'s is generally used. Now the entire RNA complement of the cell is passed through the column. The poly(*A*) sequences at the end of the mRNA's hybridize with the homopolymers and remain in the column. The RNA without poly(*A*), mainly transfer RNA and ribosomal RNA, is washed away. This technique, affinity chromatography, was the first practical means of isolating in a chemically pure form the mRNA from a eukaryotic cell.

The availability of purified mRNA gave a great impetus to the work on RNA processing. Two additional processing operations were soon found. In 1974 Robert P. Perry of the Institute for Cancer Research found that animal-cell mRNA is not composed only of the four regular nucleotides. Some of the



TRANSLATION of RNA into protein requires two kinds of RNA in addition to the mRNA that bears the genetic information. Ribosomal RNA's (rRNA's) are structural components of the ribosome (*1*). Transfer RNA's (tRNA's) serve as a hook to add an amino acid to the growing protein chain; each tRNA is specific to one amino acid. Each amino acid in the protein chain is specified by a codon: a sequence of three nucleotides in the mRNA chain. The tRNA molecule binds to the mRNA by means of an anticodon, the group of three nucleotides that are complementary to the codon (*2*). As the ribosome moves along the messenger molecule the anticodon recognizes the codon and forms hydrogen bonds with it; at the same time the amino acid at the other end of the tRNA is attached to the protein chain. When the ribosome moves to the next codon, the tRNA is ejected and replaced by another tRNA that corresponds to the new codon (*3*).

nucleotides in the chain are methylated, that is, they have extra methyl groups (CH_3) added to them. Bernard Moss of the National Institute of Allergy and Infectious Diseases, Aaron J. Shatkin of the Roche Institute of Molecular Biology and Kin-Ichiro Miura of the National Institute of Genetics in Japan found that some nucleotides in viral mRNA's are also methylated.

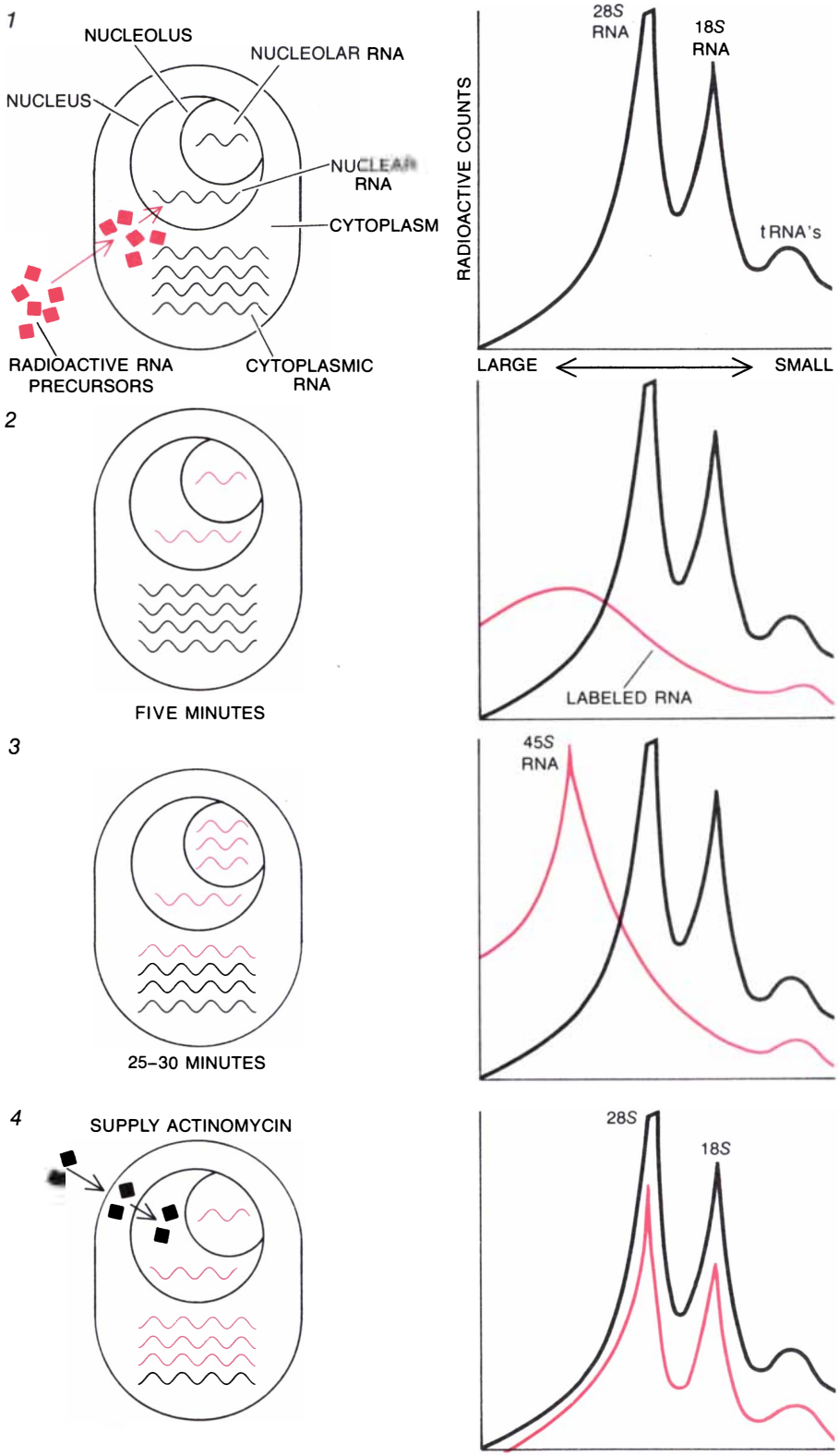
The enzymes called ribonucleases were utilized to determine where the most significant methylated structures in the messenger RNA are. Ribonucleases break the bonds between adjacent nucleotides in the RNA chain. The result is a collection of single nucleotides, each with an attached phosphate unit. When ribonucleases were applied to the methylated viral RNA, however, a complex structure that included several phosphate groups was found in addition to the single nucleotides.

Many chemical tests have been done on the ribonuclease-resistant structure, and its makeup is now understood. The structure, called a cap, is found on the 5′ end of all mRNA's that have been observed in eukaryotic cells with the exception of a single virus mRNA. The most distinctive component of the cap is a guanine nucleotide (*G*) to which a methyl group has been added. The guanine nucleotide is connected to the 5′ end of the RNA by a bond that includes three phosphate groups.

Lessons from the Adenovirus

Perry's group, Shatkin's group and my own (now at the Rockefeller University) tried to determine if the cap is added in the nucleus, as we had done when the poly(*A*) tail had been found to be a common part of cellular mRNA's. We discovered that the caps are added to the free 5′ end of the growing RNA chain by enzymes in the nucleus before the polymerase has transcribed more than about 20 bases. Moss's group has recently isolated the enzyme that adds the cap. Unlike the poly(*A*) tail, the cap is added to all mRNA transcripts. The function of the cap is not completely understood, but it appears that the structure serves to promote translation. Since the cap is added to all mRNA's, its addition probably is not a significant form of genetic regulation.

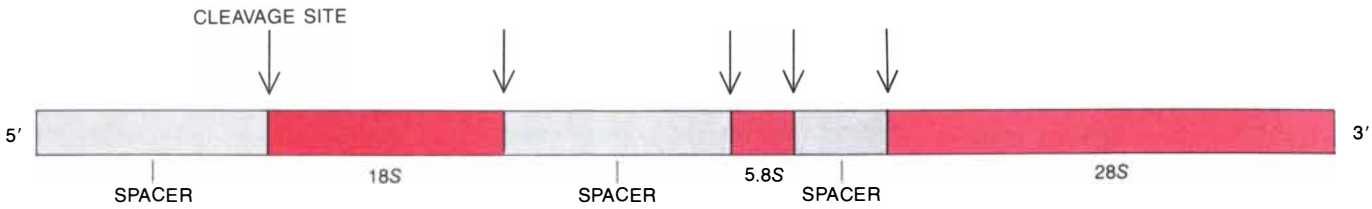
The discovery of polyadenylation and capping redirected our attention to the relation between hnRNA and mRNA. It was already known that the two kinds of molecule have a similar base composition. When hnRNA and polyribosomal mRNA were purified by affinity chromatography, it was found that the molecules in both groups have a 5′ cap and a 3′ poly(*A*) tail. Therefore if hnRNA is the precursor of mRNA, the ends of the molecule are preserved in the course of processing and transport into the cyto-



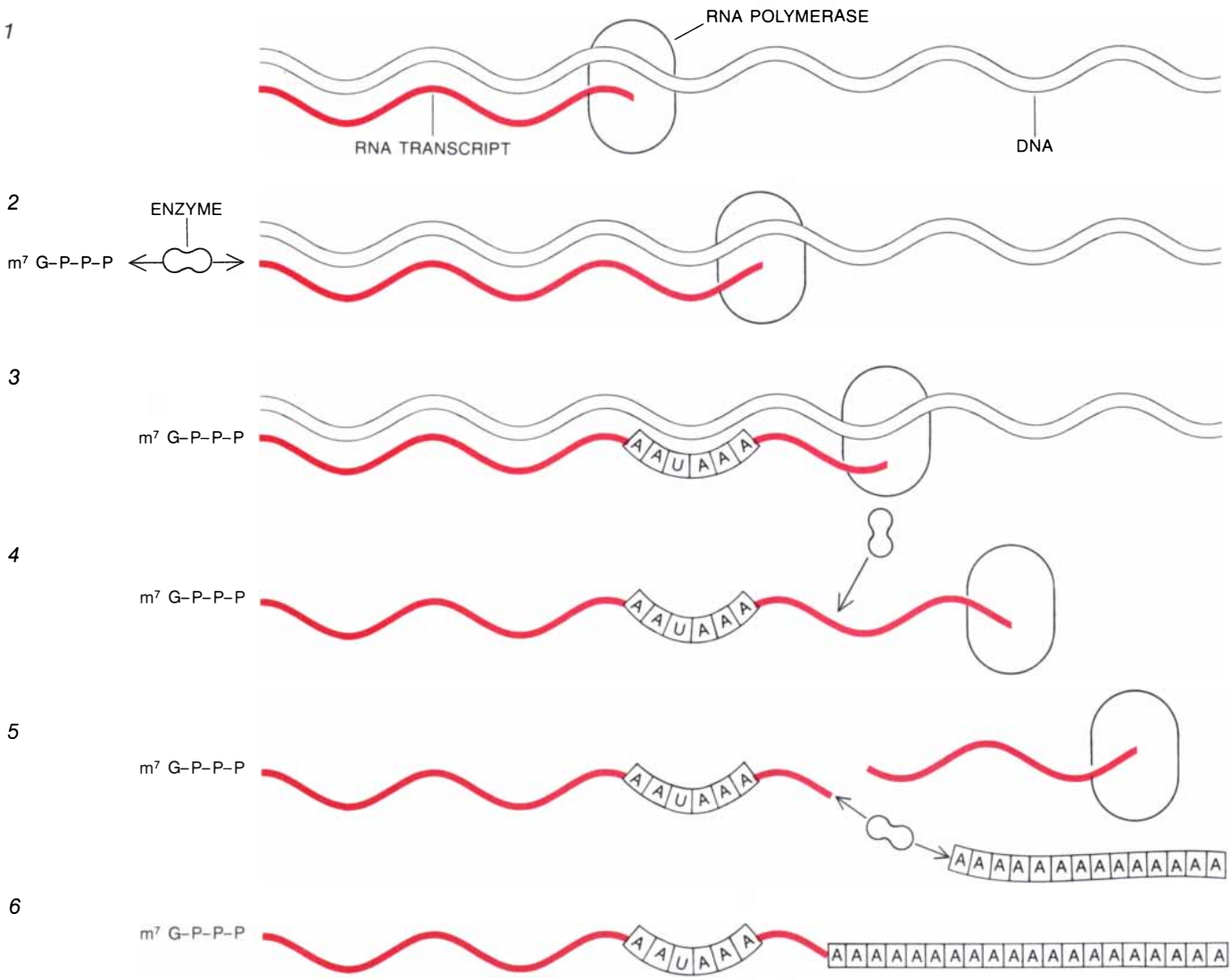
EVIDENCE FOR RNA PROCESSING was first found for rRNA. In the mammalian cell most of the stable RNA is found in the cytoplasm. A much smaller quantity of stable RNA is found in the nucleolus, an organelle of the nucleus. The size of an RNA molecule is measured by how fast it sinks when it is spun at high speed in a centrifuge; the unit of size determined in this way is *S* (for Svedberg unit). The three kinds of stable RNA are the 18*S* and 28*S* rRNA's and the smaller tRNA's. In experiments radioactive nucleotide precursors can be incorporated into new RNA, and the radioactively labeled molecules can yield information about the size of the RNA transcript. In the experiments on RNA processing mammalian cells were exposed to radioactive precursors (*1*). After five minutes the radioactive label appeared in RNA's in the nucleus with a wide range of sizes (*2*). After 25 to 30 minutes much of the label was in a nuclear molecule with a size of 45*S* (*3*). The antibiotic actinomycin, which stops RNA synthesis, was applied to the labeled cells (*4*). The label disappeared from the 45*S* molecules and appeared in 18*S* and 28*S* molecules in the cytoplasm. The 45*S* RNA therefore appeared to be a precursor that is shortened to yield the stable types of rRNA before transport to the cytoplasm.

plasm. The hnRNA's, however, were on the average five times as long as the polyribosomal mRNA's. One possible explanation for the difference seems intuitively obvious: a piece could be cut out of the middle of the hnRNA and the molecule could be spliced with the ends preserved. To molecular biologists in 1976, however, the idea appeared farfetched or even impossible.

In less than two years the farfetched possibility was shown to be what actually happens in a eukaryotic cell. Much of the work done to demonstrate that hnRNA is shortened to become mRNA utilized as part of the experimental system the adenovirus: one of many viruses that can cause infections of the upper respiratory tract in human beings. The course of adenovirus infection has been thoroughly studied. In particular the timing of the replication of the viral DNA in the cell nucleus, the composition of the viral proteins and the se-



PRECURSOR OF RIBOSOMAL RNA in eukaryotic cells includes three "spacers" that are removed in processing. Improved methods for determining the nucleotide sequences of DNA and RNA have made it possible to show precisely how the primary RNA transcript, which in human cells has a sedimentation value of 45*S*, is processed to yield the 18*S* and 28*S* rRNA's. The general structure of almost all eukaryotic primary ribosomal RNA transcripts is similar; the one shown is from the cultured human tumor cells designated HeLa. The first step in processing is for enzymes to make a cut between the 18*S* and 5.8*S* segments. The spacers are then removed by other enzymes, and the 5.8*S* RNA is attached to the 28*S* RNA by hydrogen bonds, leaving the two stable forms of RNA that are found in the ribosomes.

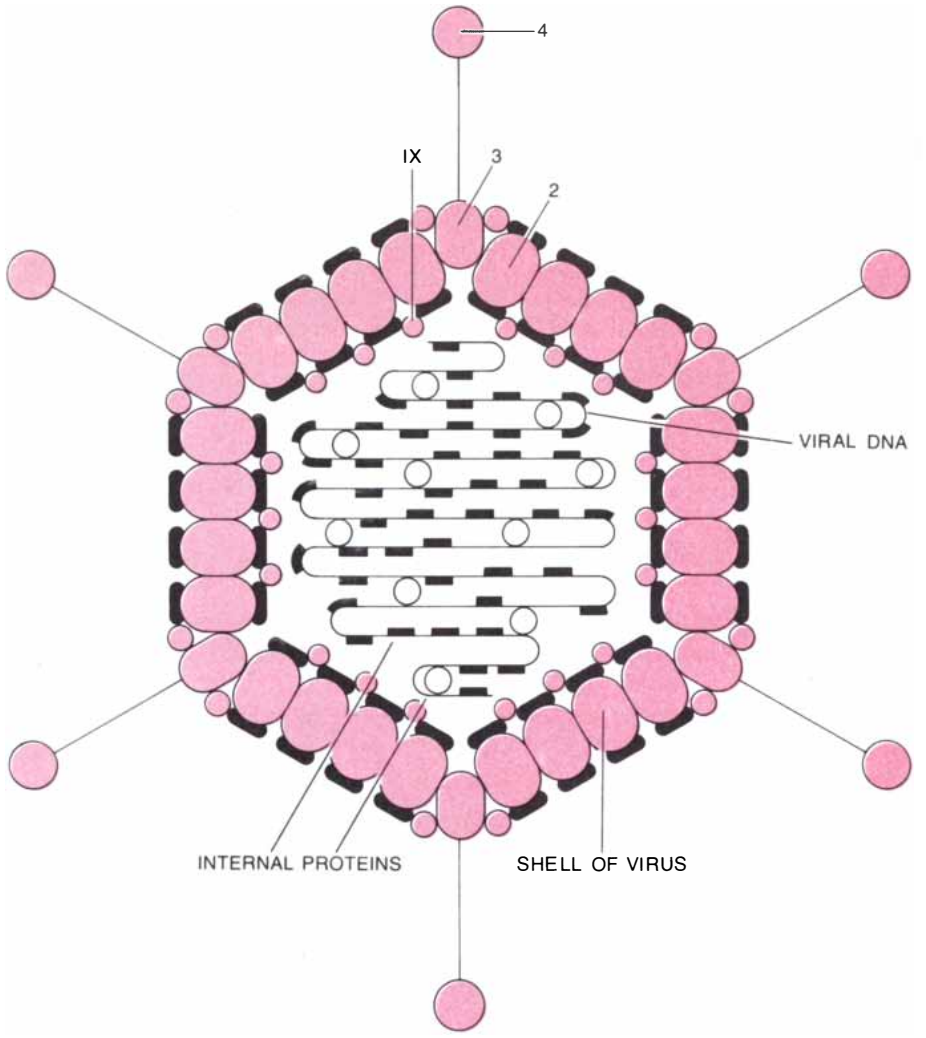


CAP AND TAIL are added to the RNA transcript in the first stages of mRNA processing. When the RNA polymerase has transcribed only about 20 nucleotides, enzymes in the nucleus add a molecular structure to the free 5′ end of the transcript (*1*, *2*). This cap consists of a modified guanine (*G*) attached to the transcript by a bond that includes three phosphate groups (*P*). As the polymerase moves farther down the DNA it transcribes the sequence *AAUAAA*, which has a role in the addition of the string of *A*'s called poly(*A*) (*3*). The RNA transcript is cut about 20 bases past the *AAUAAA* sequence (*4*). The same enzyme or another one then adds the 150 to 200 *A*'s of poly(*A*) to the 3′ end of the chain (*5*). In further processing the end structures are preserved while the interior of the transcript is modified.

quence in which the proteins are manufactured are well understood. The adenovirus was therefore a good organism to be studied for finding out how virus-specific RNA is synthesized in the cell nucleus and processed to yield mRNA.

The adenovirus genome is a double-strand molecule of DNA 36,000 nucleotides long. The position of a particular sequence of nucleotides in the viral genome is generally described according to a linear map of 100 units in which each unit stands for 360 nucleotides. Let 0 refer to the left end of the map and 100 to the right end. From eight to 10 hours after the virus particle enters a human cell the cell begins to make copies of the viral DNA. The viral proteins are classified in relation to the time of DNA replication. The "early" proteins are made before the DNA is replicated. The small group of "intermediate" proteins are made at about the time the DNA is replicated. The "late" proteins are made mainly after replication is under way. Most of the proteins that form the structure of the virus particle are late proteins. Among them are the hexon proteins, the most abundant proteins in the virus's outer shell.

The investigation of messenger-RNA processing concentrated on the late adenovirus proteins. The work relied heavily on the restriction endonucleases, a group of enzymes that had a profound effect on molecular biology when they were discovered in the 1970's. Each restriction endonuclease cuts DNA or RNA at a specific sequence of from four to six nucleotides. In a particular genome the restriction sites, the points where the enzyme cuts the DNA, are fixed. Therefore restriction endonucleases can be employed to cut a molecule of DNA into reproducible fragments. When the restriction sites have been identified, the fragments can be grouped in an ordered set with each fragment occupying a known position on the linear map of the viral genome.



ADENOVIRUS, a virus that causes upper-respiratory-tract infections in human beings, is shown in schematic cross section. This virus was an important subject in early investigations of the processing of mRNA, because at that time no mRNA's had been isolated from mammalian cells. The outer shell of the adenovirus is made up of protein molecules, most of which are those named hexons. The major hexon proteins are the ones designated 2, 3, 4 and IX. Within the shell is a double-strand molecule of DNA about 36,000 nucleotides long. When the virus enters a human cell, the viral DNA is replicated and a relatively small number of mRNA's are transcribed from it. The virus then usurps the apparatus of protein synthesis in the host cell to make proteins corresponding to these mRNA's. The hexon proteins are part of a group of "late" proteins that are synthesized mainly after the viral DNA has begun to be replicated.

Progress through Hybridization

It can readily be seen that having such a set of ordered pieces of DNA greatly increases the power of the molecular-hybridization technique. If labeled molecules of RNA are mixed with an ordered set of DNA pieces, the resulting hybrids indicate with great precision the position in the genome from which the RNA was transcribed. With this formidable technique we attempted to determine whether the adenovirus late-protein messenger RNA's are transcribed in the cell nucleus as a single long unit and then cut into smaller pieces or whether they are transcribed in units about the size of the messenger molecules.

When transcription of the viral RNA had begun, cells infected with adenovirus were exposed to radioactive nucleosides for such a short period that only a few labeled precursors were added to each RNA chain. In a population of infected cells there are RNA polymerases at almost every position on the viral DNA that serves as a template for the transcription of RNA. If label is supplied to the cells, radioactive nucleotides will be found on the ends of an assortment of RNA molecules with different lengths. The shortest labeled RNA's will be close to the starting point for transcription. Longer molecules will also be observed, with the longest near the end point of transcription.

The labeled RNA was extracted from the cells and purified. The purified RNA's were separated according to size and hybridized with an ordered set of adenovirus-DNA fragments. The molecular hybridization gave us a way of testing the hypotheses about how messenger RNA is made. If the late-protein mRNA's were transcribed in small units corresponding to individual mRNA's, the hybridization would yield a complex pattern in which short RNA's would be hybridized to the DNA near each of the multiple start sites for transcription.

Now consider what would happen if the late-protein messenger RNA's were transcribed as a single unit and then cut in pieces. There would be only one starting point for transcription, and the shortest RNA's would hybridize only with the DNA near the single starting point. Longer labeled RNA's would hybridize at the appropriate intermediate positions in the transcription unit. When the briefly labeled nuclear RNA from infected cells was hybridized to the adenovirus DNA, the shortest RNA's hybridized near only one position: map unit 16. The longer RNA's were spread out to the right of unit 16 according to their size. We therefore concluded that

the late-protein messenger RNA's are transcribed as a single unit beginning near map position 16.

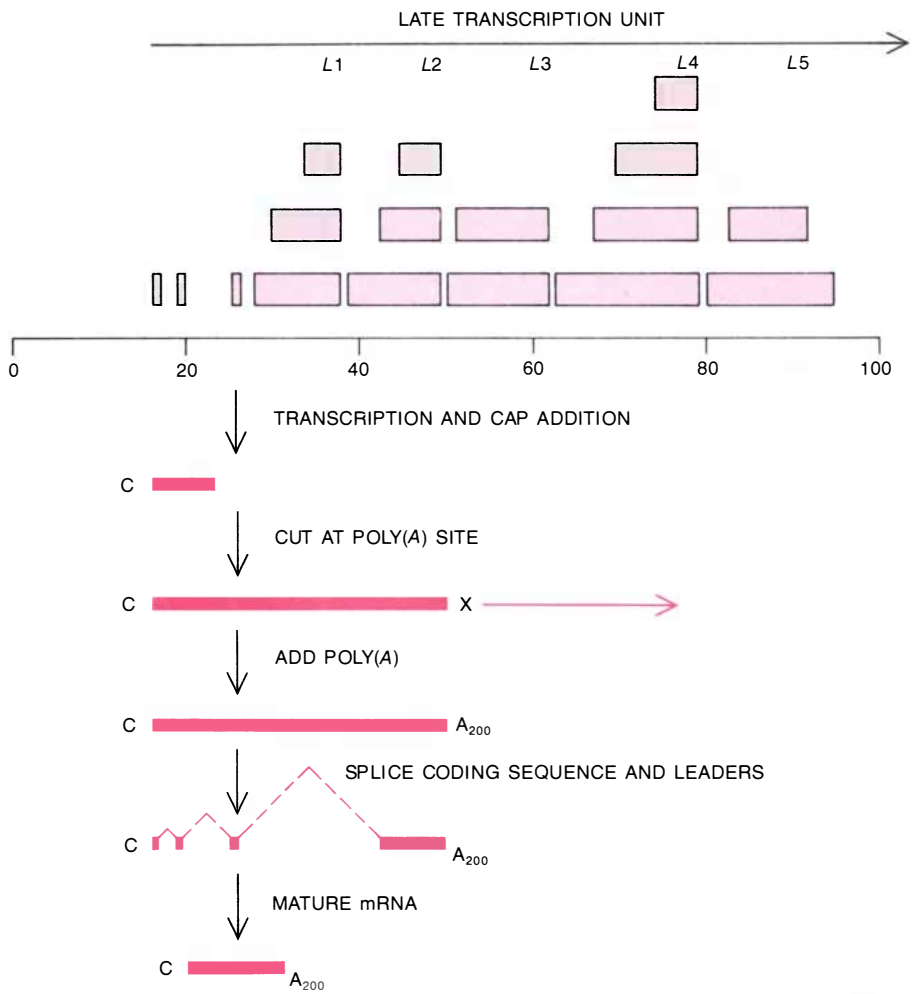
Positions on the Gene Map

Two groups of young investigators, one group at the Cold Spring Harbor Laboratory and the other at M.I.T., did a series of experiments that revealed how the primary RNA transcript from the late-protein transcription unit is processed. Richard J. Roberts and Richard E. Gelinas of Cold Spring Harbor found that all the adenovirus late-protein messenger RNA's had the same 11 nucleotides adjoining the 5′ cap. Working with the mRNA for one of the hexon proteins, Philip A. Sharp, Susan M. Berget and Claire Moore of M.I.T. found that the common sequence adjacent to the cap did not hybridize next to the major portion of the mRNA. When the hexon mRNA was mixed with DNA, it consistently formed a hybrid about 4,500 bases long in the middle of the viral genome that could be visualized by electron microscopy. Two tails, however, extended from the central double-strand structure. At the 3′ end was the poly(*A*) sequence, which was not expected to hybridize because it is not derived from the viral DNA. At the other end of the mRNA the common 5′ sequence also extended from the hybrid as a single-strand tail.

Both groups quickly recognized the possibility that the 5′ sequence might come from another part of the adenovirus genome. Sharp at M.I.T., and also Thomas R. Broker and Louise T. Chow at Cold Spring Harbor, mixed many late-protein messenger RNA's with the ordered set of DNA fragments and got an amazing result: each mRNA hybridized at four separate positions on the viral genome. Each formed a hybrid at a unique site that corresponded to the coding sequence for the protein. In addition all the mRNA's, regardless of the position of the coding sequence, formed hybrids at positions 16, 20 and 27. The result suggested that each adenovirus late-protein mRNA is a mosaic made up of three common sequences with one unique piece of genetic information.

Recent work by several investigators, including Heschel J. Raskas of Washington University School of Medicine and Joseph R. Nevins and Edward Ziff of Rockefeller University, has shown how the adenovirus mRNA's come to incorporate both common and unique sequences. In this work the adenovirus late-protein transcription unit has been shown to be a very complex piece of biological machinery. It is now known that in a mammalian cell infected by an adenovirus the main transcription product made after DNA replication is the late-protein transcription unit, which carries coding sequences for 13 or 14 late proteins. The transcription unit extends from map position 16 almost to position 100 at the right end of the map. Near unit 16 is a stretch of nucleotides called the late promoter, which induces the polymerase to begin transcription. At positions 16, 20 and 27 are the common sequences observed by Sharp, Broker and Chow. From position 27 to position 100 are the coding sequences.

The coding sequences in the late transcription unit are arranged in five groups. The groups are designated *L*1, *L*2, *L*3, *L*4 and *L*5 (in order from left to right on the map). Each numbered group includes the coding sequences for a family of related proteins. At the right end of each group is a poly(*A*) attachment site. For example, the *L*2 group extends from about position 40 to position 50; its poly(*A*) site is at position 50. Thus there is one cap site at position 16 and a total of five poly(*A*) sites in the late transcription unit.



ADENOVIRUS LATE TRANSCRIPTION UNIT has both multiple poly(*A*) sites and multiple splice sites. It can be processed to yield the mRNA's that encode more than a dozen adenovirus late proteins. A transcription unit is a continuously transcribed stretch of DNA. The adenovirus late unit extends from position 16 almost to position 100 on a linear map of the viral DNA in which each unit stands for 360 nucleotides. In all late mRNA's there are sequences complementary to positions 16, 20 and 27. From position 30 to near position 100 are the sequences that encode the late proteins, arranged in families designated *L*1, *L*2, *L*3, *L*4 and *L*5. Each family includes the coding region for several related proteins. At the right end of each family is a single poly(*A*) site common to all the mRNA's in that group. Soon after transcription begins a cap structure is added to the 5′ end; the RNA polymerase eventually transcribes the entire late unit. As it traverses the five poly(*A*) sites one of them is chosen; other enzymes cut away the nucleotides at that site and poly(*A*) is added. Here *L*2 has been chosen. The sequences between positions 16, 20 and 27 and between position 27 and the *L*2 family are removed. One of the coding segments in the *L*2 family is then chosen. The basis for the choice of poly(*A*) site and splice site is not known. The mature mRNA includes the 5′ cap, the common sequences at positions 16, 20 and 27, the code for a particular late protein and the 3′ tail.

Splicing the Messenger

For each family of proteins the coding sequences have a similar overlapping arrangement. All the coding sequences overlap at the right end of the numbered unit, and all of them include the nucleotides adjacent to the poly(*A*) site. In the middle of the group, however, the coding sequences diverge: each one includes a different segment of the nucleotides in the middle of the unit. When a mature messenger-RNA molecule is

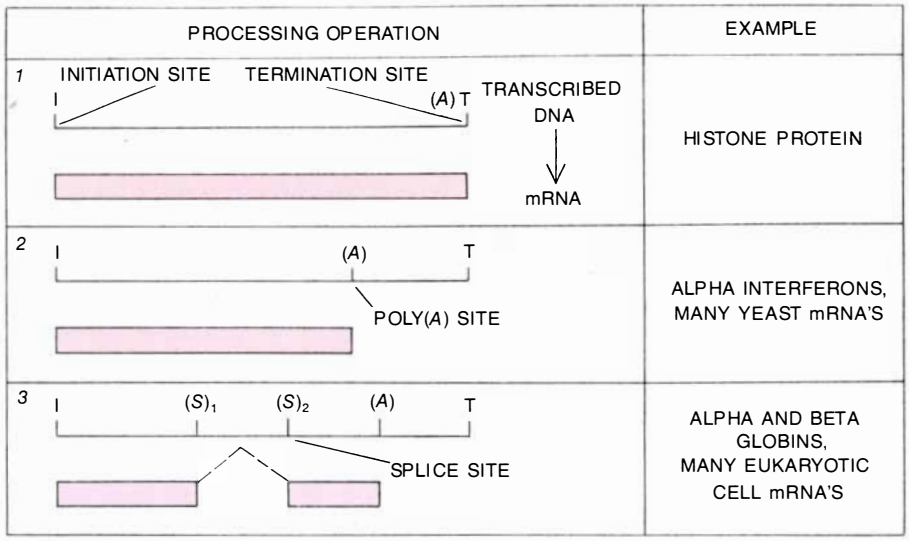
formed from the late transcription unit, only one coding sequence is included.

From many experiments it has become clear that the mature mRNA is processed in the following way. Transcription is initiated at the late promoter and moves to the right from position 16. When a few nucleotides have been transcribed, the dangling 5′ end of the RNA is capped. The polymerase then moves toward position 100, passing all five poly(*A*) sites. During the passage enzymes cut the transcript at one poly(*A*) site and attach the poly(*A*) tail there. The first RNA molecule in the stages of processing therefore includes all the sequences from position 16 to the chosen poly(*A*) site. For example, if the *L*2 site is picked, the RNA will include the sequences from position 16 to position 50; the *L*1 family of coding sequences is included with the *L*2 family but not the *L*3, *L*4 and *L*5 families. The RNA downstream from the *L*2 site (including the *L*3, *L*4 and *L*5 groups) is apparently destroyed in the nucleus and is never utilized in a messenger molecule.

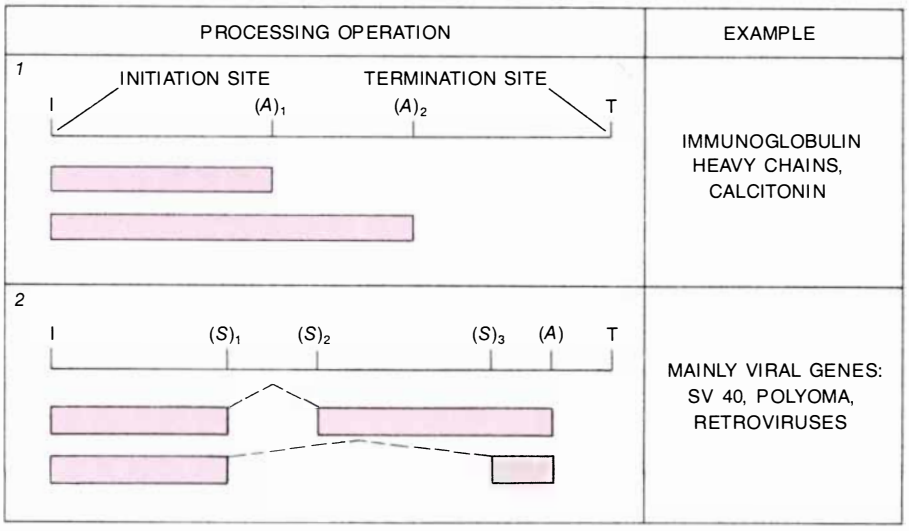
The partially processed poly(*A*)-containing nuclear RNA therefore includes several "spacers" that are not part of the mature mRNA. The spacers are removed by enzymes in a process that can take as long as 20 to 30 minutes. The *L*1 sequences are taken out. The stretches from position 16 to position 20 and from position 20 to position 27 are also removed, leaving only the common sequences at positions 16, 20 and 27. The result is a molecule with one group of related coding sequences. In this instance *L*2 has been selected. The *L*2 family has three coding sequences. One of the three is picked by enzymes that remove a variable piece of RNA from within the *L*2 family. The result is the mature mRNA, with the 5′ cap, the common 5′ sequences, the poly(*A*) tail and one unique coding sequence.

The nucleotides from position 16 to position 100 in the adenovirus genome make up an extreme example of a complex transcription unit. Such a unit is one that can be processed to make more than one kind of mature messenger. A simple transcription unit, on the other hand, yields only one kind of mRNA. By a combination of multiple poly(*A*) sites and differential splicing a formidable array of late proteins can be processed from a single adenovirus transcription unit.

It can readily be seen that either multiple poly(*A*) sites or differential splicing alone could yield a complex transcription unit. Only a few complex transcription units have been found in eukaryotic cells. All but one of the complex eukaryotic units have multiple poly(*A*) sites only. Only one has both multiple poly(*A*) sites and differential splicing: the unit for the heavy chain of the protein myosin in the fruit fly.



SIMPLE TRANSCRIPTION UNIT can be processed to yield only one kind of mRNA. The processing of simple units is shown in schematic form at the left; examples of such units and the organisms in which they are found are given at the right. The initiation site is where transcription begins; the termination site is where it ends. The poly(*A*) site corresponds to the point where the 3′ poly(*A*) tail is attached. In some instances the RNA polymerase stops at the poly(*A*) site (*1*). In other instances transcription proceeds past the poly(*A*) site (*2*). The transcript can be cut and spliced to yield a shorter finished mRNA if there are noncoding sequences within it (*3*). The majority of transcription units found in mammalian cells are simple ones.



COMPLEX TRANSCRIPTION UNIT can be processed to yield more than one mRNA and hence more than one protein. The presence of two or more poly(*A*) sites can result in a complex unit (*1*). If the unit is cut at the first poly(*A*) site, one mRNA is made; if it is cut at another, a different mRNA is made. In a transcription unit with only one poly(*A*) site there can be more than one splice site. The mRNA that is made depends on which splice sites are chosen (*2*). Complex units with more than one poly(*A*) site are common in viruses and have also been found in mammalian cells. Units with differential splicing have been found in viruses and one example has been found in a eukaryotic cell. Complex virus transcription units with multiple splice sites can be integrated into the genes of the host cell and expressed along with the host's genes.

In the genome of the rat a single transcription unit with two poly(*A*) sites has been found by Ronald Evans, Michael Rosenfeld and their colleagues at the Salk Institute for Biological Studies. The unit includes the coding sequence for two proteins: the hormone calcitonin, synthesized in the thyroid, and a newly discovered neuropeptide, a nervous-system hormone synthesized in the pituitary. The two proteins have identical "heads" (the end of the protein chain designated the amino terminal) but different "tails" (the end designated the carboxy terminal). In the cells of the thyroid gland the first poly(*A*) site is picked and calcitonin is made. In the cells of the pituitary gland the second poly(*A*) site is picked and the neuropeptide is made.

The work done since 1975 has proved that genes in eukaryotic cells can be regulated by means of RNA processing. It is not yet clear, however, how significant such processing will turn out to be as a form of genetic regulation. For most eu-

karyotic genes the chief method of regulation still appears to be the control of transcription. Moreover, the majority of eukaryotic transcription units that have been examined are simple units, which can encode only one protein.

Exons and Introns

Even in simple transcription units, however, processing is done to remove spacers. After the work with the adenovirus broke the ground it became clear that in eukaryotic genes the expressed sequences (exons) are also commonly interrupted by nucleotide sequences that are not translated (introns). Divided genes have been found in eukaryotes as unrelated as yeasts and human beings. In all the cells splicing is needed in order to get a messenger RNA without the introns and with the exons united for translation. Thus RNA processing is quite widespread among eukaryotes.

The divided genes of eukaryotes represent a remarkable departure from the genes of prokaryotes. In a prokaryotic cell the genes are uninterrupted, and extra pieces of DNA are soon discarded from the genome. The view of cellular evolution that once prevailed held that eukaryotes evolved from single-celled organisms much like current prokaryotic cells. If this view is correct, it follows that introns were introduced into prokaryotic genes in the process of evolution. On the other hand, Carl R. Woese and his colleagues at the University of Illinois at Urbana-Champaign have proposed that eukaryotes did not descend from prokaryotes and that there are two equally ancient prokaryotic lineages. Woese argues that the three lineages descended from a single precursor that he calls a progenote (meaning "before a cell").

The detailed analysis of the introns in eukaryotic genes supports the notion that eukaryotes did not evolve from prokaryotes. First, the intervening sequences in some eukaryotic genes have been in place for a very long time. For example, in the oxygen-carrying molecule hemoglobin there are two protein chains: alpha globin and beta globin. The amino acid sequences of the two chains differ, but the chains are folded to form similar three-dimensional structures in the hemoglobin molecule. The structures are also quite similar to the structure of myoglobin, the oxygen-binding protein in muscle cells.

In spite of these structural similarities, the differences in the amino acid sequences of alpha globin, beta globin and myoglobin suggest that the genes for the three proteins diverged from a common precursor perhaps a billion years ago. At the same time all three genes have three exons separated by two introns in analogous positions in the three genes. Where the amino acid sequences diverged, the arrangement of introns appears to have been preserved, so that the introns could have been in place for a billion years.

Moreover, when the three-dimensional structure of a protein is examined, it is often found that the protein chain can be divided into segments having different functions; such segments are termed functional domains. Many introns divide genes into pieces each of which codes for a different functional domain. Therefore if the introns were introduced into an existing genome at random, they had the remarkable effect of dividing genes into pieces corresponding to separate functions. It seems more likely that the introns have been in place perhaps since the beginning of evolution and that the exons coding for functional domains evolved independently of one another.

In the Beginning Was RNA

On the basis of these arguments and others W. Ford Doolittle of Dalhousie University in Nova Scotia, Darryl C. Reanney of Latrobe University in Australia and I have proposed that even in precellular times the information for proteins was not continuous. It is widely thought that even though DNA comes before RNA in the sequence leading to the synthesis of protein in the cells of today, the first coding nucleic acid was not DNA but RNA. The reasons include the fact that primitive RNA chains can be synthesized without enzymes. Furthermore, RNA can store coding information and is necessary in translation. If RNA evolved as a random nucleotide chain, its useful information might not have been continuous. RNA splicing to bring discontinuous pieces of information together would thus have been an early and propitious evolutionary event. Recently Thomas R. Cech of the University of Colorado at Boulder has shown that RNA can be spliced without enzymes, at least in the protozoan *Tetrahymena*. Therefore it is not implausible that intervening sequences existed from the earliest times and that RNA splicing was an early feature of gene expression.

Such evolutionary speculations will not be resolved for some time. Meanwhile pressing detailed questions remain to be answered. An intensive effort is under way to identify the enzymes that splice the transcript. When they are found, it will be possible to discover how one splice is selected rather than another. Similarly it must be learned why one poly(*A*) site is selected rather than another. On a more general level is the question of how significant RNA processing is in genetic regulation as a whole. Whatever the answers may be, the investigation of RNA processing will continue to have a profound effect on our understanding of how genes are expressed in eukaryotic cells.

BREAKTHROUGH: FLOAT AN EYE TO STEADY ITS GAZE.

No matter how well protected mobile cameras or telescopes may be, the motion of the vehicle carrying them causes the lenses to jitter and shake. Images are blurred and imprecise.

We discovered a way to make a moving lens sit still. By using high-energy, rare earth magnets, we suspend an electro-optical system in a magnetic field—in effect, make it float. Untouched, it remains steady while its source of transportation vibrates. This "soft ride" assures crisp, unblurred vision for an observer or a sensor.

Army scouts call it the first major advance in mobile observation since binoculars were issued to the cavalry.

We're creating breakthroughs not only in optics but also in aerospace, health care, energy and information processing.

We're McDonnell Douglas.

MCDONNELL DOUGLAS

The Dead Sea

Five years ago the world's most hypersaline lake "turned over," dissipating a dense body of fossil brine that had been isolated from any contact with the atmosphere by fresher water above it

by Ilana Steinhorn and Joel R. Gat

For thousands of years fresh water, carrying its light burden of salts leached from rock, sand and soil, has flowed south through the Jordan Rift Valley into the Dead Sea, a terminal lake. There is no outflow. Under cloudless skies the inflowing water evaporates into the desiccated desert air, leaving the salts to accumulate in the lake and its sediments. As a result the Dead Sea is the world's saltiest natural lake, with an average salinity of 280 grams per kilogram compared with the ocean's average of 35 grams. The Dead Sea is also the lowest place on the face of the earth: its surface is about 400 meters below sea level. Both the lake's salinity and its low location make it a valuable natural resource. As a storehouse of chemicals it is already being exploited by Israel and Jordan, and Israel has plans to realize the lake's potential as a sink for the generation of electric power by piping seawater to it from the Mediterranean.

Any lake is a sensitive monitor of environmental changes, the record of which is encoded in the sediments of the lake floor. In the case of the Dead Sea geologic and hydrologic history is recorded not only in sediments but also in the briny water itself and its long-term salinity structure. Among all the hypersaline lakes of the world the Dead Sea is the deepest as well as the saltiest, reaching a maximum depth of 320 meters. For centuries the fresh water flowing onto its surface mixed to only a small extent with the much saltier lake water, tending to form less saline layers floating over a dense column of fossil water. Then, beginning in the 1960's, the diversion of increasing amounts of the fresh water for irrigation lowered the lake and made its surface water saltier and hence denser. A few years ago the age-old gradient disappeared and the water column turned over, the fossil brine mixing with the younger water. In this article we shall briefly describe the Dead Sea's geologic, hydrographic and chemical history and its current and potential economic development before telling in some detail what we and other limnologists and geochemists have been able to learn about this historic overturn.

The Dead Sea has two basins: a larger, very deep one to the north and a smaller one, only a few meters deep, to the south. The two basins are separated by a broad peninsula called El Lisan (Arabic for "the tongue") that projects from the eastern shore, leaving only a narrow strait along the western bank; the lake is so low now that the sill of the strait is exposed and the southern basin is dry most of the year (except for parts maintained as evaporation ponds). The southern end of the lake is at about the latitude of transition from a Mediterranean climate to an arid one, and indeed the Judean Mountains bordering it to the west and the Moab Mountains to the east have as much as 600 millimeters (about 24 inches) of rain per year.

Yet the local climate of the Dead Sea is extremely arid and hot. The lake is in the "rain shadow" of the Judean Mountains, and the mean annual rainfall is only between 50 and 75 millimeters. At Sedom in the south there are 300 cloudless days per year, the summertime relative humidity is from 30 to 40 percent and the average monthly temperature ranges from 16 to 34 degrees Celsius (61 to 93 degrees Fahrenheit); 54 degrees C. (129 degrees F.) has been recorded during the day in summer. Considering the aridity, water evaporates from the Dead Sea relatively slowly because the vapor pressure over the surface is lowered by the water's dissolved salts.

In the 1930's (before major irrigation works were begun) the Jordan River, which combines the outflow of Lake Kinneret (the Sea of Galilee) in the north with that of the Yarmuk River drainage basin to the east, supplied some two-thirds of the Dead Sea's total inflow. The balance was accounted for by smaller rivers such as the Arnon, by a few freshwater and saline springs and by the seasonal wadis that drain the mountainous flanks of the lake. As is typical in a zone of climatic transition, fluctuations in precipitation and runoff were rather large, and the depth and area of the Dead Sea varied accordingly.

In the past two decades most years have seen a steady decrease in inflow as, beginning in the early 1960's, much of the freshwater flow was diverted, first into Israel's National Water Carrier system and then also into Jordan's Ghor Canal. Currently the level of the lake is being lowered by about half a meter per year (except in an occasional very wet period). Even if the present rate of loss by evaporation were maintained, however, it would take many hundreds of years for the lake to dry up because the northern basin is so deep. Actually the rate of loss would decrease because the surface area would be reduced as the level falls and because the salinity would increase with the reduction of volume, further decreasing the vapor pressure and hence the evaporation rate per unit area; eventually an increasingly concentrated brine becomes hygroscopic and absorbs water from the air.

The origin of the Dead Sea can be traced in terms of plate tectonics: the movement of the great plates into which the lithosphere, the rigid outermost shell of the earth, is divided. The lake lies on the Syrio-African Rift, a "transform boundary" along which two plates have been sliding past each other for some 10 million years. The crust to the east of the rift has moved north with respect to the crust to the west. The relative motion has stretched and thus attenuated the crust, which has subsided. In places the fault zone zigzags to the west, across the direction of the sliding motion, which has opened up discrete basins such as the Dead Sea's.

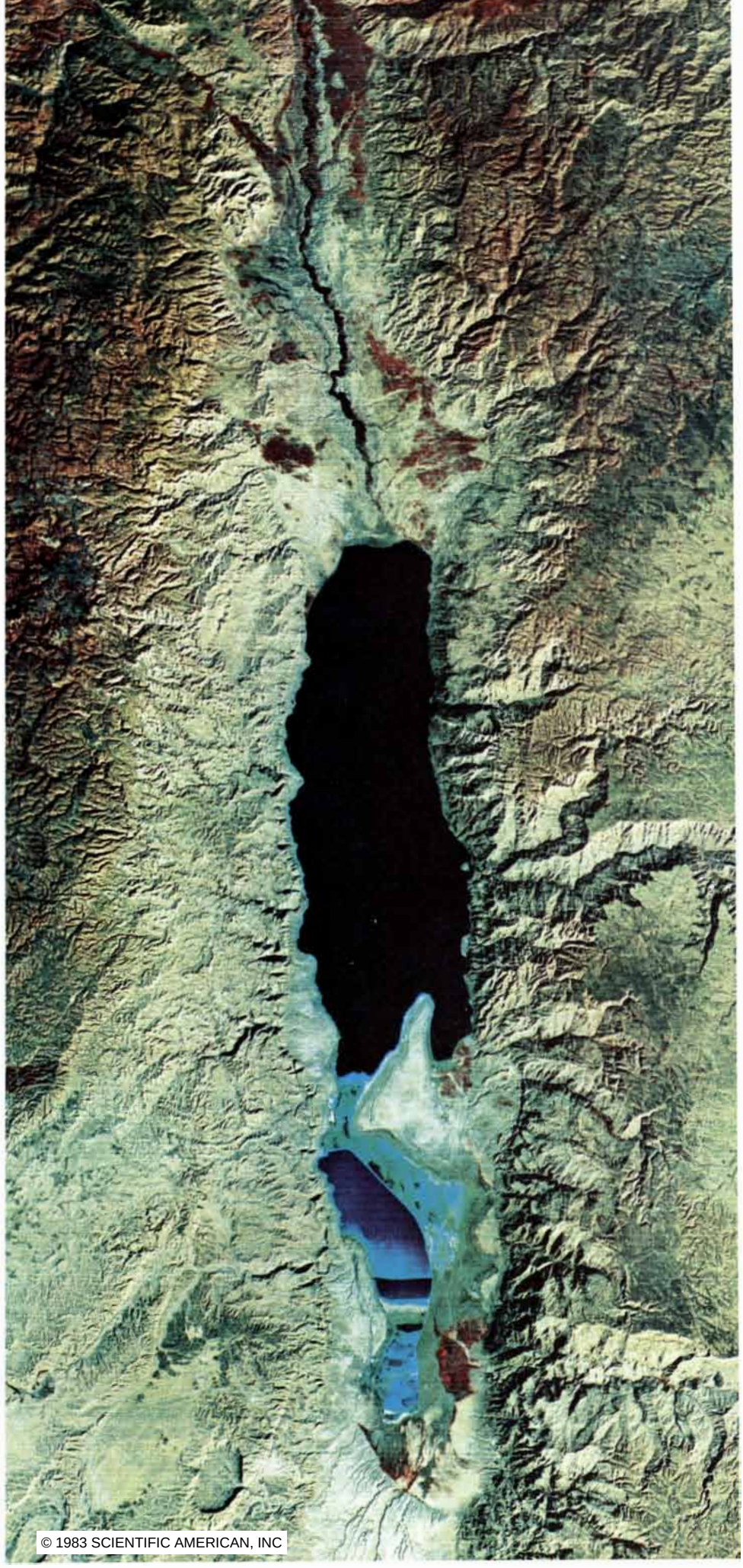
Immense layers of salt (sodium chloride) and gypsum on the Rift Valley floor reveal that during the Pliocene epoch (some two to five million years ago) the valley was in effect a great lagoon connected at times to the ocean to the west. The marine connection was disrupted by tectonic movements one or two million years ago. Thereafter a succession of lakes occupied the valley. The

best documented, Lake Lisan, was larger than the Dead Sea, much deeper (its surface was only some 180 meters below sea level) and less saline. Perhaps 10,000 years ago the valley and the Dead Sea attained what is essentially their present shape, but the level of the lake continued to fluctuate slightly.

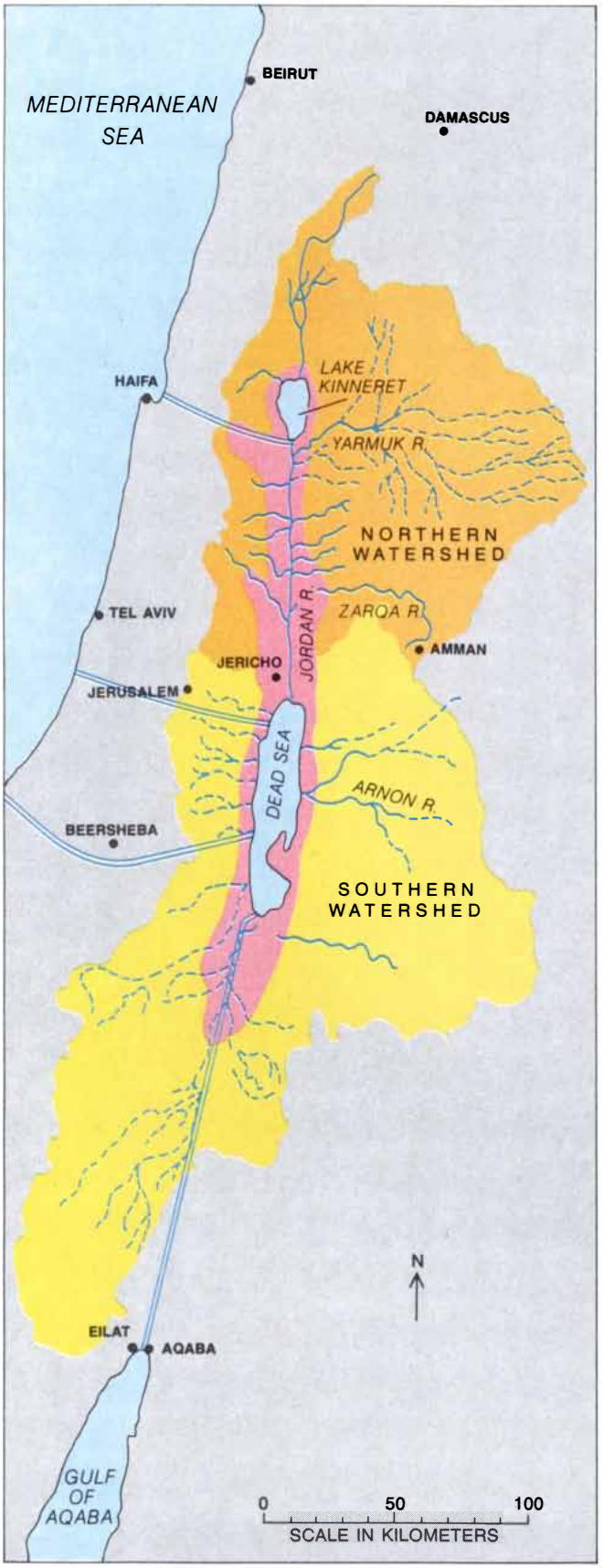
Allusions in the Bible suggest that the water was quite low, leaving the southern basin dry. The earliest map showing the Dead Sea, a mosaic from A.D. 560, shows only the northern basin. A fairly reliable reconstruction of changes in water level is possible from the beginning of the 19th century, based on floodmarks, the dating of driftwood or submerged tree trunks and travelers' reports (telling, for example, whether or not the Lisan ford 402 meters below sea level could be traversed). Actual measurements, recorded since the late 1920's, show a high-water mark of 392 meters below sea level in 1930; since then there has been a gradual decline.

The chemical character of the Dead Sea brine evolved along with the lake and its basin. The brine holds a unique assemblage of salts. Compared with brines having a marine origin, it is enriched in calcium, magnesium, potassium and bromine and is depleted in sodium, sulfate and carbonate. Such a composition could not have evolved from evaporating seawater, nor could it result simply from the weathering of continental rocks or the dissolution of minerals formed earlier by evaporation. The detailed steps in the evolution of the Dead Sea brine are still in dispute, but there must have been several sources.

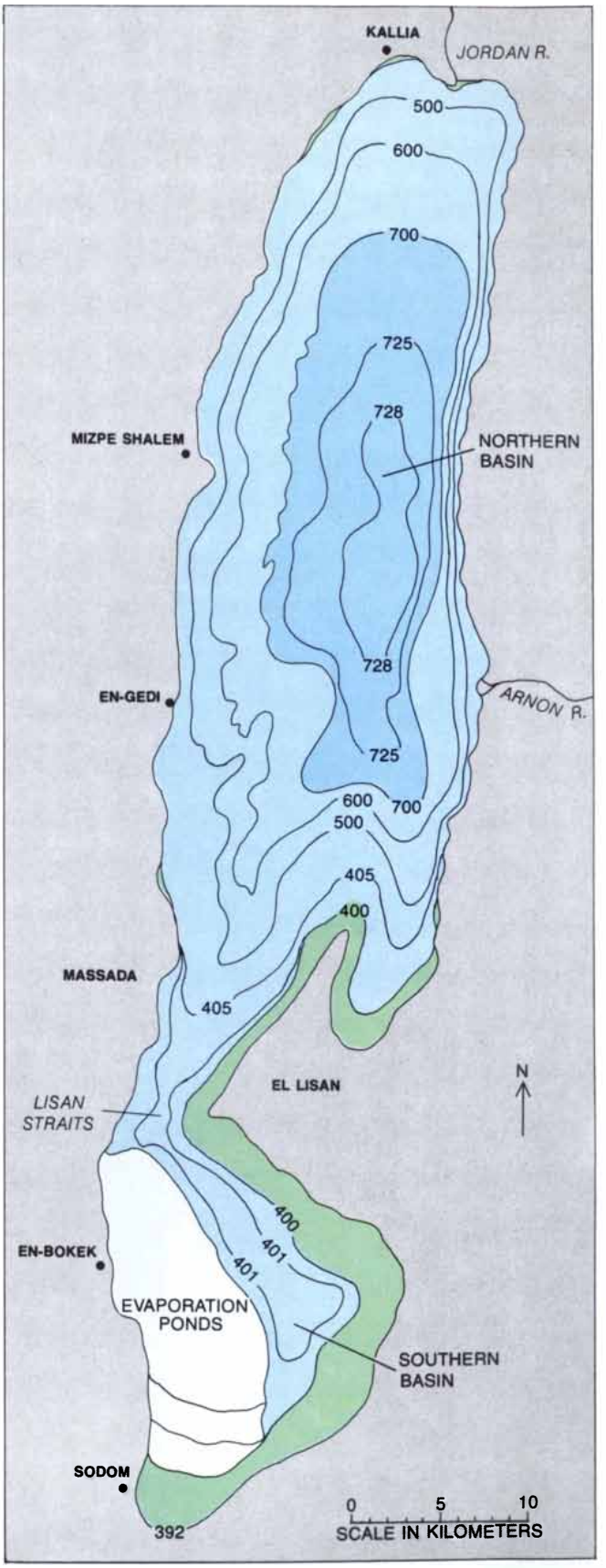
Efforts to determine the age of the brine lead to a similar conclusion. As long ago as 1715 the English astronomer Edmund Halley suggested that one might compare the rate of influx of salts with a chemical inventory of the salts in the lake and its sediments, and so learn how long it had taken for the brine to accumulate (and thus, he proposed, establish the date of the Creation). In 1961 Yaacov K. Bentor of the Hebrew University did such a calculation with data on the chemical load of the Jordan River and of known saline springs and seepages. He arrived at an age of some 12,000 years for the Dead Sea's salt as-



JORDAN VALLEY AND DEAD SEA are seen from an altitude of 570 kilometers in this false-color Landsat image. The deep saline water of the lake's large northern basin absorbs light rather than reflecting it, and so it is black. The swampy flats of the smaller, dried-up southern basin are dark green and light blue; the diked evaporation ponds are various shades of blue. Vegetation is red and urban areas are blue gray. The satellite image was acquired in December, 1978, about when the Dead Sea's waters were turning over.



NATURAL DRAINAGE BASINS of the Dead Sea are shown in yellow and orange. Most of the northern watershed's supply has been diverted for irrigation, reducing total inflow to the lake. The lowered lake's potential as a sink for the generation of electric power could be realized by bringing water to it from the Mediterranean Sea or the Gulf of Aqaba. Four proposed routes are shown; the one passing south of Beersheba is currently favored. The area below Mediterranean Sea level is in light red. Broken lines indicate seasonal wadis.



DEAD SEA'S TWO BASINS are very different, as is made clear by this bathymetric chart. Depths are indicated in meters below mean sea level. The lake as it was when the surface was 392 meters below sea level, in the 1930's, is shown in blue and green. By 1975 the shoreline had receded to about the 400-meter contour; water from the deep northern basin still crossed over the sill of the Lisan Straits into the shallow southern basin. Now the surface is even lower and the southern basin is largely dry except for the diked evaporation ponds.

semblage. Such a result implies that the salts in the lake are almost as young as the lake itself, and hence that the entire salt load of the Dead Sea's precursor lakes is sealed off under its sediments.

Closer examination reveals, however, that most of the salts are actually brought into the lake not by the major river system but by local springs and seepages. Many of the latter sources have a chemical composition very much like that of the lake itself: they are recycling the brine of the Dead Sea or that of its precursors. The accumulation of salts in the lake therefore results from a lower rate of influx than Bentor calculated, maintained for a longer time. The brine's unique composition reflects its derivation not only from the recent and current inflow of the products of continental erosion but also from the recycling of older deposits, including those of the ancient marine lagoon. Such an explanation is consistent with the Dead Sea's location at the deepest spot on the earth's terrestrial surface, from which the flushing away of accumulated salts is quite impossible.

Hypersaline water is not hospitable to life, and the absence of higher life forms long ago gave the Dead Sea its name. (The less judgmental Hebrew name is *Yam Hamelach:* the Salt Sea.) It was only in 1936 that Benjamin Elazari-Volcani of the Sieff Institute in Israel established that the lake was inhabited by microorganisms. He found several species of bacteria and one species of alga. The alga, the green *Dunaliella,* is ordinarily found in fresh water or seawater but can adapt to a hypersaline environment by synthesizing large amounts of viscous glycerol, which increases the osmotic pressure inside the cell and thus prevents the entry of salt.

Halotolerant bacteria, which are able to live in water with a moderate salt concentration, were found only at the northern end of the lake where the fresh Jordan water mixes with the lake water. A number of truly haloresistant species were more widely distributed. The most abundant species, however, were found to be aerobic, halo-obligate ones: bacteria that require oxygen and that cannot survive in media containing less than 150 grams of sodium chloride per kilogram. The halobacterial cell contains a very high concentration of potassium, and the cell membrane has an extraordinary specificity for potassium as opposed to sodium. The bacterium can therefore retain its potassium and so maintain its integrity.

There is a strong correlation between the physical and chemical properties of the Dead Sea and the number and types of microorganisms it harbors. One study done when the lake was stratified showed that the total number of bacteria decreased by a factor of 100 at a depth of 50 meters. No living algae at all were found below 100 meters. In 1970 investigators counted 40,000 *Dunaliella* cells per milliliter at the surface; below 50 meters they could find only anaerobic bacteria.

The commercially important minerals in the Dead Sea brine are potash, or potassium chloride (KCl), which constitutes 1 percent of the brine; common salt, or sodium chloride (NaCl), 8 percent; magnesium chloride ($MgCl_2$), 13 percent, and the bromide ion (Br^-), .3 percent. The first practical steps toward their extraction were taken in the 1930's by M. A. Novomeyski, a mining engineer from Siberia who received a concession for potash production from the British mandate administration. Novomeyski's process of selective precipitation is still the basis of production by the Dead Sea Potash Works. Lake water is transferred into a series of shallow evaporation pans, and each of the various salts precipitates as its concentration reaches the saturation point. Gypsum (calcium sulfate) crystallizes first, followed by sodium chloride. The mineral carnallite (a hydrated potassium and magnesium chloride) begins to crystallize when the brine reaches a specific gravity of 1.3 grams per cubic centimeter. To extract potash, whose major application is as a fertilizer, a slurry of carnallite is broken down into its components and the potassium chloride is further refined. A small fraction of the remaining "end brine" is treated with chlorine gas to extract bromine.

At first the evaporation ponds were on the shore at the southern end of the lake, but their total area was extended to about 130 square kilometers in 1966 by dikes built out into one half of the shallow southern basin. Changes in the lake since the ponds were built have affected the operation. The increased salinity shortens the time required for evaporation, but it also means increased precipitation of salt in conduits and pumps. The lowered level of the lake means that the brine has to be pumped from farther away and raised a greater distance.

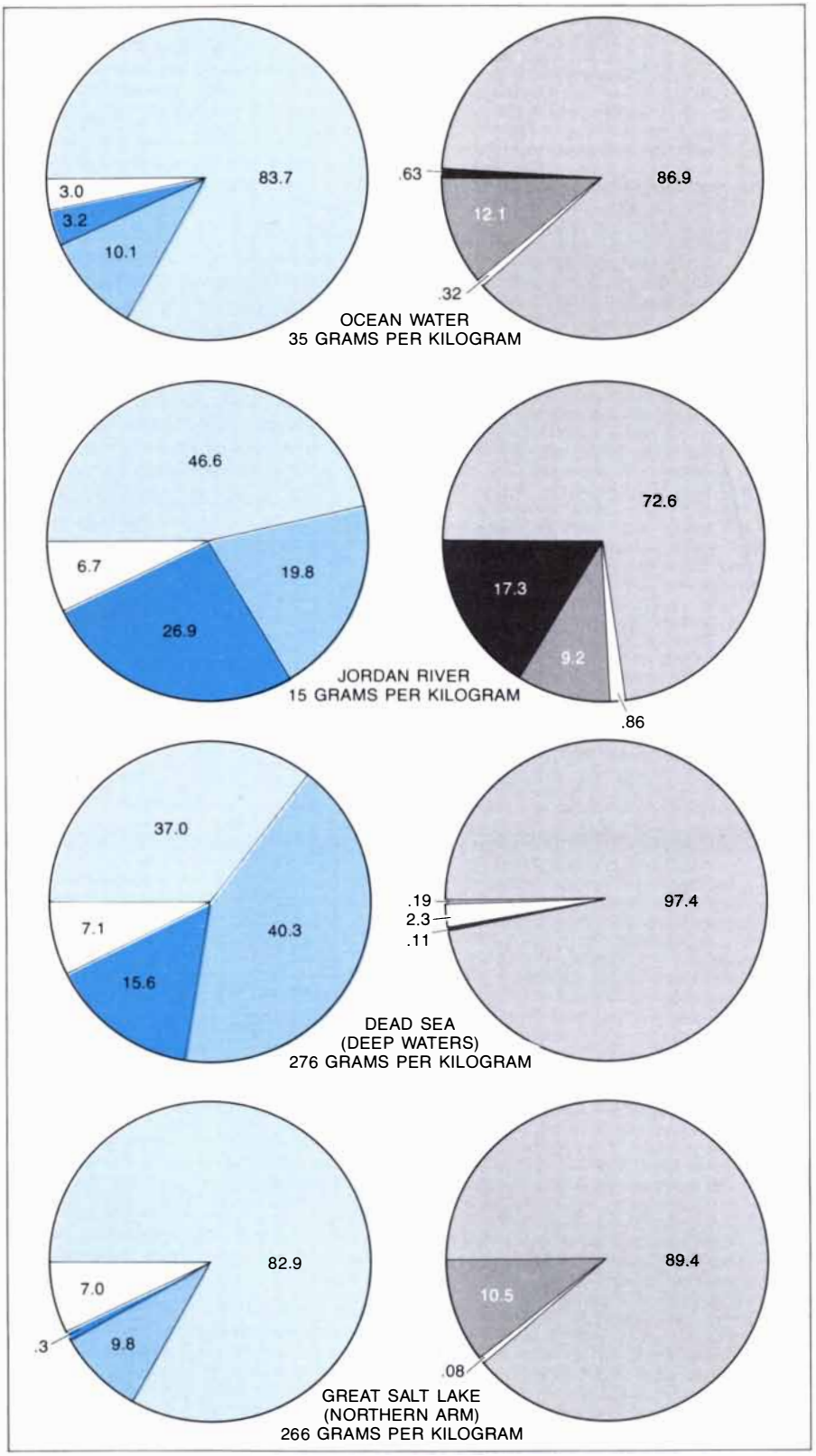
In 1902 Theodor Herzl, the visionary of the Zionist enterprise in Palestine, suggested in his book *Altneuland* that it should be possible to take advantage of the 400-meter difference between the level of the Mediterranean Sea and that of the Dead Sea to generate hydroelectric power. A broad Jordan Valley plan put forward 40 years ago by the American conservationist Walter C. Lowdermilk included a proposal to divert Jordan water for irrigation and build a canal from the Mediterranean to compensate for the loss of inflow to the Dead Sea and produce 100 megawatts of electric power. Now the Jordan has indeed been largely diverted (and the Yarmuk as well). The resulting lowering of the Dead Sea's level makes the hydroelectric scheme particularly attractive now. It makes possible a large throughput of water without any flooding of tourist and industrial sites along Israel's Dead Sea shores, at least until the lake has been refilled to its pre-1960's level.

In 1977 a planning group appointed by the Israeli Government considered four alternative routes: one from the Gulf of Aqaba to the south and three from the Mediterranean. The northernmost route (the one envisaged in the Lowdermilk plan) would put a canal through the Valley of Jezreel from near Haifa to just south of Lake Kinneret, flooding the lower Jordan Valley; in effect it would copy the ancient natural connection between the sea and the Rift Valley. This route would be expensive and would have a major environmental impact, in particular on important aquifers: permeable strata that are sources of fresh water. The other three routes would require substantial tunneling. The study group favored the southernmost route from the Mediterranean. It is not the shortest one, but it avoids the country's major aquifers and has the potential of promoting development in the northern Negev.

The plan calls for refilling the lake to a typical level of the 1930's, 393 meters below the Mediterranean, over a period of from 10 to 20 years. An inflow of about 1.6 cubic kilometers of water per year could be accommodated, which would generate up to about 800 million kilowatt-hours of electricity per year, saving some 275,000 metric tons of liquid fuel. Storage reservoirs would be built on the steep escarpment at Massada, some 300 meters above the lake so that the generation of electricity could be regulated to meet peak demand.

Once the Dead Sea has been refilled the rate of inflow will have to be modulated to the mean water-balance deficit. Even if the remaining flow of the Jordan and local flood flows are completely diverted to irrigation, the mean rate of inflow of Mediterranean seawater that will balance evaporation is estimated to be only some two-thirds as much as the rate of inflow during the filling stage, so that the hydroelectric system would inevitably become less profitable than it had been during the first 10 to 20 years. The permissible rate of inflow can be improved to the extent that the rate of evaporation from the lake's surface can be increased. The seawater's vapor pressure will be higher than that of the more saline Dead Sea brine, and so it will be helpful to avoid mixing the seawater deeply with the lake water, thus maintaining a sharply stratified layer of seawater mixed with some brine on top of the denser lake water.

The layering effect is also central to a novel "solar pond" scheme for energy



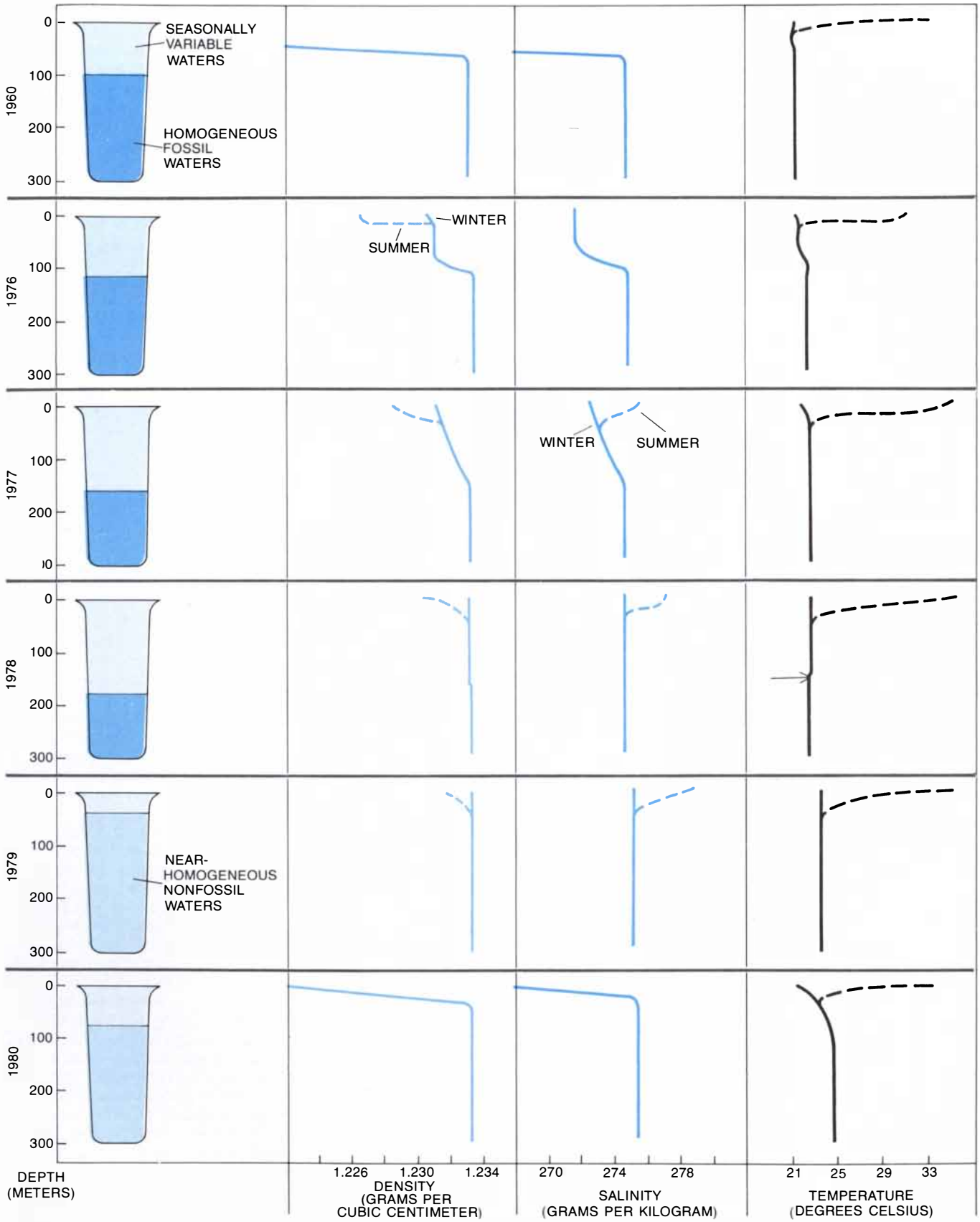
UNIQUE CHEMICAL COMPOSITION of the Dead Sea is compared with that of other bodies of water. The overall salinity of each is given in grams per kilogram. The pie charts show the percentage (on a weight basis) that is accounted for by each positively charged ion (cations) and negatively charged ion (anions). It is clear that the Dead Sea's salt assemblage could not have been derived simply from either ocean or Jordan River water.

production. If a thin layer of relatively fresh water is maintained over a briny pond, the sun heats the brine, whose density prevents it from rising and losing its heat to the atmosphere. The heat can be extracted by a heat exchanger that generates steam, and the steam powers a generator. In small-scale experimental solar ponds built near the Dead Sea, temperatures as high as 110 degrees C. (less than the boiling point of the brine) have been achieved. The mean electricity output of such a solar collector could be as much as five megawatts per square kilometer of Dead Sea area. Many physical and technological problems of floating the pools on the surface of the Dead Sea remain unresolved, however, and so the feasibility of the scheme is still not established.

Any lake in a climate such as the Dead Sea's undergoes a seasonal cycle. In the case of a freshwater lake, the sun heats the surface water in the summer, decreasing its density, while the deeper water remains cooler and denser. A stabilizing density gradient is established based on the temperature difference. A thermocline, a boundary region where the gradient is steep, isolates the largely undisturbed deep water from the top 10 meters or so that are warmed by the sun and stirred by the wind. Total circulation, with mixture of the surface water and deep water, is reestablished when the surface water cools enough in the autumn or winter. In the Dead Sea salinity as well as temperature affects the density of the water. A complex pattern of stratification ensues that can change but does not go through a simple repetitive annual cycle.

Variations in salinity arise from dilution of the brine by freshwater inflow or enrichment of the brine through evaporation. Theoretically the changes in density caused by such fluctuations in salinity could be compensated for by temperature changes in the right direction. For example, an increase of 20 degrees C. in temperature, if it were balanced by an increase of 9.2 grams per kilogram in salinity, would leave the density unchanged. In actuality, however, in this century the Dead Sea's surface salinity has varied by as much as 40 or 50 grams per kilogram, and there was even greater variation in the past. The large changes in salinity resulting from excesses of freshwater inflow over evaporation, or from the opposite condition, cannot be compensated for by the annual temperature cycle of from about 18 degrees C. in the winter to 35 degrees in the summer. The water-temperature change is usually not of sufficient magnitude to balance the change in salinity, nor are the two kinds of change likely to be precisely in phase.

The result is that the structure of the Dead Sea's water column and its season-



EVOLUTION OF WATER COLUMN (*left*) **and the density, salinity and temperature profiles that influenced it are traced from 1960 to 1980. In 1960, as for many years before, a large density difference (caused by a large change in salinity) separated the variable upper layers from the deep fossil waters. The density and salinity profiles are almost congruent on the scale chosen here (a scale at which the low surface values go off the chart). By 1976 the interface between the surface and the fossil waters had descended. The upper layers' salinity and density had increased, but in the summer the surface density was decreased by warming. These trends continued in 1977, but there was a new reverse salinity gradient in the summer. In 1978 the salinity was uniform throughout the column; a small temperature difference (*arrow*) maintained the stability of the fossil water body. In 1979, after the overturn, the fossil water body had been dissipated and the entire column was more saline and somewhat warmer. In 1980, after a rainy winter, there was a new but shallow salinity gradient.**

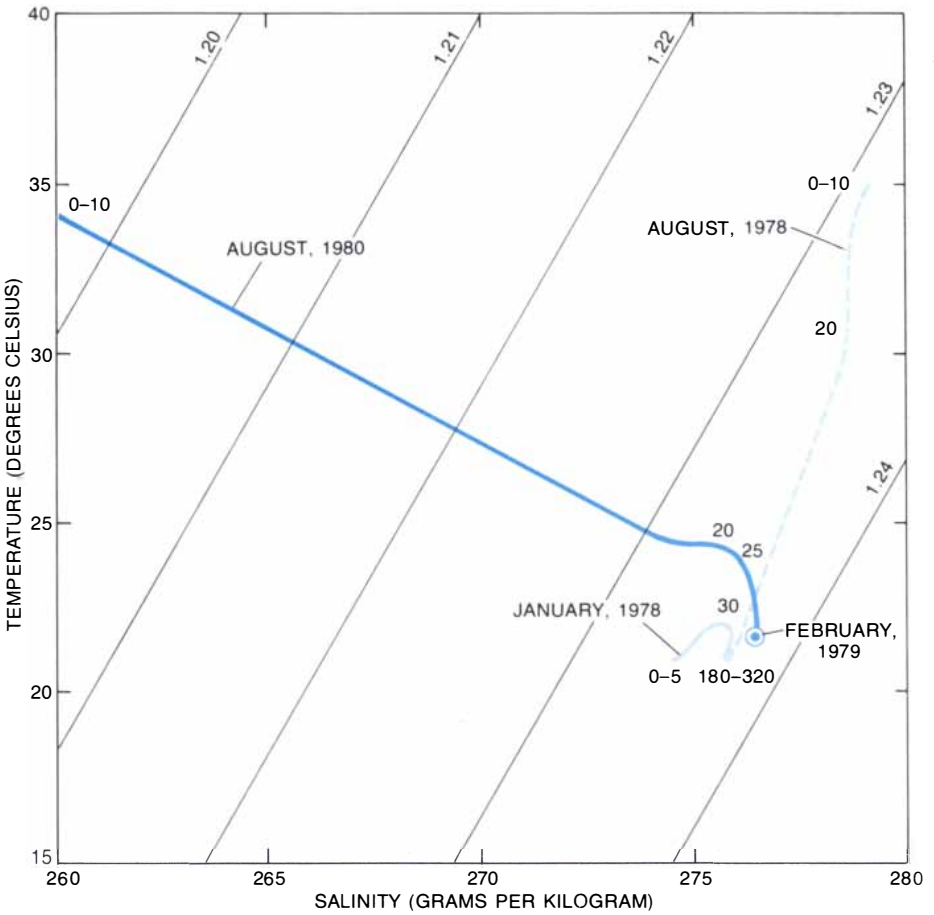
al and long-term evolution are very different from those of a freshwater lake and also (because the Dead Sea is so deep) from those of most saline and hypersaline lakes. The first hydrographic measurements, made in 1864, showed that the Dead Sea's water column was stratified by virtue of a salinity gradient. This was confirmed by measurements made in 1919; it appeared to be a long-term characteristic. David Neev of the Geological Survey of Israel and Kenneth O. Emery of the Woods Hole Oceanographic Institution studied the stratification in 1959 and 1960. They reported a density of between 1.20 and 1.21 grams per cubic centimeter (corresponding to a mean salinity of about 250 grams per kilogram) in the upper layers of the lake. A salinity gradient—a sharply defined difference in salinity of 25 grams per kilogram at a depth of from 35 to 40 meters and a more gradual transition zone going down to 80 meters—separated these upper, seasonally variable layers from the deeper water. Within the upper layers there were sharp differences in temperature and salinity that varied with the season.

Below 80 meters the water was essentially homogeneous, with a temperature of 21.3 degrees C. and a salinity of 276 grams per kilogram. That was a higher salinity than had been reported for any surface water in either basin. Moreover, a strong odor of hydrogen sulfide emanated from deep-water samples, suggesting that the water contained no dissolved oxygen and harbored anaerobic bacteria deriving their energy from the reduction of sulfates. The lack of oxygen was confirmed by the fact that iron appeared in the reduced, bivalent state. It appeared that the homogeneous water below 80 meters constituted a body of fossil water that had remained undisturbed for a long time, isolated by the density gradient from any contact with the upper layers and the atmosphere.

The fossil water body was finally to dissipate during the winter of 1978–79 by mixing with the overlying layers. The dramatic overturn and the events leading up to it were documented by hydrographic surveys carried out since 1975 by our group at the Weizmann Institute of Science in Israel. From the beginning of the survey it was clear that the salinity of the surface layers had increased significantly: the difference in salinity between the surface water and the deep water had diminished from about 25 grams per kilogram in 1959 to only two grams per kilogram in 1975; the stability of the water column was diminished accordingly. The water column was becoming more homogeneous as the mean salinity of the younger, upper layers approached that of the deep fossil water. The interface between the younger and the fossil waters was successively lowered. From a depth of between 60 and 80 meters in 1960 it descended to between 80 and 100 meters in 1975 and to 200 meters in the fall of 1978. The fossil water body was being eroded, but what remained of it stayed essentially unchanged.

By the summer of 1978 the upper layers had actually become saltier than the deep water. Yet stratification was maintained, now by virtue of a temperature gradient. The surface water was warmer, and therefore continued for a time to be just a little less dense, than the bottom water. During the next winter the nonfossil water cooled somewhat, and that was enough to bring about the final mixing. When the overturn took place, the surface water was more saline, and still somewhat warmer, than the fossil water. As a result the homogenized water column was half a degree warmer at the time of the overturn than the fossil water mass had been, and also .4 gram per kilogram saltier.

How long had the long-term stratification persisted before the overturn? How old, in other words, was the fossil water body? Marianna Stiller of the Weizmann Institute and Y. C. Chung of the Scripps Institution of Oceanography determined the age of two radioactive isotopes recovered in 1978 from below the deepened interface: radium 226 and carbon 14. They assumed that both isotopes had been introduced into the surface layers and had been mixed through the water column before its stratification. (Radium 226 originates primarily in warm saline springs along the Dead Sea's shores; carbon 14, which is present in trace amounts in atmospheric carbon dioxide, becomes dissolved in surface water that is in contact with the air.) Once the deeper water was disconnected from the surface the supply of the two isotopes could not have been replenished. The isotopes were subject to radioactive decay, with a half-life of 1,260 years for the radium and of 5,600 years for the carbon. Measurements of the extent to which they had actually decayed indicated that the water below 180 meters had begun to be isolated about 300



TEMPERATURE, SALINITY AND DENSITY of water at various depths are shown at four stages before and after the lake's overturn. The chart is a temperature-salinity diagram. A given temperature and salinity combine to yield a particular density. The diagonals are isopycnic curves: curves of equal density (in grams per cubic centimeter). The short profile of January, 1978, shows conditions were not very different at the surface from what they were at depth. By August the surface water had become more saline than the deep water, but it was warmer and so it remained less dense. In February, 1979, during the overturn, temperature and salinity were about the same throughout the water column, so that the entire profile is contracted to a single point. In August, 1980, a large inflow of less saline waters had temporarily reestablished a density gradient, and there was a shallow, sharp pycnocline, or density boundary.

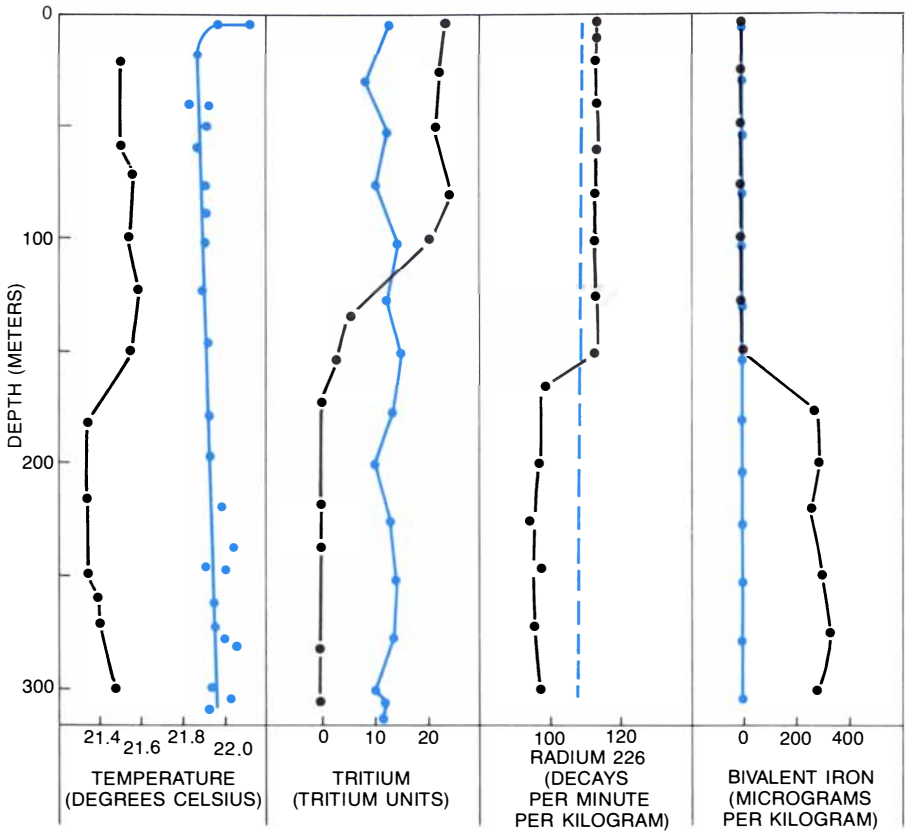
years ago, toward the end of the "little ice age" in the 18th century.

The calculations that are described above were based on the assumption that the deep fossil water constituted an absolutely closed system. In reality no such system can be completely closed; there is always some exchange by diffusion even across a pycnocline, or density boundary. To what extent, then, was the deep water truly isolated during the long-term stratification?

In 1967 Abraham Lerman of the Weizmann Institute calculated the rate of mixing across the pycnocline that could be expected simply on the basis of the random Brownian motion of molecules. He concluded that mixing by molecular diffusion would be a very slow process and would take thousands of years. Actually the picture is not quite so simple. There is seepage and there are springs at the bottom of the lake. On occasion a plume of dense surface brine from the southern basin may plunge deep into the northern basin. Temperature profiles in the deep-water mass and transition zone allow one to estimate the amount of influx of hot (and perhaps saline) water into the deep-water mass. In effect, then, the system is not truly sealed off. By measuring short-lived radioactive tracers such as tritium (which is introduced from the atmosphere) one can, however, calculate an upper limit to the rate of renewal of the fossil waters. It must be a slow process indeed, on a time scale of at least 1,000 years.

Even in the years immediately preceding the overturn (when the stability of stratification had decreased, increasing the chance that parcels of surface water would invade the deep-water mass), temperature and tritium measurements indicate that less than 2 percent of the fossil water was being renewed per year. It was only the final overturn in the winter of 1978–79 that brought water down from the surface to mix with the fossil water body.

What combination of conditions can bring about an overturn in Dead Sea waters? The essential requirement is undoubtedly a decrease in the water column's stability due to an increase in surface-water salinity resulting from a decline in the water level. For all this to happen conditions throughout the younger, upper layers have to be such that vertical mixing can take place. Such conditions evidently do not exist in the Dead Sea in the summer, when the surface layers are warmed, establishing a thermally controlled pycnocline. Moreover, in the winter or spring an influx of fresh water may dilute the surface brine and establish a pycnocline based on a salinity gradient. It is generally in the fall or early winter that a pycnocline near the surface is deepened by cooling of the surface layers; the depth to which mixing takes place depends on the current state of the water column. Often one then encounters a hierarchy of layers of increasing age, ranging from very young water at the top to the fossil layer at the bottom.



MIXING OF FOSSIL WATER with surface water during the overturn is documented by vertical profiles of temperature and of the concentration of three chemical components. Measurements were made in January–February, 1978, one year before the overturn (*black*), and the next February, during the overturn (*color*). Broken lines indicate estimated data. The preoverturn profiles show a significant difference between the younger waters and the deep fossil water; such differences are no longer evident after the overturn. The long isolation of the fossil water body gave it characteristic chemical and radiochemical properties: the low values for radioactive tritium and radium and the presence of bivalent iron, which indicates a lack of oxygen.

It is only after a succession of dry seasons that the surface layers become salty enough (and thus dense enough) for the autumn mixing to reach all the way to the transition layer delineating the fossil water body and on to the bottom of the lake, and so bring about an overturn. A particularly rainy season may, on the other hand, cause a pycnocline to persist at a shallow depth for several years. After the wet season of 1979–80, for example, the water column (which had been homogenized during the overturn) was stratified again for three years, until the end of 1982. The three-year period was not, however, long enough to reestablish the "fossil" nature of the deep waters.

Have there been overturns in the past? In searching for a record of such events one might start with the fact that a period of relatively low water (and consequent high average salinity) is a necessary condition for overturn (although perhaps not a sufficient condition, since overturn can still be avoided by occasional flooding). During the recent overturn high salinity resulted in the precipitation of halite, the mineral form of sodium chloride, from the Dead Sea brine. Any previous overturn may have been accompanied by a similar precipitation event, which should be recorded by the presence of halite crystals in the Dead Sea's sediments. A careful search for layers of precipitated halite in the sedimentary column might yield evidence for dry periods that may have been associated with previous overturns in the long history of the Dead Sea.

As one might expect, the changes in salinity we have been recounting had a major impact on the Dead Sea's biota. In 1979, after years of low water and increasing salt concentration had led to the overturn, the lake seemed to be sterilized. Then came the rainy winter of 1979–80. The number of microorganisms increased dramatically, with up to 19 million cells per milliliter at the surface. The bloom of microorganisms changed the optical properties of the surface water. The lake changed from blue green to reddish blue, giving visual evidence that the Dead Sea is not quite dead.

The world's densest computer is now the heart of the world's most 32-bit computer.

Our 32-bit CPU.

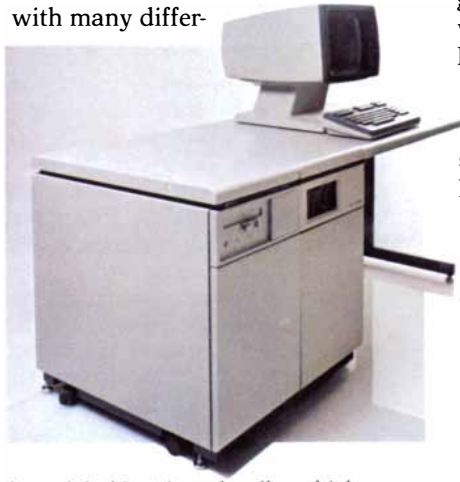
From time to time, miracles of technology come along to make previously impossible tasks not only possible, but easy. That tiny 450,000-transistor integrated circuit is one of those technological miracles.

Hewlett-Packard didn't develop it just to break the record for most transistors on a chip, but to put on an engineer's or scientist's desk a computer so powerful that it can do the work of mainframes costing four times as much.

32-bit computers for 32-bit applications.

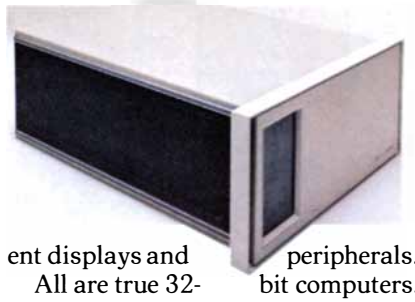
The new HP 9000 computer based on this and four other 'superchips' can handle formidable engineering and scientific problems. The scientist solving complex systems of equations, the mechanical engineer doing finite element analysis or three-dimensional modeling, the electrical engineer analyzing complex circuits or designing very large-scale integrated circuits — these are the kinds of technical people and problems the HP 9000 family is designed for.

It comes in three versions. The integrated workstation is complete with keyboard, color or monochromatic graphics display, fixed and flexible disc drives, and printer. For systems manufacturers, there's a rack-mountable box. And for a variety of single-user and multi-user applications, the minicabinet version works with many different displays and peripherals.



As a minicabinet, it can handle multiple users.

A rack-mountable version is available, too.



All are true 32-bit computers, with 32-bit CPUs, memories, and data paths. And the multi-CPU architecture lets you nearly double or triple your processing power at any time by adding one or two CPU boards. Without increasing the computer's size.

Two operating systems are better than one.

The integrated workstation is available with a choice of operating systems. One is HP's highly evolved, high-performance Enhanced BASIC, augmented with 3-D graphics and a software innovation called a run-time compiler. This substantially increases program execution speed, while retaining an interactive development environment.

The other operating system, called HP-UX, is a fully supported, extended version of the popular UNIX® HP-UX, available on all HP 9000s, adds virtual memory, graphics, data base management, data communications, and enhanced file capability to the basic UNIX 'shell.' High-level programming languages available with HP-UX are FORTRAN 77, Pascal and C.

Software, and plenty of it.

Much of the vast range of existing software written in HP BASIC, FORTRAN 77, Pascal and C is transportable to the HP 9000. HP will also be offering proprietary software packages emphasizing computer-aided design and engineering. These will tie the HP 9000 into HP's Manufacturer's Productivity Network (MPN). Third-party software suppliers will be providing many of the most widely used CAE packages for 32-bit computer systems. And both HP 9000 operating

The 32-bit CPU chip is bonded to the finstrate which doubles as a signal carrier and heat sink.

Up to three CPU boards and three Input/Output Processors can fit into a single HP 9000.

TCG-207

chip affordable

systems offer extensive program development tools.

You also get a choice of communication tools. The HP 9000 is currently compatible with Ethernet,™ and with HP's Shared Resource Manager (SRM) which lets clusters of HP 9000 and 16-bit desktop computers share data and use common peripherals.

Links to central computers are also available. And in late 1983, HP will offer local area networks based on the IEEE-802 standard.

New technology from the silicon up.

The five superchips that make the HP 9000 possible are the 32-bit CPU, which can execute a million instructions per second; an eight-channel Input/Output processor (IOP); a random-access memory chip capable of storing 128K bits of data; a memory controller that 'heals' up to 32 bad memory locations; and an 18-megahertz clock.

Hewlett-Packard's advanced NMOS-III process makes it possible to put 450,000 transistors on a chip only 0.4 centimeters square. This tremendous density of electronic components could have required an expensive and elaborate cooling system.

Instead, HP engineers developed a new mounting structure called a finstrate, a copper-cored circuit board, which acts as both cooling fin and substrate. The finstrates containing the CPU, IOP, memory, and clock chips are housed in a lunchpail-sized module.

One user, one mainframe.

Clearly the trend in engineering and scientific computation is away from large machines shared by multiple users and towards networks of powerful personal workstations, sharing peripherals and data bases. The reason is compelling. An engineer or scientist in personal control of an HP 9000 can solve so many more problems more easily that the increased productivity alone makes the cost of individual computers easy to justify.

For complete information about this powerful breakthrough in 32-bit computing, contact the local HP sales office listed in your telephone directory. Ask a Technical Computer Specialist for a demonstration. Or write to Pete Hamilton, Dept. 41151, Hewlett-Packard, 3404 East Harmony Road, Fort Collins, CO 80525.

HEWLETT PACKARD

UNIX is a trademark of Bell Laboratories. Ethernet is a trademark of Xerox Corporation.

This illustration of an optical fibre cable was created for Northern Telecom's Optical Systems Division by Acorn Technical Art Studio Inc., Toronto. Northern Telecom's unique star-shaped optical fibre cable is popular with telephone companies and specialized common carriers and is in operation throughout major telecommunications networks in Canada, the United States and the Caribbean.

CANADIAN TELECOMMUNICATIONS

Nearly 80% of Canada's 25 million people are spread along a narrow but very long corridor (6,400 km) just north of the U.S. border, with the remaining 20% thinly spread all the way to the Arctic Ocean. According to R.D. Sloane, President of TransCanada Telephone System (TCTS): "The highly sophisticated [communications] network that serves Canadians today was historically a response to the stimulus and imperatives of geography. Canadians have always felt the need to talk frequently to one another, to overcome distance and to avoid the consequences of personal and regional isolation."

In what Sloane calls "a unique blend of monopoly and competition," ten major telephone companies provide 94% of Canada's telephone service and together form the umbrella organization, TCTS. Six of these companies are investor-owned, three are operated by provincial governments, and the tenth, Telesat Canada, which provides domestic satellite services, is a federal Crown Corporation.

It is thus not surprising that there is federal participation in most of the major technological development being mounted by the Canadian telecommunications industry.

There are currently three major thrusts of development in Canadian communications technology:

(1) The creation of an all-digital communications network across Canada adapted to the simultaneous transmission of voice, data, and other communications services (an "Integrated Services Data Network," or ISDN).

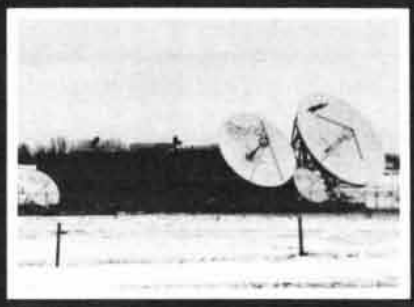
(2) Continuing development of satellite communications, following Canada's establishment in 1972 of the world's first domestic satellite communications system.

(3) Pioneering of optical fibre transmission media for land-line voice and data transmission.

The move to integrated digital networks

The Canadian telecommunications industry, as stated by Sloane, is divided into areas of monopoly and open competition. Its two major intra-Canadian operating components are TCTS and CNCP Telecommunications. TCTS is responsible for the nation's

We built our reputation from the ground up



Designing and operating a reliable satellite system for one of the world's largest countries presents many unique challenges. Telesat Canada has met every challenge with innovation and has been involved in the design of a variety of systems:

- FDMA Message
- SCPC
- TDMA
- TV and Radio program services
- DBS

Our reputation for technical excellence coupled with operating experience in these services has spread beyond the borders of Canada. Today, international consulting is a growing and important part of our business. Consulting services are offered in system design and program management in the following areas:

- satellite systems
- earth stations
- communications networks
- satellite control systems
- operations and training

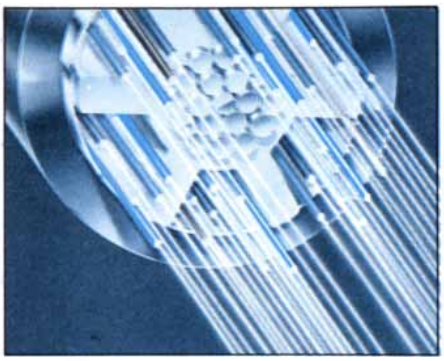
In space or on the ground, our commitment to excellence and innovation has earned us international recognition as the company on the leading edge of satellite communications technology. For more information on Telesat Canada and our consulting capabilities, contact:

Consulting Services
Telesat Canada
333 River Road, Ottawa
Ontario, Canada K1L 8B9
Tel: (613) 746-5920 ext. 359

Telesat

Telesat Canada

New Horizons in Communications



long distance telephone network, and its members provide most of the public local telephone service in Canada. CNCP Telecommunications, which began as a consortium of the two major railroads in Canada, is responsible for the provision of public telegram service. Teleglobe Canada, a federal Crown Corporation, provides international telecommunication services, except for Canada-USA traffic, which flows over an integrated North American network.

Beyond these basic monopolies, strong competition exists for the carriage of radio and television signals and data and computer communications.

The potential for enhanced speed and reliability of digital transmission has long intrigued Canada's communications planners. Digital data transmission for inter-office applications was made available in 1965, via pulse code modulation (PCM) of analog signals. By 1975, North America's longest (700 km) high capacity broadband digital transmission system using 12 coaxial copper tubes, was in place between Montreal, Ottawa, and Toronto. This was the precursor of "The Dataroute," a transcontinental broadband data highway with links to the USA at major border crossing points. This year, an advanced digital radio system was completed across the country (6400 km) by TCTS, using ten working and two standby radio channels providing 1344 voice-equivalent channels operating at 90 megabits per second.

The availability of digital transmission has made possible the goal of integrating voice, data, and other communications services. Says Robert Haughton, Director International of TCTS, "Integration has two components: one applicable to the fusion of digital transmission and digital switching into a single ... system dedicated to a particular service such as telephone or data – referred to as the Integrated Digital Network (IDN) – and the other focussing on the provision of different services over a single digital channel – the Integrated Services Digital Network (ISDN).

"Progress towards all-digital long distance networks is expected to be relatively rapid: within the next decade about one half the nation's long distance circuits should be digital ... and by the end of the century perhaps 90% or better."

The ISDN concept, in which a single channel can be used to carry various services (such as video, telephony, and data transmission) over the same loop, is now being intensively investigated by the Canadian industry. One key to the requirement for broadening bandwidth and decreasing signal attenuation, inherent in ISDN service, is the introduction of fibre optic cable, first in transmission trunks, and then into the customer loop.

Fibre optics: key to the communications of tomorrow

Fibre optic systems are defined by Terence Heenan of AEL Microtel Ltd. as "a combination of hair-thin glass fibres and electronics with the capability of carrying over 4,000 voice circuits per glass fibre pair ... the state of the art method for transmitting sound, video, and data simultaneously by using high speed streams of laser generated light pulses over glass fibres."

Initial experiments in the use of optical fibres, carrying signals in the form of light pulses through transparent fibres, were carried out by Bell Telephone starting in 1976. The first major field trial is being carried out in a rural area, surrounding the village of Elie, Manitoba.

Meyer Akgun of the federal Department of Communications makes the point that: "People living in rural areas have actually a greater need for communications to satisfy their information needs compared to urban dwellers who have easier access to such services. In recognition of this situation, the ... Government of Canada initiated a rural communications study program. Among many approaches ... the application of fibre optics technology to an integrated services subscriber access network proved to be one of the most promising."

While the trial was completed this March after 18 months of operation, its performance was so satisfactory that it was decided to continue the operation as a test-bed for future technology and service trials.

In 1980, the Saskatchewan Telephone Co. began to install a 3,400 km fibre optics broad band network linking the province's major population centres. Now completed, it is the world's longest commercial fibre optics network, providing full voice and data services, as well as cable television signals to 52 communities.

At Regina, the provincial capital, Northern Telecom has built a $14 million fibre optics manufacturing facility occupying 91,000 square feet. The company sold $37 million worth of fibre optic transmission systems in 1982, and this year announced its first contract for single-mode optic fibres. Single-mode fibre offers three to five times the number of communications channels as multi-mode fibres.

Satellites: bringing people and continents together

Canada, with her problems of a population thinly scattered over a vast area, saw early the advantages of satellite relaying of communications. Telesat Canada, the federal Crown Corporation, was founded in 1969. In 1972, the launch of the Anik A satellite established the world's first geostationary space satellite in domestic communications service.

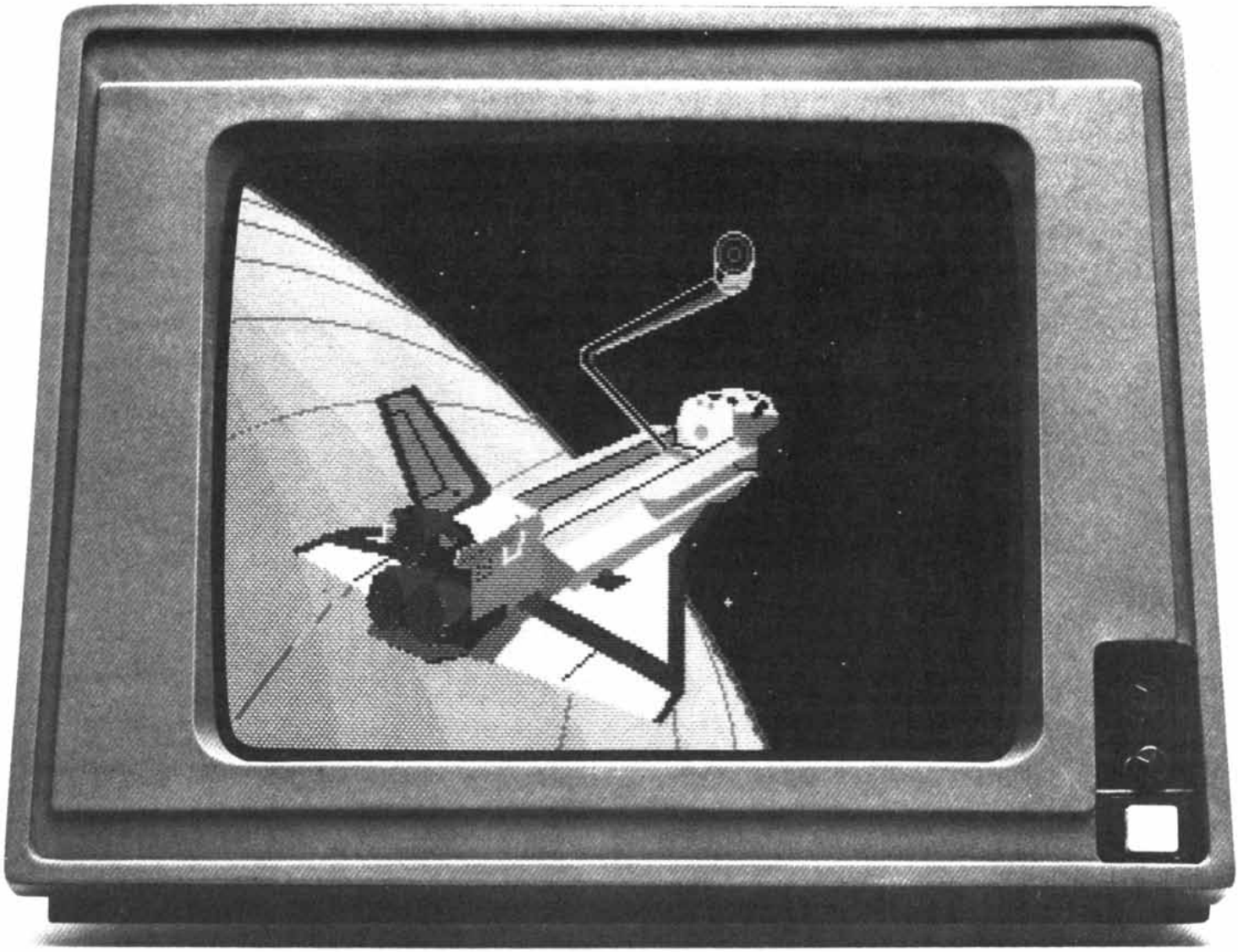
R.M. Lester of Telesat explains the inherent simplicity and effectiveness of the satellite system for distribution of broadcast signals this way:

"To reach an unlimited number of television receivers scattered randomly throughout a service area, requires the use of only one satellite earth station transmitting to a satellite in-orbit. This in turn transmits the signal back to earth where it can be received over an area which may be regional or country-wide in scope. Satellite television transmissions have utilized FM techniques where the broadband satellite channels have had sufficient power to support excellent picture quality while requiring only modestly sized receive antennas ranging from 1.2-4.5 metres in diameter."

The Telesat reliability factor is better than 99%, providing such service as global TV relay with local-area distribution, telephone service, computer data transfer, teletype, and facsimile. Canada now has over 100 earth stations in operation and more communications satellites than any other country except the USA and the USSR.

The development of Canadian satellite technology has given several Canadian firms an entry into a significant and growing world market. Spar Aerospace Ltd., for instance, employs 2,000 people, and did $178 million worth of business last year in the aerospace, communications, and military markets. The company received world-wide attention for its provision of the "Canadarm," the manipulator system for the US space shuttle program, which will play an important role in future in the orbiting, retrieval, and repair of space satellites. Last year, the company signed its largest contract yet for $125 million with the Brazilian state company Embratel for two satellites of the Anik "D" type, which can each carry 16,000 two-way voice channels or 24 TV channels. This will be the first domestic communications satellite system in Latin America.

AEL Microtel Ltd., a subsidiary of British Columbia Telephone Co., has just sold its "Spacetel" system to Manitoba Telephone. The central control system in Winnipeg will connect remote Indian settlements in the sub-arctic north of the province to the North American network, via light-weight terminals. As described by Microtel president Terence Heenan, Spacetel is: "A thin-route



NEW HORIZONS: ONTARIO/CANADA

The growth of the high technology industry is happening faster in Ontario than just about anywhere in the world today.

For example, the research, development and manufacturing of the Spar Remote Manipulator "Space Arm" and the Telidon Videotex System, are just two of many major developments taking place in Ontario.

Another exciting project is the establishment of the Microelectronics Technology Centre in Ottawa which will provide a design, production and testing capability for our high tech industry.

We think the technological innovation now going on in Canada has a lot to do with the kind of tomorrow all of us will be experiencing. And the more our high tech community grows, the greater our collective contribution to that tomorrow will be.

If you, or your company would like to be part of the new horizons Ontario is developing today, contact us.

ONTARIO Ontario **CANADA**

Honourable Frank S. Miller
Minister of Industry and Trade

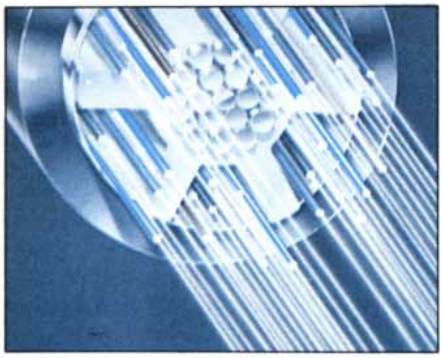
Honourable William G. Davis
Premier of Ontario

Ontario House
Rue Royale 97-99
Brussels,
Belgium
Telephone: 32-2-218-0600
Telex: 46-63559

Ontario House
Charles II Street
London SW1Y 4QS
England
Telephone: 44-1-930-6404
Telex: 51-262517 ONTLDN

Ontario House
109, rue du faubourg St.-Honoré
Paris
France
Telephone: 33-1-563-1634
Telex: 42-650865F ONTPAR

Government of Ontario, Canada
Bockenheimer Landstr. 51/53
D-6000 Frankfurt/Main
West Germany
Telephone: 49-611-72-0971
Telex: 41-416176 ONFRA



14/12 GHz single channel per carrier (SCPC) system, configured as a star network to extend subscriber services available at a central site to any location within the appropriate satellite footprint. High quality voice transmission is provided using 32 kilobit per second digital encoding and quaternary phase shift keyed modulation."

In application, subscribers in the isolated area are assigned a metropolitan exchange number, receive dial tone from that centre, and gain access to all telephone services available, as well as broadcast services.

Telephony for the third world

The emphasis on improvement of rural services, and for adapting high-technology equipment to low-technology environments, is a major basis for the increasing trade in communications hardware and software between Canada and the Third World.

Bell Canada's assistant vice president (Engineering), R.C. Terrault, describes his company's recently completed Non-Urban Service Improvement program (NUSI) this way:

"Prior to the program, many of Bell's rural subscribers shared their telephone lines with up to seven or eight other customers; 450,000, or nine per cent of all main telephones, were located outside urban areas, and of those, 250,000 were in multi-party service . . . The program meant that urban areas were extended to provide urban service to expanding concentrations of customers, and locality rate areas for islands of denser population were established wherever needed; the introduction of DMS-1 digital multiplexers and rearrangement of telephone facilities was required throughout Bell territory to provide all customers with access to four party lines, and, in many cases, with individual or two-party lines. At the conclusion of the program in 1981 the number of multi-party line services totalled approximately 200,000 and the number of subscribers per line was reduced to an average of 2.5 from 4.6."

Such a program is evidence of the strong sense of social responsibility which has been a tradition of the Canadian telephone industry. (It may be remembered that Alexander Graham Bell's invention of the telephone originated from his work in trying to alleviate the problems of deafness.) J.S. McNeice of Bell Canada gives this short list of recent "action taken" on telecommunications problems of the handicapped:

"* Centres for Special Needs were established in two major Canadian cities with staff specially trained in the communications needs of the disabled.

* A standardized portable keyboard device was developed for use by the deaf, with a special Assistance Centre for dealing with calls from keyboard users.

* A small voice synthesizer was produced to convert visual display material to audio output, in order to facilitate the employment of blind operators.

* A "handsfree" telephone was developed to dial the operator through the use of switches designed for paraplegics."

Global business pushes toward office automation

The Canadian communications industry, of course, did not grow and thrive on social responsibility alone. The message for business is well expressed by A.J. de Grandpre, Chairman, President and Chief Executive Officer of Bell Canada Enterprises, Inc.:

"It is the senior executive in business organizations today on whom the microelectronic era may well have the greatest impact – not the secretary, the clerk or the factory worker. While these workers have to learn new techniques, new Information Age technology is forcing on executives an entirely new way of thinking and new ways of doing business."

With the increasing density of business information available, Oscar Stubits of CNCP Telecommunications reports, "there is an increasing demand for new services. This demand is, to a large degree, based on the need to provide the already large installed and rapidly increasing base of 'dumb' and intelligent terminals with the capacity to communicate between them. Most recently, we introduced Teletax, electronic mail, and an asynchronous communications service for word processors."

The demand for new services means a correlative demand for new products. Mitel Corp. is a ten year old company that has made an outstanding success in developing PBX exchanges for business, to which it is now adding work stations and advanced business telephones called "Supersets." The company has grown from two to 5,000 employees, with $250 million in annual sales and manufacturing plants in the USA, Mexico, Ireland, the United Kingdom, and West Germany.

One of Mitel's design emphases is to configure its systems for compatibility with the major existing data processing systems.

Mitel's vice-president, marketing, James Mackie, warns, however, of the dangers of misapplication of office technology. He quotes the aphorism "Yes, I know office technology is the answer – but what is the question?" Frequently, he believes, management makes the right decisions on office automation for the wrong reasons. Thus, video conferencing will bring great benefits to far-flung corporations – but it won't obviate the need for personal travel, any more than the telephone has eliminated the importance of personal contact in business.

Cellular radio systems being developed

One new development of communications technology which has immense potential for both business and private use is the development of "cellular" systems for mobile telephony. While telephone companies in some countries see this as a possible infringement of their communications jurisdiction (as earlier Citizens' Band communications were also sometimes regarded), Canadian telephone systems are in the forefront of developing "cellular" radio links.

NovaTel's Dr. Aremus Slekys describes the "Aurora," an "AUtomatic ROaming RAdio" system developed by NovaTel:

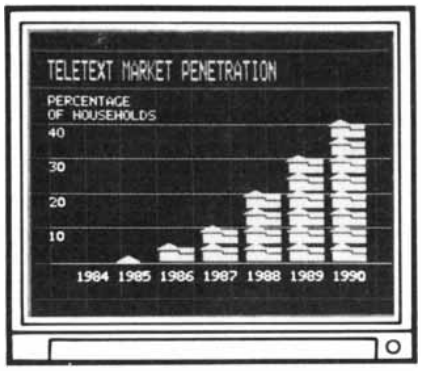
"Aurora is a medium to high capacity cellular mobile telephone system . . . developed to satisfy the widely varying needs of both public and private users in the Province of Alberta – one of the largest users of mobiles in North America, with 30,000 units in service in 1983.

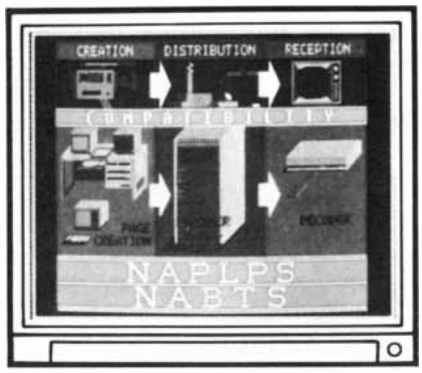
"The system is designed to interface directly with the nearest telephone exchange thus eliminating the need for an overlay network, dedicated central switches and extensive trunking. Computer control of the overall system forms a heirarchy beginning with the Master Mobile Centre followed by Regional and Local Mobile Centres. Aurora has the flexibility to be compatible with numerous signalling protocols, national or international standards, and can be implemented economically over a wide range of frequency bands."

Playing a role in a worldwide revolution

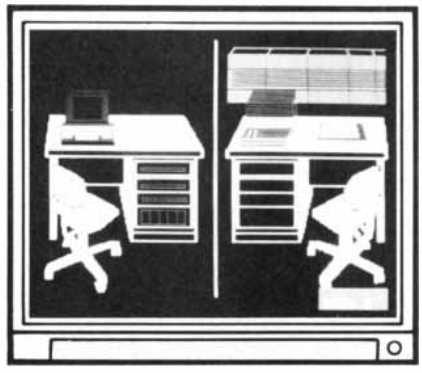
Telecom 83, a world showcase on telecommunications technology, will be taking place at Geneva, Switzerland from Oct. 26 to Nov. 1. The meeting represents one of the key focal points to "World Communications Year" as designated by the United Nations.

Telecom 83 is the fourth in a series of quadrennial World Telecommunications Exhibitions organized by the International Telecommunication Union (ITU), a UN agency representing 146 countries. The meeting is expected to be the largest so far, with 650 exhibitors from 40 countries. The exhibition is accompanied by a prestigious World Telecommunications Forum, with



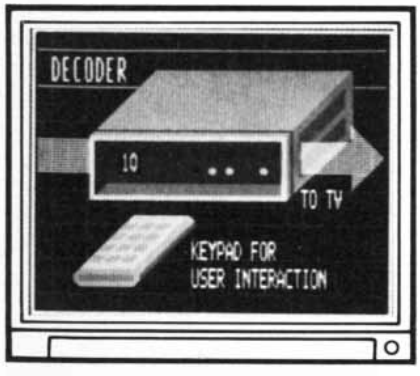


Telidon, the world's most advanced videotex computer protocol was developed in Canada.



Today, Canadian companies continue pioneering technological advances in electronic information.

Discover the exciting developments in information technology and telecommunications

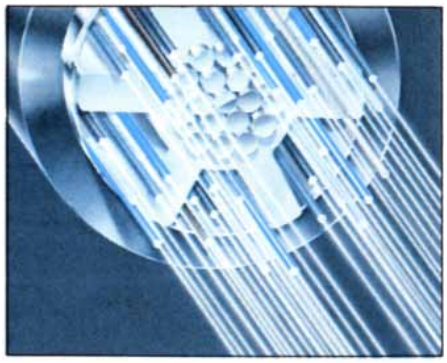


at Telecom 83, Hall 2, Stands 117-145, Palais des Expositions et des Congrès de Genève.

Wherever you live the Canadian embassy, consulate or High Commission near you can provide information about Canadian companies and their capabilities in telecommunications.

External Affairs Canada Affaires extérieures Canada

Canada



nearly 200 carefully selected original papers presented in sessions devoted to the technology, economics, and legal aspects of telecommunications.

While the USA boasts the largest single national pavilion, with 80 exhibitors crowding 64,000 square feet of floor space, its northern neighbour, Canada, is taking an impressively major part in both the exhibits and technical proceedings.

Canada's Federal Department of External Affairs is coordinating a national pavilion of 15,000 square feet, in which 17 manufacturers are participating. Four large companies, Bell Canada, Northern Telecom, Teleglobe Canada, and Mitel, also have their own exhibit space, aggregating almost as much area again.

In the technical Forum, Canada's contribution is also disproportionate to its size in terms of population. Canadian communications organizations submitted 20 abstracts of proposed papers, of which seven were accepted for presentation, and another six for publication in the printed Proceedings of the Forum. R.D. Sloane, President of Trans-Canada Telephone Systems and A.J. de Grandpre, Chairman, President, C.E.O. of Bell Enterprises Inc., were chosen as world telecommunications leaders to make official opening presentations. R.N.E. Haughton, Director, International of TCTS, was chosen to chair the Mobile Communications session.

The Papers Committee reported that Canada is presenting eight per cent of the total Forum papers, and has the highest ratio of submissions accepted for presentation: 35%, vs 29% for Germany and Japan and 21.4% for the USA. (All papers are presented in simultaneous translation in English, French, and Spanish.) This showing reflects the importance of the telecommunications industry to Canada.

Summing up the raison d'etre of Canada's participation in Telecom 83, Douglas Sloane of TCTS says:

"Rapid advances in (telecommunications) technology are now generating a worldwide revolution in which Canada has a chance to play a leading role. This is an opportunity which, properly exploited, can create new jobs, improve trade balances, and make a significant contribution to the economic recovery of this country."

Canadian Papers Accepted for Presentation at Telecom 83

A Fibre Optic Integrated Services Field Trial in Canada: M.B. Akgun (DOC), K.B. Harris (Cdn. Telecommunications Carriers Assoc. – CTCA); G.A. Tough (Manitoba Telephone System). Rural Networks Session.

Planning for the Introduction of New Digital Customer Services and Loop Technologies: F.M. Banks (Bell Canada); G. Gara (Bell Northern Research). ISDN Session.

An Integrated System Implementation in Canada: O. Stubits (CNCP Telecommunications). Enhanced Services Session.

Technology and Social Responsibility: J.S. McNeice (Bell Canada). Terminal Equipment Session.

Aurora – An Automatic Roaming Radio System: A. Slekys (Alberta Gov't Telephones). Mobile Systems Session.

Software Aids for National Architecture Planning: D. MacDonald; M. O'Leary (Bell-Northern Research). Technology Trends Session.

Satellite Applications in Canadian Broadcasting: R.M. Lester (Telesat Canada). CATV-Broadcasting Session.

For Publication Only

Network-based Data Services of TCTS: A.M. Rybczynski (TCTS).

Integration of Satellite and Terrestrial Digital Technologies for Business: P. Kiar (Bell Canada).

A Single Channel Per Carrier Satellite System: S. Hussain (AEL Microtel).

Optimizing Rural Telephone Networks: R.C. Terrault (Bell Canada International).

Microwave Frequency Coordination in Canada: M. Derzai (CTCA).

Optimizing Management Training and Development in a Changing Technical Environment: E.J. Clifford (Bell Canada).

Canadian Companies Exhibiting at Telecom 83

AEI Telecommunications Canada Ltd., Winnipeg, Manitoba. *(Small and large telephone switching systems.)*

AEL Microtel Ltd., Burnaby, British Columbia. *(Satellite and other receiving and multiplexing systems, advanced R&D).*

Allcom Data Ltd., Nepean, Ontario. *(Data Communications Products.)*

Bell Canada International, Ottawa, Ontario. *(Major telecommunications system consultants and designers).*

Canadian General Electric Ltd., Toronto, Ontario. *(Fibreglass and other telephone conduit systems.)*

Canadian Marconi Co., Montreal, Quebec. *(Data switching and radio systems.)*

Century III Electronics Inc., Vancouver, British Columbia. *(Broadband communications networks.)*

Croven Crystals, Whitby, Ontario. *(High frequency crystals for communications and radar systems.)*

Dept. of Communications, Ottawa, Ontario. *(Federal government agency responsible for all media of communications in Canada.)*

Farinon Canada Ltd., Dorval, Quebec. *(Analog and digital microwave radios.)*

Gandalf Data Ltd., Ottawa, Ontario. *(Data communications products.)*

Global Thermoelectric Power Systems Ltd., Bassano, Alberta. *(Thermoelectric power products.)*

Hermes Electronics Ltd., Dartmouth, Nova Scotia. *(Antennas and other communications equipment.)*

Idacom Electronics Ltd., Edmonton, Alberta. *(Data communications test equipment.)*

Memotec Data Inc., Montreal, Quebec. *(X.25 communication processors and multiplexers.)*

Mitel Corp., Kanata, Ontario. *(PABX switching systems, work stations, telephone handsets.)*

Northern Telecom Ltd., Mississauga, Ontario. *(Manufacturers of complete line of telephone utility and subscriber equipment.)*

Novatel Communications Ltd., Montreal, Quebec. *(Cellular mobile telephone systems.)*

Spar Aerospace Ltd., Ste. Anne de Bellevue, Quebec. *(Satellite and aerospace systems.)*

Spillsbury Communications Ltd., Vancouver, British Columbia. *(Specialized radio equipment.)*

SR Telecom Inc., St. Laurent, Quebec. *(Urban and rural subscriber radio systems.)*

Teleglobe Canada, Montreal, Quebec. *(Crown Corporation responsible for overseas communications services.)*

Hugh C. McIntyre, the author of this report, is a technical writer based in Toronto who has covered developments in computers and communications over the last 20 years.

Art direction, supervision of text and illustration and coordination of production were provided by Camp Associates Advertising Limited, Toronto.

Around 5,000 years ago, Sumerian messages were written on clay tablets. Some even came with their own clay envelope.

"...the globe has contracted spatially, into a single large village."

Marshall McLuhan
The Gutenberg Galaxy

In ancient times, a message could travel only as fast as the messenger.

Today, thoughts and words are flashed around the globe electronically, at the speed of light.

Teleglobe Canada carries oversea messages to and from Canada, allowing Canadians to trade information with people in more than 80 countries as easily as with their next door neighbours.

Behind this ease of communication is a vast system of satellites and undersea cables linking the continents. Teleglobe Canada operates the Canadian part of this sophisticated system, providing telecommunications to the four corners of the earth.

Teleglobe Canada

Bringing people and continents together

Six Millenniums of Buffalo Kills

At a site in western Canada named Head-Smashed-In, Indian hunters slaughtered buffalo by stampeding the herd over a cliff. They started in 3700 B.C. and continued until well after the white men had come

by B. O. K. Reeves

According to many early 19th-century accounts and illustrations, the Indians of the Great Plains of North America hunted buffalo by riding them down on horseback. The implication is that these peoples were not successful buffalo hunters until some time after Europeans introduced horses into North America in the 16th century. Archaeological work in the wide grasslands east of the Rocky Mountains contradicts this assumption. From the time the first Paleo-Indians entered the region some 10,000 years ago, they were redoubtable hunters even though they hunted on foot. Mammoths were the game they favored at the start, and when those great beasts became scarce, they turned to hunting two different species of buffalo: the large, straight-horned *Bison antiquus* and the smaller *Bison occidentalis,* both now extinct. The Paleo-Indians' successors on the plains continued to hunt buffalo on foot, and as a communal enterprise.

Here I shall describe what has been unearthed at one such communal bison-hunting site, 130 kilometers south of Calgary at the southeastern edge of the Porcupine Hills in western Alberta. There the Piegan Indians of historical times and their predecessors have been stampeding buffalo to their death over a cliff for at least 5,600 years and possibly as long as 9,000. As with other "buffalo jump" sites in Canada and the U.S., the topography of the site favored group stalking and stampeding of buffalo herds. In their language the Piegan call the place Head-Smashed-In.

The cliff the hunters used as a jump is a sandstone outcrop that had weathered and collapsed over the centuries so that a talus slope of detached sandstone slabs and smaller fragments built up along its foot. Today the vertical drop from the cliff edge to the top of the slope measures between nine and 10 meters. Westward, back from the edge of the cliff, the valleys of six tributaries to a central stream, Olsen Creek, occupy a shallow basin, some 36 square kilometers in extent, rimmed by a continuous highland area except where Olsen Creek leaves the basin. More than 500 cairns, rock piles about a meter in diameter and a third of a meter high, still mark paths as much as eight kilometers in length along which the communal hunters drove the buffalo to the cliff.

The talus slope below the cliff was not formed by erosion alone. Most of its bulk is the result of the detachment from the cliff face and subsequent downhill movement of two separate massive blocks of sandstone. The first of these block falls, called slumps by geologists, came in about 3700 B.C. and the second at about the start of the Christian Era. It is difficult to estimate how high the cliff stood above the talus after the first slump, but even after the second it was nearly twice as high as it is today.

Stampeding buffalo over the edge of a cliff was not the only hunting method pursued by the Plains Indians of the fourth millennium B.C. To judge by the archaeological evidence and by Piegan practices in historical times, the buffalo were sometimes driven into bogs, arroyos and box canyons and even into corrals or pounds built by the hunters for the purpose. The first white man to visit Piegan country, a Hudson's Bay Company trader named Peter Fidler, left a vivid account of pound drives he witnessed at Stimson Creek in December, 1797. "Our Chief is the Pound Master," Fidler wrote, "and whenever a herd [of buffalo] comes into the pound he must go & kill the first one. He generally shoots his one with a gun. The young men kill the rest with arrows, bayonets tied upon the end of a pole &c. The hatchet is frequently used & it is shocking to see the poor animals thus pent up without any way of escaping.... Some with a stroke of an axe will open nearly the whole side of a buffalo & the poor animal runs some times a considerable while all thro' the pound with all its internals dragging on the ground & trod out by the others."

In the course of a six-week stay at the pound, which measured 30 by 45 meters, Fidler estimated that the Piegan had trapped and butchered more than 250 buffalo. They could have taken more, he wrote, except that "when the wind happened to blow from the pound in the direction of the tents, there was an intollerable stench of the great number of petrified [*sic*] carcasses, &c on which account the reason of our leaving it."

Junius B. Bird of the American Museum of Natural History was the first professional to dig at Head-Smashed-In, but the results of his work in 1938 were never published. In 1949 Boyd Wettlaufer, then a graduate student at the University of New Mexico, ran test trenches both into the talus slope and at a campsite some 18 meters below the jump where the prime parts of the slaughtered buffalo had been carried for more detailed butchering. The Province of Alberta erected a cairn at Head-Smashed-In to commemorate his investigation, which was thought to be the first in Alberta. The cairn only attracted illicit excavators. Their appetite was further whetted by the news of an excavation in 1958 at a nearby jump site, "Old Women's," where the remnants of hunting activity had accumulated to a depth of more than seven meters and the earliest strata dated back to the first century A.D. By 1964 robbers had stripped the surface of Head-Smashed-In over an area of 1,400 square meters, digging pits as big as two meters in diameter and three meters deep.

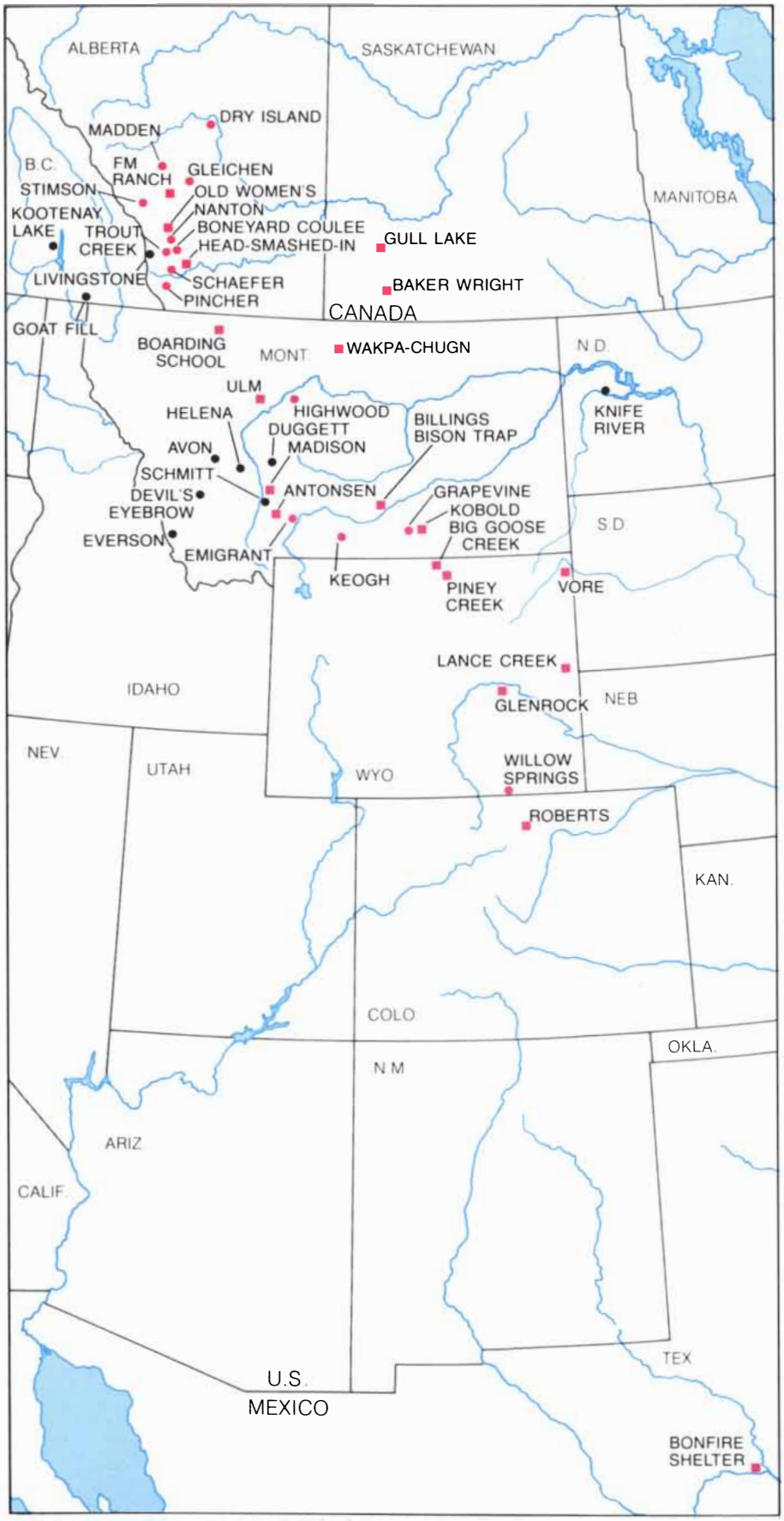
With the integrity of the site in jeopardy the Glenbow-Alberta Institute and the University of Calgary joined forces to mount a major rescue effort over two seasons (1965–66). In the three months of the first season my associates and I worked mainly on the south part of the talus, opening up an area three by six meters in extent. At a depth of eight meters the area was reduced to a shaft 1.5 meters square, which was continued to 11 meters. Below the eight-meter level the shaft passed through a two-meter stratum of sterile fill before we encountered further traces of buffalo hunting. The reduced dimensions of the shaft

kept us from acquiring either bones or projectile points at this lowest level in quantities adequate for establishing phases of occupation and dates. The more plentiful material from the eight-meter level, however, dated back to about 1000 B.C., and we were confident that the bottom strata would prove to be considerably older.

In the second season our main effort was concentrated on the talus some 100 meters to the north of the 1965 shaft. One of the excavation units opened there, three by three meters in area, was excavated to a depth of four meters before slump-block sandstone was reached. The bottom stratum—a layer of sand, gray gold in color, from half a meter to one meter thick—held a bed of buffalo bones. Carbon-14 analysis of the protein collagen from the bones yielded an age determination of 3710 ± 100 B.C. Associated with the bones were side-notched projectile points that, although they were made from local stone, are typical of those first found some years ago at a Wyoming site known as Mummy Cave, 850 kilometers to the south.

The earliest slump block, which underlies the oldest bone strata in both the northern and the southern areas of the talus slope, consists of a 10-foot thickness of sandstone. Canadian government geologists, who helped us with our excavation in the 1966 season, trenched down to buried soils that had washed out from under the block. In the outwash they came across simple cobble tools and butchered buffalo bone. Both because of the depth of burial and be-

PRAIRIE VISTA occupies the middle distance in this view of the southeastern edge of the Porcupine Hills in Alberta. The diggers in the left foreground are members of the author's party who examined a Plains Indian buffalo-jump site here. The Indians who killed the buffalo made some of their stone points and knives out of pebbles and cobbles of chert and quartzite unearthed from the prairie's glacial till. Other tools, however, were made from exotic stones such as chalcedony brought from the Rocky Mountains, seen on the horizon.



GREAT PLAINS OF NORTH AMERICA are the scene of numerous buffalo-hunting sites discovered by archaeologists in recent years. They date from about 8000 B.C., in Paleo-Indian times, to post-Paleo-Indian periods that include the arrival of European settlers. Excavated and unexcavated buffalo-jump sites in Canada and the U.S. are respectively indicated by colored squares and dots. The sources of the kind of stone used to manufacture points and other tools by the occupants of the Alberta jump site, Head-Smashed-In, are indicated by black dots.

cause of the instability of the geologists' trench our group could not exploit their find. The geologists' deep trenching did not yield enough buffalo bone for carbon-14 analysis, and so the exact antiquity of these strata, evidently the lowest at Head-Smashed-In, remains undetermined.

One possible clue to their age comes from a chance discovery by Wettlaufer in 1948. Among the surface finds in his single season's work was a Paleo-Indian projectile point. It had evidently been an inclusion in soil dredged up during the construction of a water reservoir for the cattle that now graze the area. If the point, unmistakably of the Paleo-Indian tradition named the Cody Complex, was originally associated with outwash from under the earliest slump block, then Head-Smashed-In may have been a buffalo jump as long ago as the sixth millennium B.C.

In order of decreasing age the cultural debris we unearthed in our two seasons' work (and in an additional month's work at the site in 1972) provides a record of consistent although not continuous use of the buffalo jump from at least 3700 B.C. until the beginning of the 19th century A.D. Let me summarize the archaeological evidence for the use of the site by four successive prehistoric cultures and for its final use by the buffalo-hunting Piegan of modern times. To flesh out the bare bones of the archaeological record I shall comment on what the artifacts tell us about exchange networks and possible shifts of population over the same period, starting with the presence at the site of members of the Mummy Cave culture between 3700 and 3100 B.C.

Two preliminary notes, one climatic and one geologic, will be of help in interpreting what follows. First, studies of paleoclimate have established that the time between roughly 5500 and 3000 B.C., known as the Altithermal, was a period when conditions were generally drier and somewhat warmer than they were either before or after. Because the prairies are semiarid even today, it has long been thought that the earliest Americans would have shunned the plains in this period of even greater aridity. Such was apparently not the case. Quite apart from the early evidence at Head-Smashed-In, cultural debris has now been found at various Wyoming box-canyon buffalo-trap sites that date between 4700 and 4000 B.C. and belong to the Mummy Cave cultural tradition. Other evidence that the Altithermal was not a period of inactivity on the prairies comes from sites in Crowsnest Pass in the Rockies, 90 kilometers west of Head-Smashed-In. There a series of buffalo kills, accomplished by stampeding the herds into boggy ground, have been dated from 5200 to 2800 B.C.: a span of time that extends from the late Paleo-In-

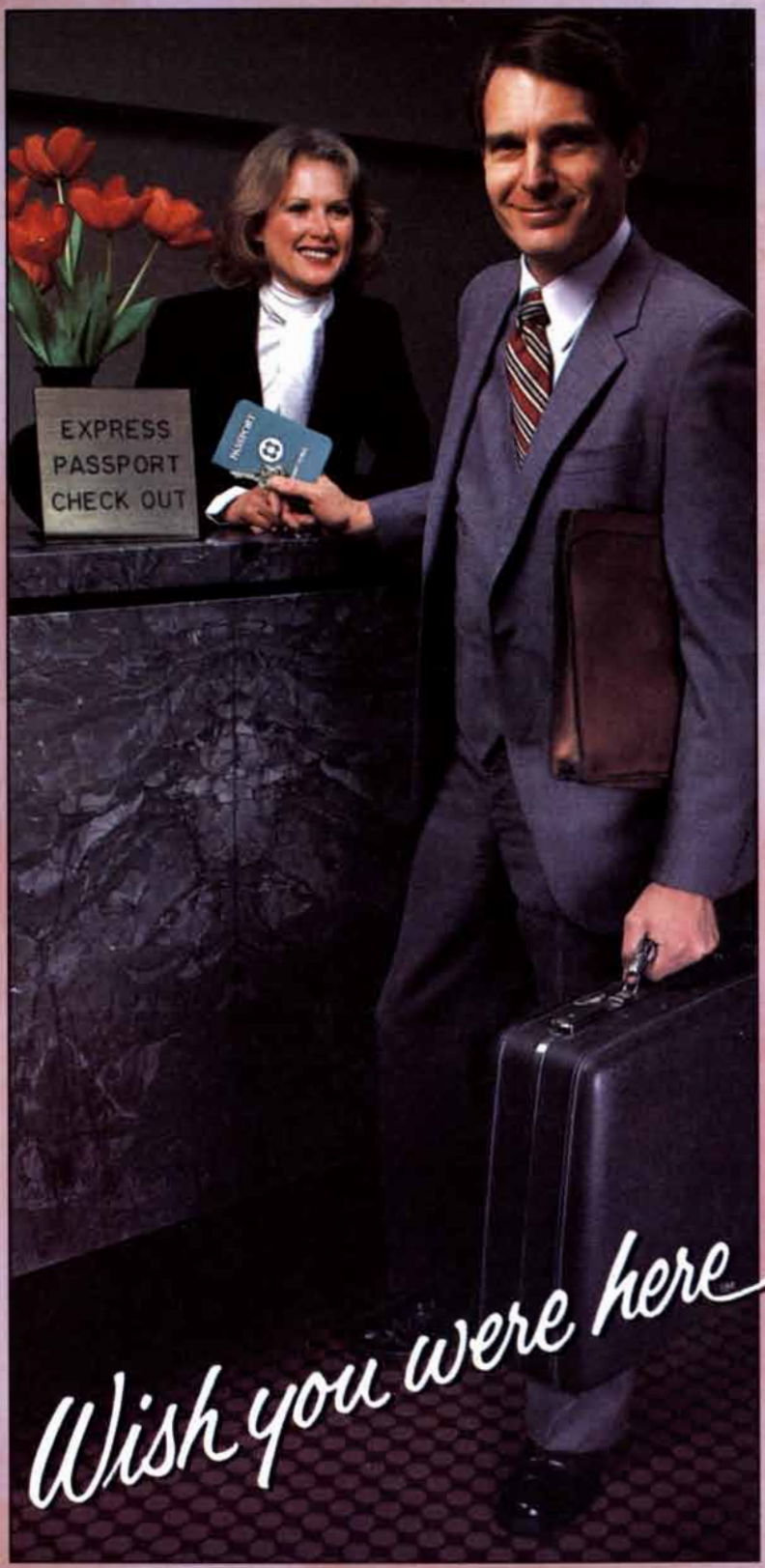
Why we make checking out of a Hyatt just as pleasant as staying at one.

The way we figure it, we give you so many extra touches at Hyatt, it would be a pity to have a long check-out line spoil them for you.

That's why when you check out of a Hyatt you simply hand in the passport you received when you checked in. You're checked out. Your bill is mailed to you within 24 hours, so there's absolutely no waiting in line. Absolutely no way you can forget how pleasant your stay was.

Any hotel can give you the essentials, but it's those extra touches ... like express check-out, that make the trip.

For reservations at 109 hotels worldwide, call your travel planner or 800 228 9000.



Boston Overlook the Boston skyline from the Hyatt Regency Cambridge.

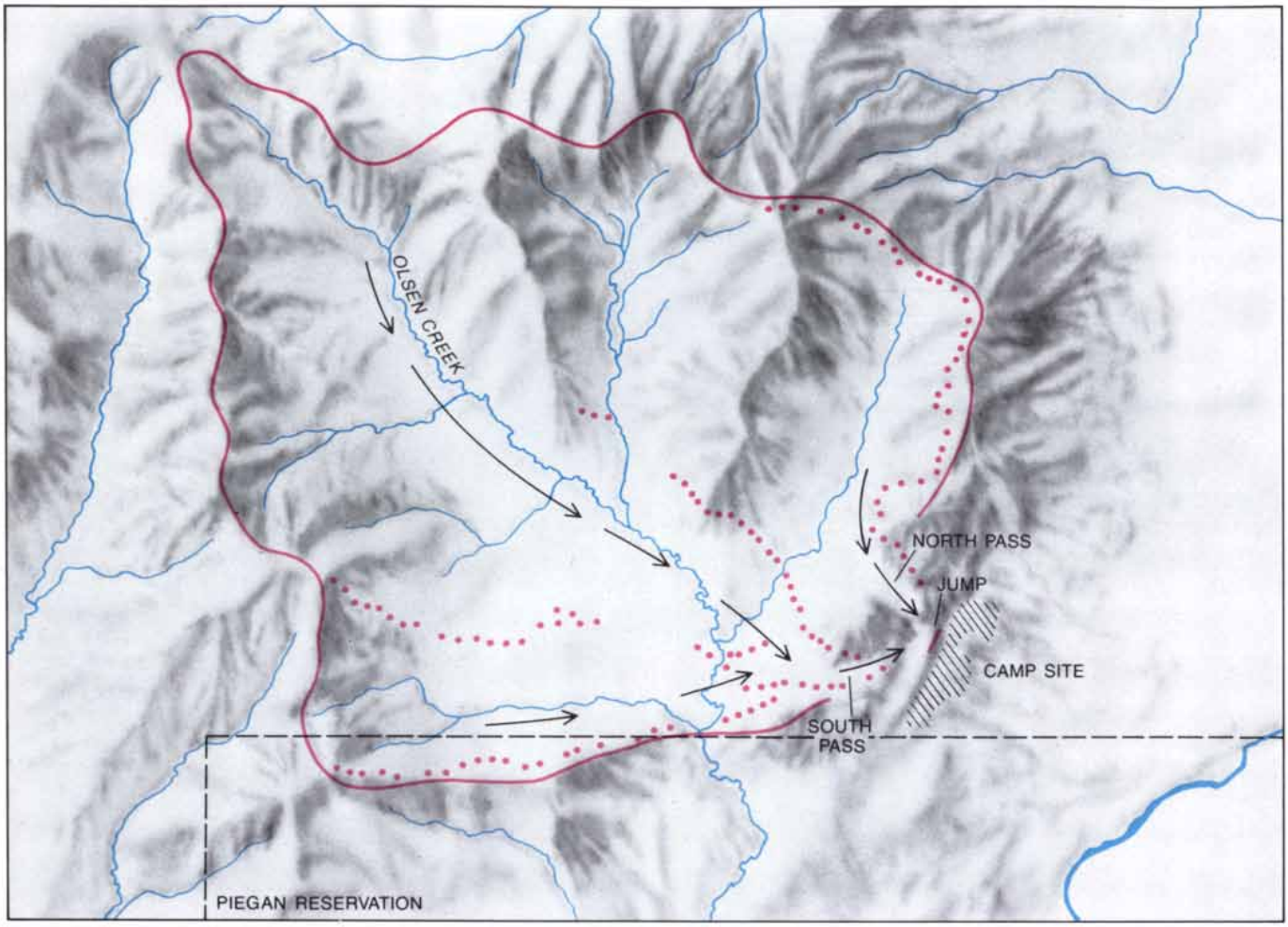
Chicago In Illinois Center overlooking Michigan Avenue and Lake Michigan.

Washington, D.C. Hyatt Regency Crystal City is the closest hotel to National Airport.

Princeton Two miles from Princeton University, midway between Philadelphia and New York City.

Washington, D.C. Walk to Capitol Hill, government agencies, art galleries and museums.

HYATT HOTELS®



HIGHLAND BASIN leading to the cliff-edge jump-off at Head-Smashed-In covers an area of 36 square kilometers where the valleys of six streams tributary to Olsen Creek provided natural runways (*arrows*) for the stampeding buffalo. The rows of cairns helped the stampeders to keep the buffalo aimed toward their jump point (*color*), which was 20 meters above the talus slope in the second century A.D.

dian period, before the Altithermal began, to 200 years after present climatic conditions had returned to the prairies.

The geologic note may surprise those who know the Great Plains as a generally featureless flatland. So they are, flat as a pancake if one neglects the terrain associated with stream erosion, occasional hilly sections and the prairie mountain ranges. The flatness, however, is the product of the Pleistocene glaciation that mantled the preglacial landscape with a thick cover of glacial till. The till is virtually a pudding of potential raw material for stone tools: quantities of quartzite and chert cobbles and pebbles. Moreover, at least in southern Alberta, the Cretaceous bedrock that underlies the till contains quartzite and chert conglomerates, moderate amounts of petrified wood and in one formation (the Bearspaw shale) quantities of black chert pebbles. Flint quarries in the Knife River area of North Dakota are another well-known source of tool material. They yield a honey-colored flint that was much sought after and widely traded.

The Rockies that form the western boundary of the prairies offer both similar and quite different kinds of tool material. High-quality cherts are common, but so are beds of metamorphosed siltstone and nodules of chalcedony. The most distinctive tool materials of all from the region are obsidians. Most of them came from the area that is now Yellowstone National Park, and Yellowstone obsidian was traded to as far away as sites of the Hopewell culture east of the Mississippi.

So much for the background. To return to the people of the Mummy Cave phase at Head-Smashed-In, they used local quartzite as the raw material for their projectile points. They prepared stone cores from quartzite cobbles, struck blanks from the cores and reworked the blanks into projectile points that were bifacial (worked on both sides) and notched at the sides. The size of the points suggests they were mounted on the kind of dart shaft that was propelled by a hand-held throwing stick (called by the Aztecs an atlatl). The Mummy Cave people also struck large, irregularly shaped flakes from quartzite cobbles, but evidently they fashioned very few of the skinning knives characteristic of succeeding cultures; we found only one. They were also not much interested in exotic tool materials. Only 1 percent of their points were made of imported stone: chert from Montana.

Overlying the four strata left by the Mummy Cave people was a sterile layer of talus wash and windblown sand that ranged in thickness from a little more than half a meter to nearly two meters. A mature grassland soil had developed on the top of this layer, suggesting that the buffalo jump had not been in active use for some centuries. Above the sterile layer were a series of bone beds with a total thickness of one to two meters. With one anomalous exception, the carbon-14 dates for these strata ranged from 1090 ± 120 B.C. at the bottom to A.D. 25 ± 80 at the top. All four strata represented a well-known buffalo-hunting culture of the northern plains and Rockies known as Pelican Lake after a site in southern Saskatchewan.

Among the buffalo bones were characteristic Pelican Lake projectile points, which are notched at the corners. They had been made from bladelike flakes struck off conical or polyhedral cores of good-quality chert. The Pelican Lake

COLORTRAK

PALE BY COMPARISON.

That's how a conventional 19-inch TV measures up against this ColorTrak 2000. RCA's remarkable new ColorTrak 2000 model #FJR2020W puts 25" of picture (measured diagonally) into the same space as conventional 19" sets. And along with 70% more picture, this new ColorTrak comes with a combination of exclusive RCA features: 58-function Digital Command Center remote control, high-compliance speakers, 127-channel tuning (including cable) and RCA's advanced detail processor, which delivers a picture that appears almost 3-dimensional. See your RCA dealer for a demonstration. And see 25" of picture that sits in 19" of set. Beautifully.

For more information and a free copy of the "Living with Video" book ($2.50 retail value), write: RCA Consumer Electronics, Department 32-312L, P.O. Box 1976, Indianapolis, Indiana 46206.

WE'LL OPEN YOUR EYES.

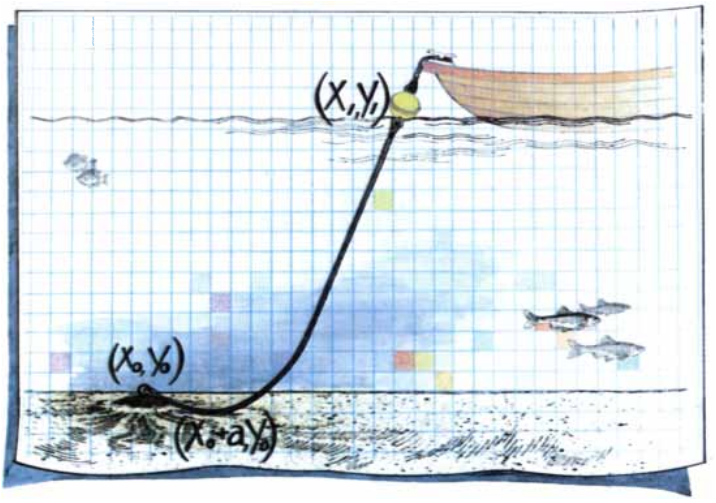
RCA

TWO THOUSAND

The Texas Instruments Because y(x)=(1/k) co

Home Computer. sh [k(x+a)]+b.

Whether it's beginning math or this catenary equation, the TI-99/4A Home Computer gives you real power to solve real problems.



The problem: A 100-foot-long cable, whose weight is 0.67 pounds/foot (corrected for buoyancy) is used to secure a mooring buoy to an anchor in 30 feet of water in a flat-bottomed lake. Determine the horizontal and vertical force components at the anchor and buoy when the buoy is displaced horizontally 92 feet from the anchor. If any of the cable lies on the bottom of the lake, find the distance from the anchor at which it breaks away from the bottom. When the cable is unconstrained (i.e., not touching bottom), the equation of the catenary is $y(x) = (1/k)\cosh[k(x+a)]+b$. See the computer screen below for the solution.

A true home computer should be user friendly to every family member, novice or professional. It takes power to do it.

That's what makes the TI-99/4A Home Computer the one to choose. It's a powerful package designed around our 16-bit TMS 9900 microprocessor. And it contains a lot of fully usable memory – 16K RAM and 26K ROM, plus up to 38K more ROM in each solid state cartridge.

With TI's BASIC system built into ROM, it doesn't use up Random Access Memory (RAM). Others, who load their operating systems into RAM, can use up half their memory before you even get started.

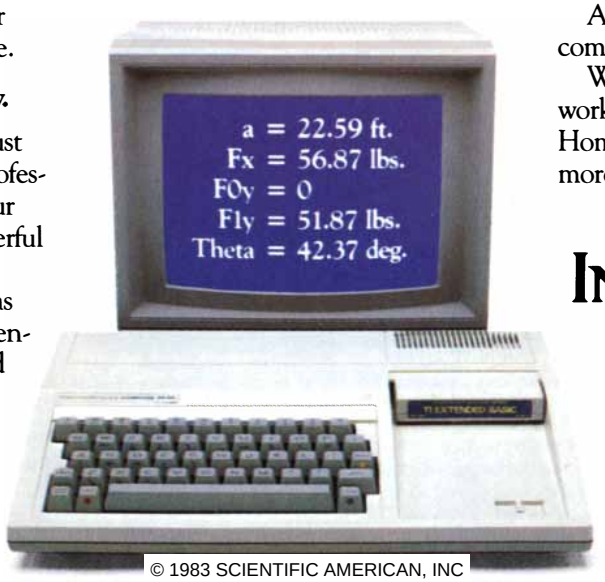
The result is that the TI Home Computer performs highly sophisticated computing tasks as easily as it teaches third grade math. For the money, no other computer is better suited for technical or scientific use.

Greater arithmetic accuracy.

Our unique 16-bit processor is just like the one found in expensive professional computers. Coupled with our rich TI BASIC, or still more powerful TI Extended BASIC, it makes our scientific programming capability as good as that provided by many scientific languages for mainframes, and better than some.

We give you 13-digit accuracy, and number range spanning $1x10^{\pm 127}$. All other home computers, using 8-bit processors, limit you to 6 to 9 digits, and only $1x10^{\pm 38}$ range. It's a big difference. And it means you can solve problems on the TI Home Computer which aren't feasible on the others.

TI BASIC also gives you more powerful commands and better flexibility for naming variables, since it recognizes up to 15 character descriptive names. Some others recognize only the first two significant characters in names, which means they can't tell the difference between "TAX" and "TARIFFS." So you have to resort to confusing acronyms.



The TI Home Computer is fluent in seven languages.

You can choose languages for all programming levels, from built-in TI BASIC to TI Extended BASIC, TI LOGO II, UCSD Pascal,* TI PILOT, TI FORTH and our powerful TMS 9900 Assembly Language.

You can also write useful non-scientific programs with the TI Home Computer. It's the only one in its price range that lets you combine 16-color graphics, single-command animation, sound effects, music, and speech with unlimited vocabulary into the same TI BASIC program.

And only TI's home computer comes with a 1-year warranty.

Whatever kind of problem you're working on, work it out with the TI Home Computer. You can't find more computer for the money.

TEXAS INSTRUMENTS

Creating useful products and services for you.

*UCSD Pascal is a trademark of the Regents of the University of California.

SANDSTONE CLIFF at Head-Smashed-In stands about 10 meters above the talus slope at the southeastern edge of the Porcupine Hills, a region of rolling terrain. The Plains Indians of the culture named Mummy Cave may have been the first to drive buffalo herds over the cliff to their death on the slope below. Three other groups of buffalo hunters, including the predecessors of the Piegan Indians, who gave the site its name, used the jump thereafter. The trenching on the slope, to the right of center, was done by the author and his associates in 1965 when the Glenbow-Alberta Institute and the University of Calgary began an investigation of the site.

MAIN TEST AREA was a three-by-six-meter shaft, to the right of center, that was pinched down to a narrower shaft at a depth of eight meters. The material from the shaft, which eventually reached a depth of 11 meters, was brought to the surface by means of the improvised crane seen in action here and screened for its contents. Buffalo bones from the eight-meter level, when they were dated by carbon-14 analysis, proved to be about 3,000 years old. Objects from the bottom of the lower shaft, however, were too few to yield a culture identity or a date.

people, unlike their predecessors, had a taste for exotic tool materials. Their knives (large bifaces), their scrapers and their smaller retouched flake tools were made from Rocky Mountain cherts and chalcedonies, Yellowstone obsidian and the honey-colored flint from the Knife River quarries in North Dakota.

Some of the projectile points from the Pelican Lake strata have stems rather than being notched at the corners. These too were made from an exotic raw material: metamorphosed argillite from the Kootenay Lake area of British Columbia some 800 kilometers west of Head-Smashed-In. Both their source and their alien shape suggest that visitors from Kootenay Lake occasionally participated in the Pelican Lake people's buffalo drives.

One attribute the Pelican Lake people had in common with their predecessors was the use of the atlatl in hunting. Both whole and broken atlatl projectile points were found among the buffalo bones. The bases of broken points, however, were uncommon, suggesting that atlatl dart shafts with projectile tips broken off were usually retrieved and taken back to camp for rehafting. Such retrieval makes sense; an atlatl dart shaft, larger than an arrow shaft and probably made with far greater care, is the critical element in the atlatl ballistic system, just as the bow is in the bow-and-arrow system. As will be seen, once bows were substituted for atlatls, the bowman hunters considered arrows and their arrowheads expendable.

The second cliff-face slump took place in about A.D. 100. In the southern section of the talus massive chunks of sandstone buried themselves in the uppermost Pelican Lake stratum. To the north an entire section of cliff, ranging from 15 to 21 meters in thickness, fell a distance of 12 meters, rotated and then slid down along the tilted bedrock, pushing some of the overlying Pelican Lake strata downhill ahead of it. Although buffalo driving appears not to have been seriously interrupted by the catastrophe, the northern half of the talus slope was little used thereafter. The initial impact of the slump block had left a deep depression; the hunters exploited it as a natural corral, driving the buffalo over the cliff so that most of the dead and maimed animals ended up in the hollow. Among the buffalo bones that had accumulated there we encountered arrowheads for the first time.

The distinctive small points for arrows usher in the Avonlea phase at Head-Smashed-In. The phase takes its name from a site in Saskatchewan, and the Avonlea people were sophisticated buffalo hunters, equally adept at driving the animals over a precipice or herding them into a corral. The culture may have evolved from the Pelican Lake

Buick's leather-bound classic.

Space permitting, we could write a book about the 1984 Riviera: the independent rear suspension, the front-wheel-drive technology, the computer-monitored chassis, and much more.

But in spite of all the rational, high-tech reasons to admire Riviera, there's another, more time-honored factor.

Because Riviera is a classic. With the unmistakable flair of top-down motoring in genuine hand-fitted leather-trimmed seating.

And, of course, items such as air conditioning, power seats, and automatic level control are standard.

Coupe or Convertible, buckle yourself into a genuine classic, at your Buick dealer.

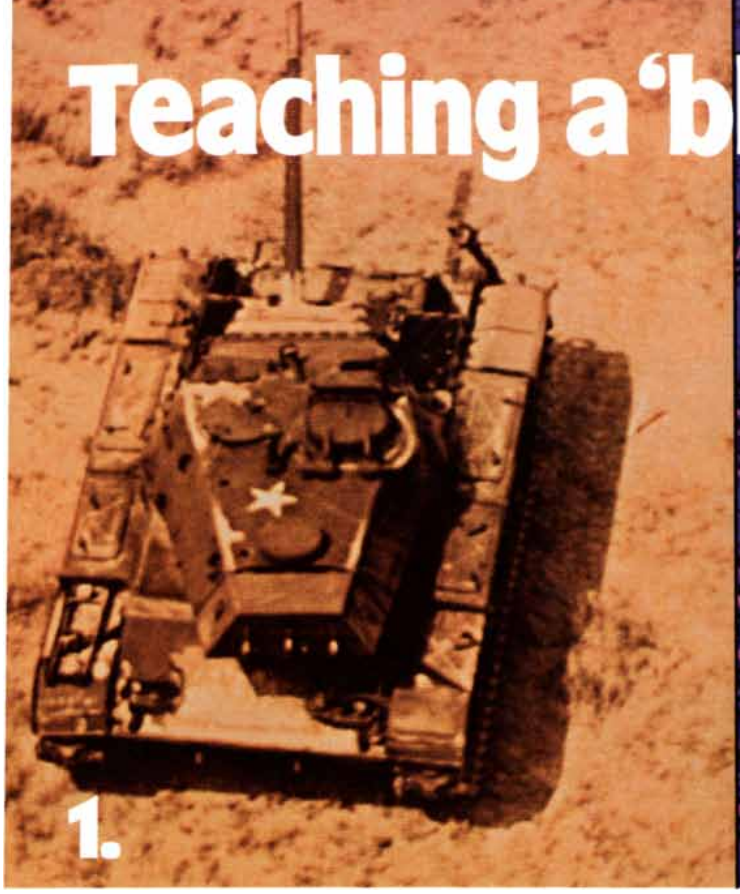
Official Car of the XXIIIrd Olympiad
Los Angeles 1984

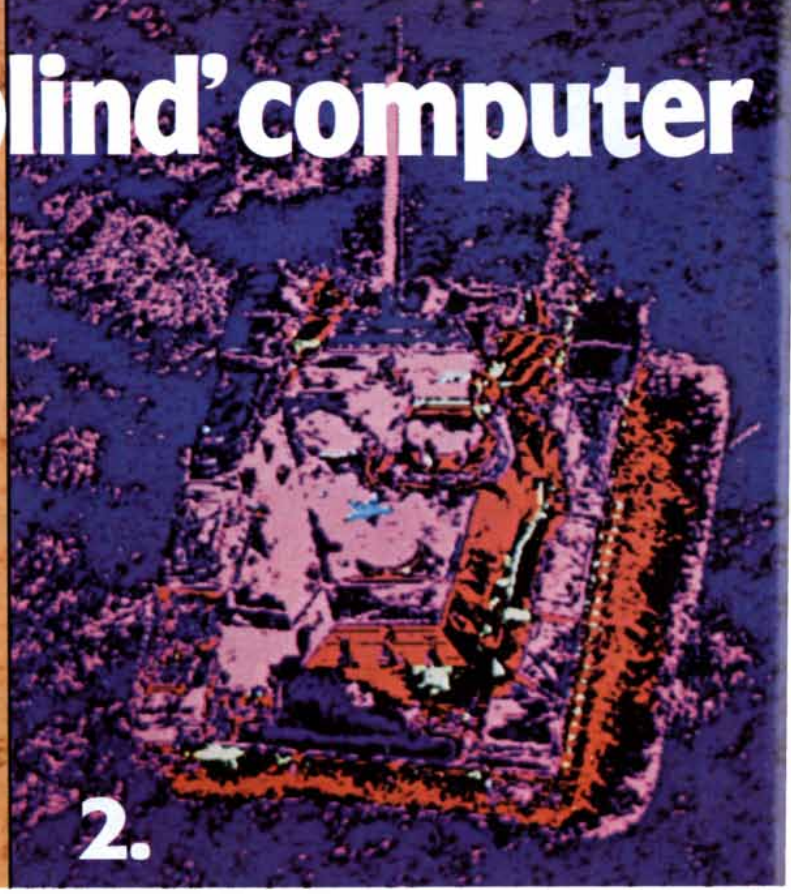
BUICK

Wouldn't you really rather have a Buick?

Some Buicks are equipped with engines produced by other GM divisions, subsidiaries or affiliated companies worldwide. See your Buick dealer for details.

Teaching a 'blind' computer





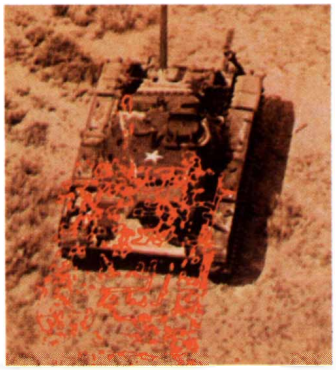
Lockheed knows how.

One of the growth technologies of the future is computerized image processing.

It's a vital technological thrust. More and more, industry, medicine, science and defense are making use of huge numbers of images gained from many sources—radar, infrared, acoustic, television cameras.

Until recently, most images have been analyzed or compared only by specialists. But now, computers are being taught to "read/understand" and make decisions about torrents of images that would otherwise swamp the human eye and brain.

"The tanks just moved."



The orange lines, which are offset from the original image of the tank, are part of the recognition technique that shows the tank has moved.

This can be critical input to a threatened commander, and he needs it almost instantly.

A reconnaissance aircraft or satellite carrying a sensor such as a television camera or radar would make the discovery. The sensor's images then are converted into electrical signals and sent to a computer, where they are stored as arrays of numbers. Computer programs manipulate the numbers until the tanks are "recognized." An enhanced image showing the tanks can be reconstructed and displayed for the commander.

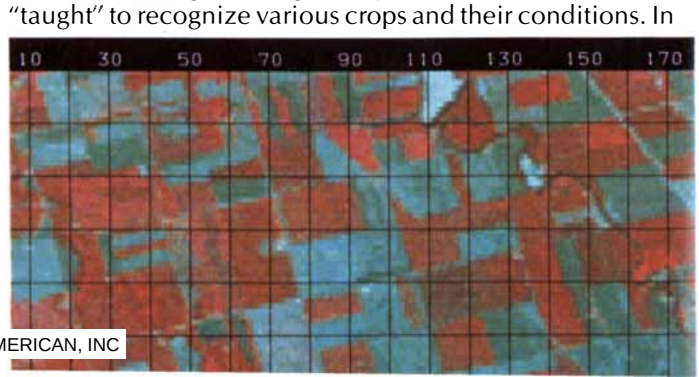
But a computer, unlike a human being, has to be given a mathematical description in advance to know what a tank looks like. The sensor, covering everything it sees, sends a staggering volume of signals. So the computer must be "trained" to eliminate unimportant images and concentrate on significant ones . . . for example, to look for the tanks that were spotted yesterday to see if they moved.

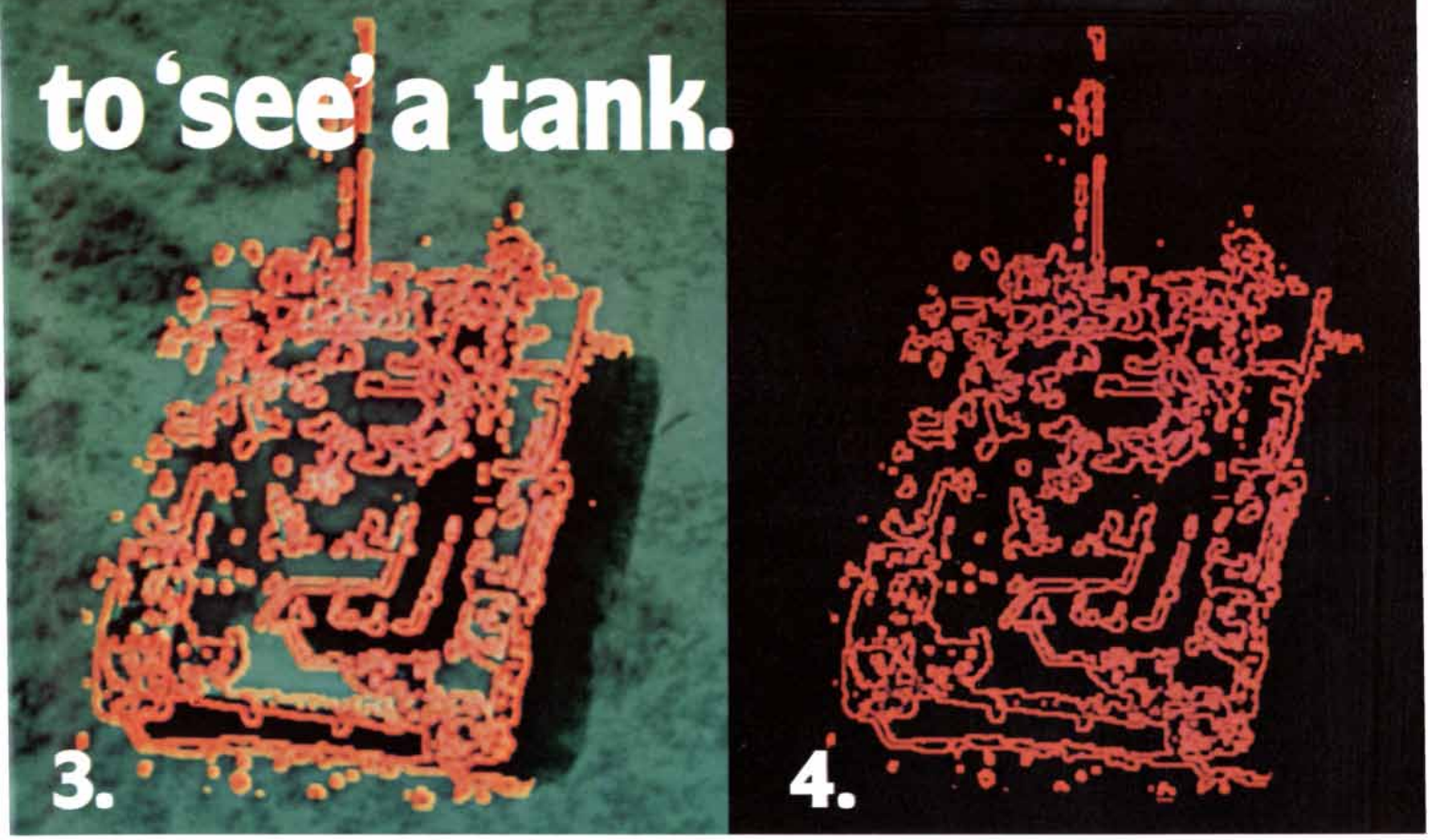
This is not just laboratory theory. Lockheed teams right now are training computers in this automated image understanding, or "computer vision."

How big is the wheat crop?

Identifying wheat from corn from sagebrush or other growth is another triumph of computerized image processing.

The photo here came from a Landsat satellite. The red color, assigned by a computer, indicates wheat. Bare ground, plowed ground, and stubble are in shades of green. Working with NASA, Lockheed scientists, engineers and mathematicians have developed techniques to process huge numbers of images through computers, which they have "taught" to recognize various crops and their conditions. In





To the human eye, a tank looks like the picture in Frame 1. But to a computer, the picture is simply a large array of numbers stored in its memory. It has to process that data to "recognize" the tank. In Frame 2, it analyzes light intensities of the picture. In Frame 3, it manipulates its stored data to identify edges of the tank. And in Frame 4, it has eliminated background and now has abstract edges and shapes from which it can proceed to recognize the tank.

use today, this valuable technology enables Lockheed to determine the size of world crops.

Navigating by images.

How do you navigate an unmanned vehicle when an inertial guidance system is too expensive?

One way is with an image-based system being developed by Lockheed.

Like a human pilot, the computerized system will "read" numbers of cues, like woods, ridges, and hills. It will recognize a lake, for instance, even when iced over or shrunken by drought. With this input, along with other data such as airspeed and compass readings, the computer will weigh all its information and initiate accurate navigational orders.

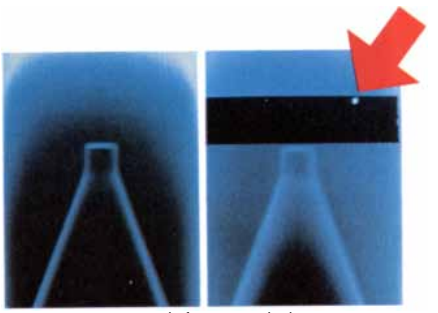
Lacking human eyes that can tell a lake from a hill, the computer will rely on mathematical descriptions of topographic features. These descriptions, involving such features as edges or brightness contrasts, will "teach" the computer to read and react correctly to the three-dimensional world.

Automating X-ray inspection.

Detecting subtle differences or flaws shown by X-ray photographs has traditionally been a slow, tiring job for human specialists, particularly in industry.

But now Lockheed has developed an Automatic X-ray Inspection System—AXIS—that examines X-rays by the thousands, at great speed. It converts X-ray images into numbers and compares the results against established norms, thus isolating defects. With quick, tireless repeatability, it makes accept/reject decisions and records the data on magnetic tape.

First developed for the defense industry, AXIS can be easily adapted to medicine and other industries. It will be increasingly important in applications where large numbers of images or articles must be checked fast for subtle, critical variations.



Arrow points to a defect revealed in an AXIS X-ray image of an artillery shell casing.

Image processing: the future.

If a system of sensors and computers can recognize instantly the movement of tanks or scan the ground below to guide an unmanned vehicle, cannot more advanced systems be developed to guide surgeons as they operate? Cannot systems such as AXIS lead to immense improvement in the quality of American products?

Great as have been the advances in image processing, it is a field only now coming into its own, and Lockheed knows how to develop this emerging technology.

Lockheed

EXCAVATOR WITH TROWEL works to expose additional buffalo bones in the east area of Head-Smashed-In during the 1972 season. Jaw fragment and rib cage have been cleared.

PROCESSING PIT in the campsite adjacent to Head-Smashed-In was used to boil the fat out of buffalo marrowbones. A buffalo hide, lining the pit, was filled with water heated by dropping into it stones that had been baked in a campfire. The fat, ladled out of the pit and allowed to congeal, was the base for pemmican: a mixture of foodstuffs that could keep for months.

complex itself. At least the first Avonlea arrowheads at Head-Smashed-In are corner-notched ones made of chert obtained from the Pelican Lake quarries in Saskatchewan. The evolution, if such it was, did not take place at Head-Smashed-In and its vicinity. Of all the points we recovered from the lowest Avonlea strata, points for atlatl darts make up less than 1 percent of the total.

The Avonlea people are the first among the plains populations to have adopted the bow and arrow for hunting. They acquired the new weapon through contact with fishing people in the interior of British Columbia, who in turn had learned about bows and arrows from Indians of the Northwest Coast whose bowmanship was by then 1,000 years old. At Head-Smashed-In the Avonlea people drove buffalo in such numbers over the cliff edge that the natural corral left behind by the slump came to hold a thick bed of bones. In the lowest part of the three- to four-meter Avonlea deposit, which is dated at about A.D. 110 ± 90, Avonlea arrowheads were numerous. Many of them were unbroken; others were represented only by the tip of the head or by the base of the head and its haft. Evidently the Avonlea bowmen made no particular effort to retrieve their arrows after each stampede, perhaps because many arrow shafts would be broken when the falling buffalo hit the ground.

The Avonlea people imported very little Yellowstone obsidian and no chert at all from the Montana mountain quarries as raw material for their arrowheads and other stone artifacts. Instead they brought chert of exceptionally high quality in from British Columbia and from other sources that are as yet unidentified. In any event, working with imported chert, the Avonlea craftsmen turned out the finest stonework seen on the Great Plains since the time of the Paleo-Indians, some 8,000 years earlier. Their arrowheads, made from small blades struck from conical cores, are extremely thin and were delicately flaked into final shape. Other distinctive Avonlea tools included skinning knives, end scrapers, small flakes and wedges, the latter perhaps serving to split buffalo leg bones for their marrow. At first the exploitation of local stone was confined to heavy-duty implements for chopping, hacking and smashing, but as time passed the Avonlea toolmakers came to depend more and more on Great Plains stone.

The upper Avonlea levels, which are dated at about A.D. 850, differ in character from the lower ones. Here the massive lens-shaped deposits of buffalo bone are heavily charred and in some instances completely calcined. Above them lie a final series of bone beds, 2.5 meters deep, associated with the last

When it comes to superior performance, we study our lines very carefully.

Superior printer performance is not a fluke. It evolves from analyzing printed line after printed line. Taking the time to test and retest. After 30 years of manufacturing precision parts, we know that there are no shortcuts.

And so we took the Gemini-10X and methodically put it through its 120 cps pace. We achieved a print head life of over 100 million characters with an extremely precise dot alignment creating each crisp character.

So far so good.

Next, sophisticated performance demanded versatility. A wide choice of character sets, a buffer expandable to 8K, and the ability to interface with all popular personal computers. We added macro instruction, giving Gemini-10X the capability to perform up to 16 operations with one command. We included as standard a paper feed system that has a friction and fully adjustable tractor feed. Then we even built in the dexterity to print graphics and text on the same line.

Done.

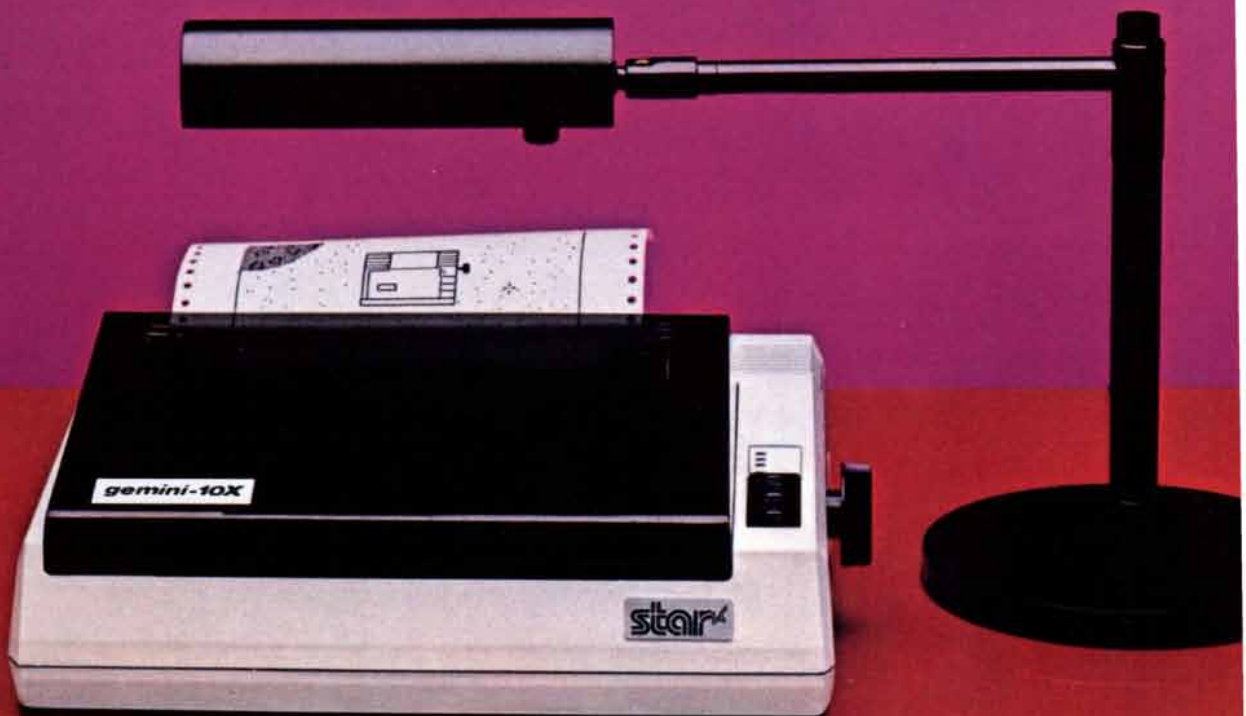
And, of course, staying the best means constant reviewing and fine-tuning. Keeping the Gemini easy to find, easy to afford and so reliable it can be warranted for up to twice as long as its major competitors.

Only the most careful engineering has built the new hard-working Gemini-10X. You'll applaud its performance.

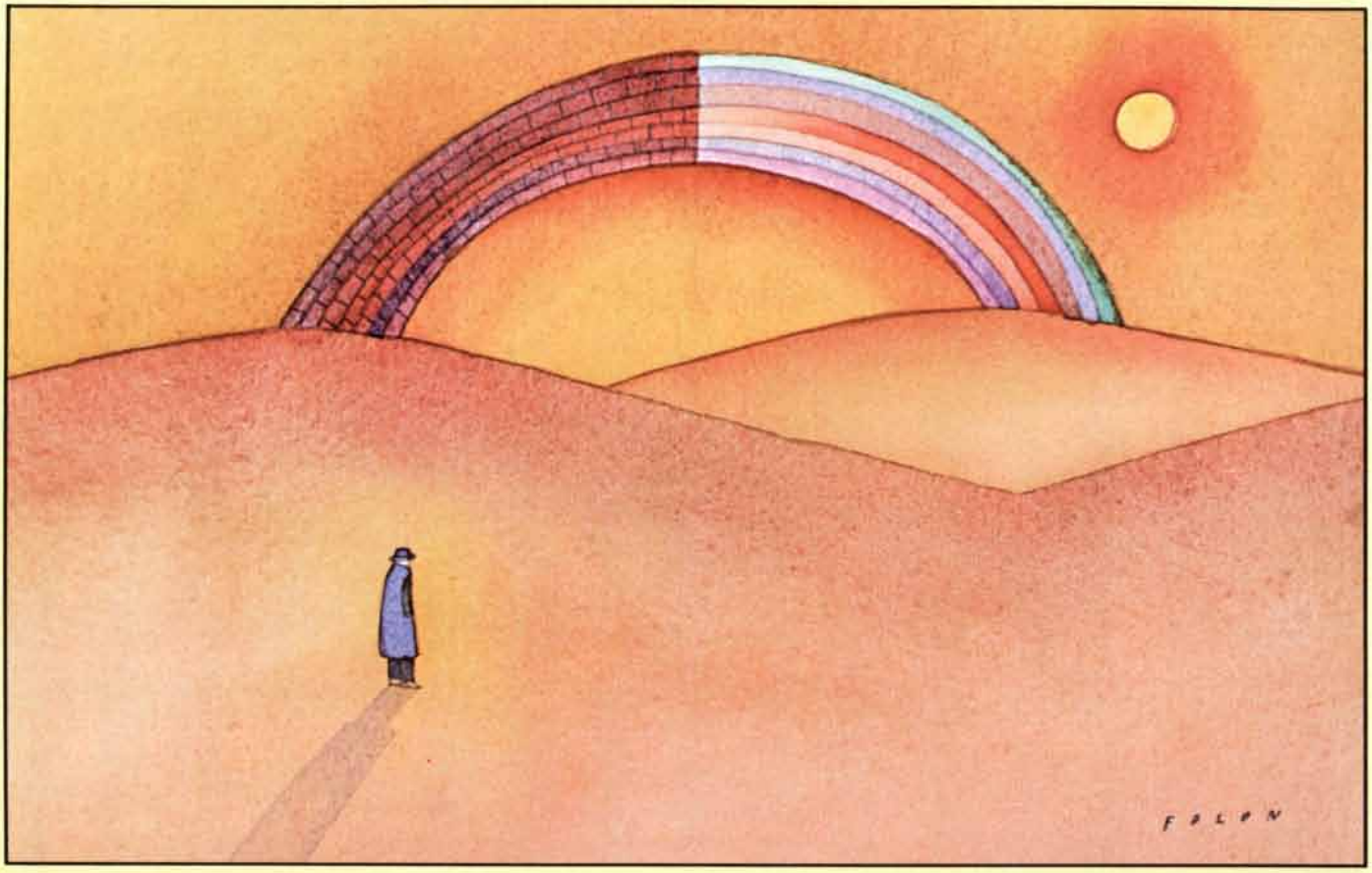
star™ micronics·inc

THE POWER BEHIND THE PRINTED WORD.

Computer Peripherals Division
2803 N.W. 12th Street, Dallas/Ft. Worth Airport, TX 75261



ENERGY OPTIONS
The Practical and The Promising



The energy crises of the 1970's jolted America into greater awareness of alternative energy development. Some of the alternative sources being explored today will play an increasing role in the years to come. The question is, how much will the new alternatives be able to supplement our major energy sources?

Although overall energy demand in the U.S. dropped slightly over the last decade, the use of electricity actually rose more than 20 percent. This electrification trend has gone on throughout the century and is expected to continue. The United States Department of Energy recently reported that "the economy is very likely to turn increasingly to electricity for its energy requirements."

As this reliance on electric energy continues to grow, *all* the resources that can generate electricity are being examined. Some of the alternatives are discussed here. Others, like fusion and ocean thermal energy conversion, may play a role in the more distant future.

Sun, wind, earth, and water

SOLAR. In some respects, solar energy has begun to pay off. For the heating of water, solar systems are now economically competitive in some regions of the U.S. with plenty of sunshine. Also, there are new buildings benefiting from "passive" solar designs. They utilize the sun through nonmechanical means such as skylights and heat-storing rock beds.

For the generation of electricity, however, solar technologies are in early stages of development. Although some limited uses are being made, solar electricity is still too expensive for widespread practical use.

One possible system is the solar-thermal electric station, or "power tower." A small solar-thermal plant in the Mojave Desert uses a large field of mirrors to track the sun and focus its heat onto a centrally mounted steam boiler that drives a turbine-generator.

Another solar electric technology is photovoltaics. It uses silicon or other semiconductors to convert the sun's rays directly into electricity. Researchers are working on increasing the efficiency and reducing the high costs of photovoltaics.

WIND. Wind power, like many alternative energy sources, depends on geography. It is most promising in the Great Plains, in mountain passes,

and along coastal areas, where winds are strong and steady.

Some of the larger wind projects have had problems. But they are being addressed, and utility companies today are involved in well over 100 wind-power research projects. California's Energy Commission has

Reliability and strength of the wind play an important role in the location of "wind farms" like this one in Altamont Pass, east of San Francisco. Wind generators are spread over hundreds of acres of land.

predicted a wind-power potential of 1000 megawatts for the state by the year 2000, if current trends continue. That's the equivalent of one major electric power plant, or approximately 2 percent of the state's present electrical capacity.

GEOTHERMAL. The internal heat of the earth is another energy source. Geothermal energy is captured from hot water or steam created by hot or molten rock. 1300 megawatts of geothermal electric capacity are now available in this country, mostly in California.

HYDRO. Falling water generated almost 14 percent of the nation's electricity last year. Most U.S. sites for large-scale hydro projects are already in use, but there is potential for further development of low-head or "minihydro": the use of small and medium-sized dams, either newly built or upgraded. By 1985, there may be about 400 new small-scale hydro projects, largely in the Northeast. Like other energy sources, though, hydro has limitations. These include the environmental changes that can be caused by damming a river, as well as the uncertain reliability of power that is fed by rain and snow.

BIOMASS. This term refers to a wide variety of fuel sources, including plant and animal waste, wood, algae, and garbage. The largest user of biomass in the U.S. today is the forest products industry, which gets about 50 percent of its energy from wood wastes. Another form of biomass is methane gas produced from decaying organic materials.

Energy sources we can count on today

Some of our important energy options involve not new production technologies but more efficient ways of delivering and using energy. So conservation methods, including industrial cogeneration, will also help meet our energy needs.

With all of America's energy alternatives, it's easy to forget how much of our electric power will still be generated from conventional fuels. The Department of Energy projects that by the year 2000, over 80 percent of the country's total electricity generation will still come from the abundant domestic resources of coal and uranium.

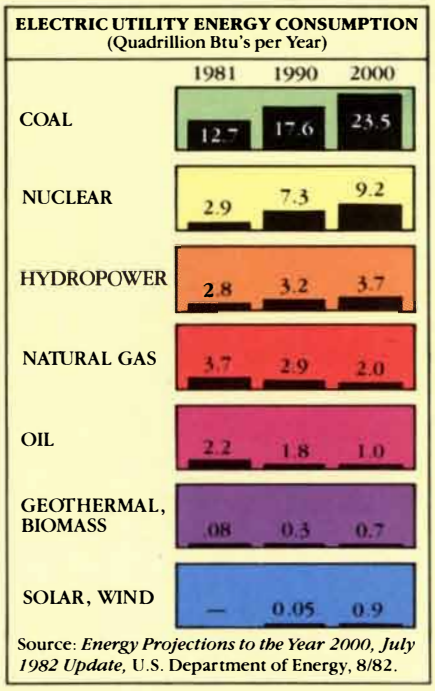
Oil and natural gas are more valuable fuels for transportation and manufacturing than for burning in power plants. Also, these fuels, especially oil, are subject to uncertainties over price and future supply.

On the other hand, we have enough coal to last hundreds of years. Coal will remain our dominant

We have enough coal in the U.S. to last hundreds of years. It is estimated that by 1990, electric utilities will be burning over 780 million tons of coal a year to supply more than half of America's electricity.

source of electricity. And advanced technologies such as coal gasification and fluidized-bed combustion are creating new ways to burn coal cleanly.

To secure a well-balanced supply of energy, America is also relying on nuclear power. Aside from the 80 plants already generating nuclear electricity in the U.S., 56 more have been granted construction permits by



The Department of Energy foresees sizable growth for both nuclear energy and coal in this country's electrical future.

the U.S. Nuclear Regulatory Commission. And they are being built.

A steady and secure supply of electricity is critical for a healthy economy. Some of the alternative energy sources discussed here may eventually become significant contributors to America's electrical supply, depending on what part of the country you live in. Some may not. Whatever the future holds, we need to take advantage of the domestic energy resources already within our reach. We need to understand not only the electricity potential of tomorrow, but the electricity realities of today.

For a free booklet on *Energy Options* and the electrical future of America, send this coupon to:
U.S. Committee for Energy Awareness
P.O. Box 37012
Washington, D.C. 20013

NAME _____

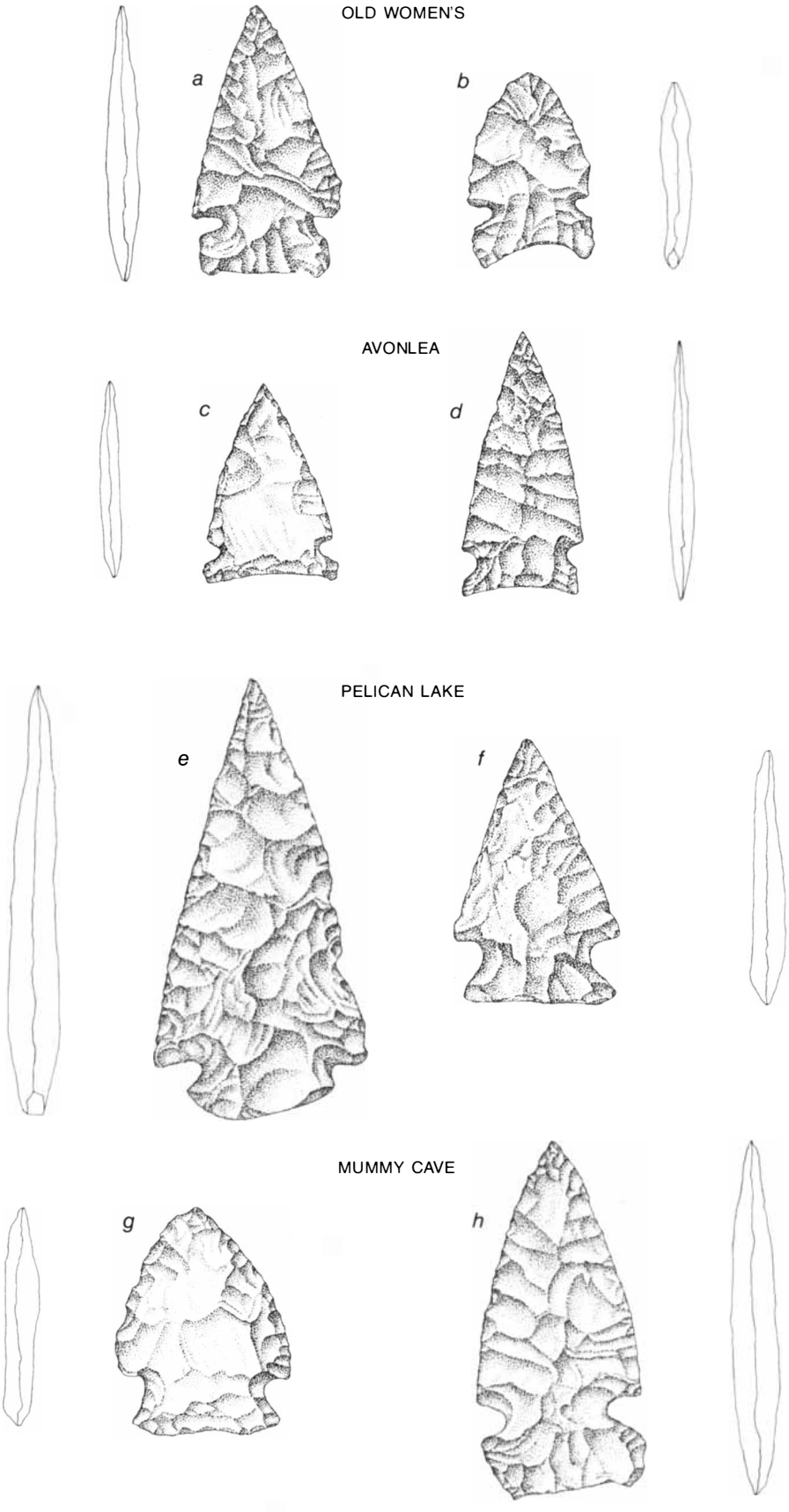
ADDRESS _____

CIT _____ STATE _____ ZIP _____

325

Information about energy America can count on today

U.S. COMMITTEE FOR ENERGY AWARENESS



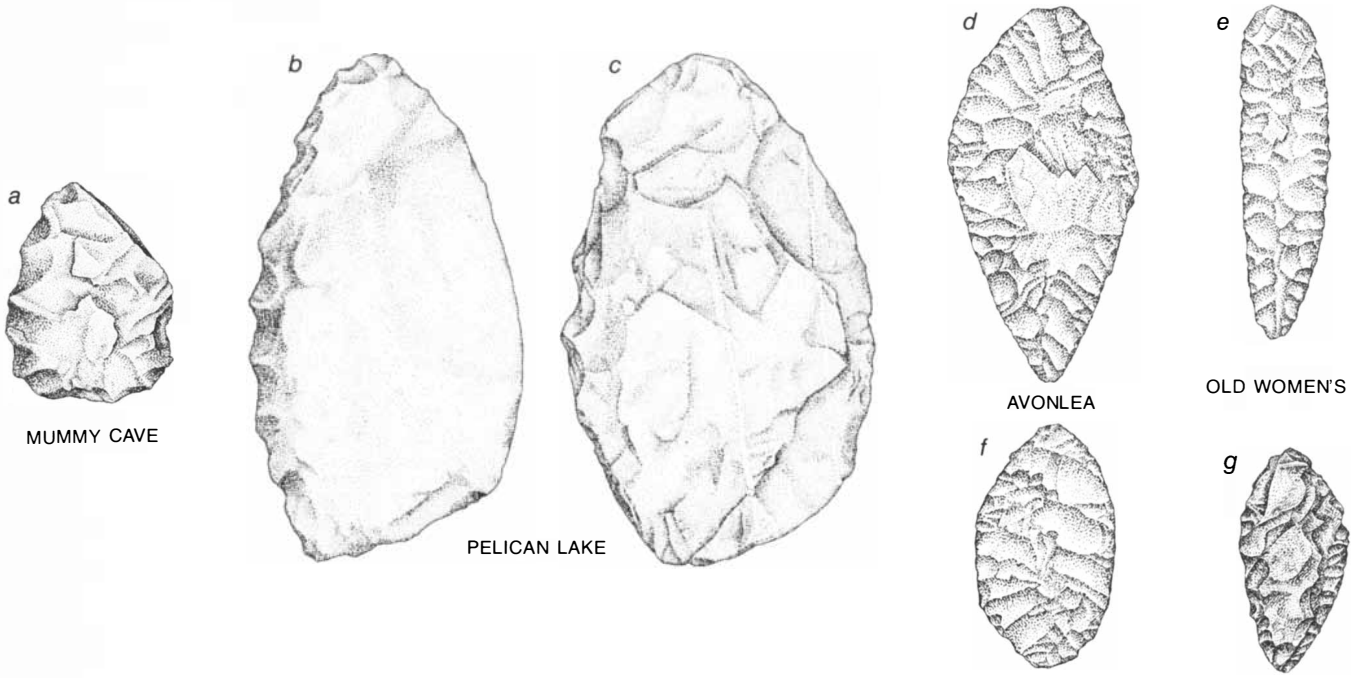
EIGHT PROJECTILE POINTS from the four phases uncovered at Head-Smashed-In appear in profile and edge on. The lower four (*e–h*) are points for atlatl darts; point *e* is obsidian. The upper four (*a–d*) are arrowheads; the atlatl, a dart-launching stick, was replaced by the bow at the start of the Avonlea phase at the site. The flaking done by the Avonlea people was the best on the plains following the end of the Paleo-Indian period. Point *d*, an obsidian piece, is a good example of Avonlea workmanship; it can be compared with point *a*, which, although it too is obsidian, has a much rougher finish. All the points are shown enlarged 50 percent.

culture phase at Head-Smashed-In: Old Women's. The name is that of the nearby site excavated in 1958. This phase extended from A.D. 850 to the historical present (A.D. 1800), or shortly after Peter Fidler's contact with the Piegan at Stimson Creek, 80 kilometers to the northwest. It is probable that the Old Women's people were prehistoric Piegan and that their culture was a further evolutionary stage of the preceding Avonlea phase. The transitional strata between the two show a gradual change in arrowhead style and in other stone technology.

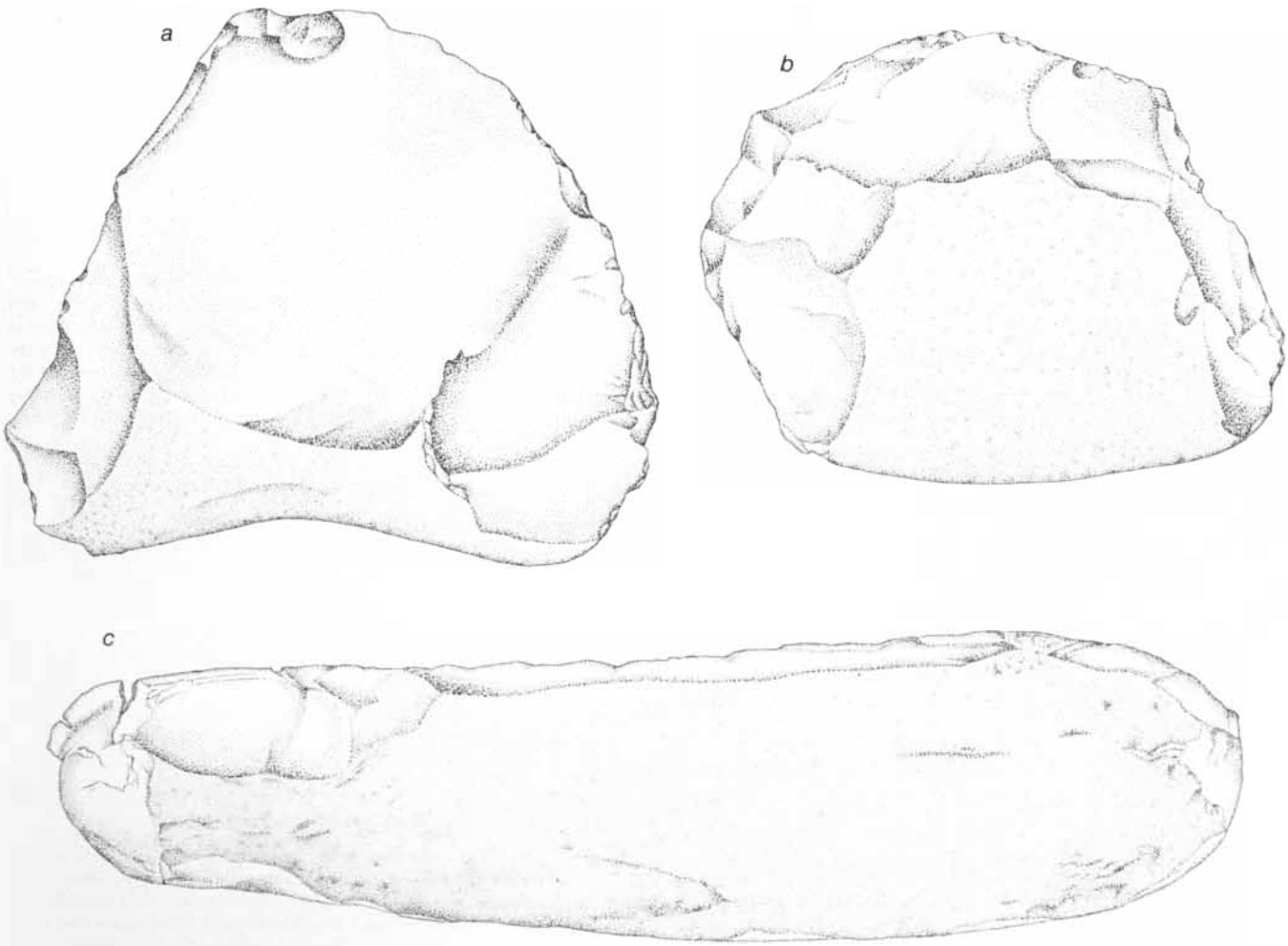
The Old Women's phase is characterized by small, side-notched arrowheads, cigar-shaped skinning knives hafted sideways into wood or bone handles, end scrapers and wedges, all made from local pebbles of chert. The Old Women's people, like their predecessors, also made use of large quartzite cobbles and flakes as choppers, bone-smashers, and anvils and hammers for striking flakes from small chert pebbles to make arrowheads and knives. Their workmanship in the early phase was not as fine as that of the Avonlea people, a fact that may be attributable at least in part to their reliance on local cherts of indifferent quality. They even made a few artifacts out of petrified wood. Near the end of the Old Women's phase, however, the toolmakers reduced their dependence on Great Plains raw materials and imported Yellowstone obsidian and porcellanite from southern Montana. A third exotic material, often used in earlier Head-Smashed-In phases, the distinctive honey-colored Knife River flint, was rarely exploited by the Old Women's craftsmen.

The buffalo-bone beds of the Old Women's phase varied considerably in composition. The one-meter strata of the lower deposits include lenses of charred bone among the unburned and well-preserved buffalo skeletons. Overlying this lower deposit was a stratum of charred and uncharred bone, buffalo horns and decomposed hair and hide, mingled with the contents of the animals' intestines, including feces. The final strata, 1.2 meters deep, contained well-preserved bones, unmarked by fire, in a powdery red orange matrix composed of decayed hide and hair. We found European trade goods—metal arrowheads—in the uppermost stratum and recovered a musket ball from its surface. On the basis of trade goods found here and at the nearby campsite we assigned to the upper part of the deposit a date of about A.D. 1800. The Old Women's deposit is topped by a layer of sandstone rubble, the remains of an unsuccessful 19th-century effort to establish a sandstone quarry at the site.

The campsite area, a broad, flat glacial bench 18 meters below the talus



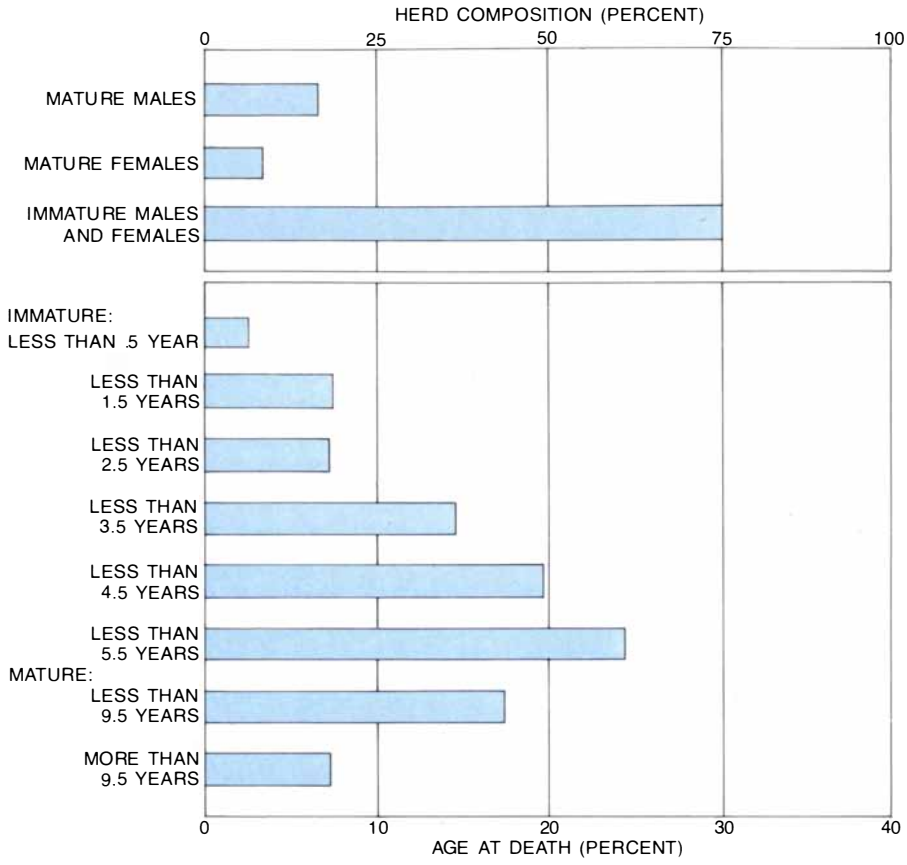
SEVEN KNIVES representative of the phases at Head-Smashed-In are shown at four-fifths actual size. The number of knives from the site is low compared with the number of projectile points; the Mummy Cave strata included only one (*a*). Both the Avonlea and the Old Women's knives are more refined in flaking than the earlier ones. Old Women's knives were fitted into a wood handle along one edge.



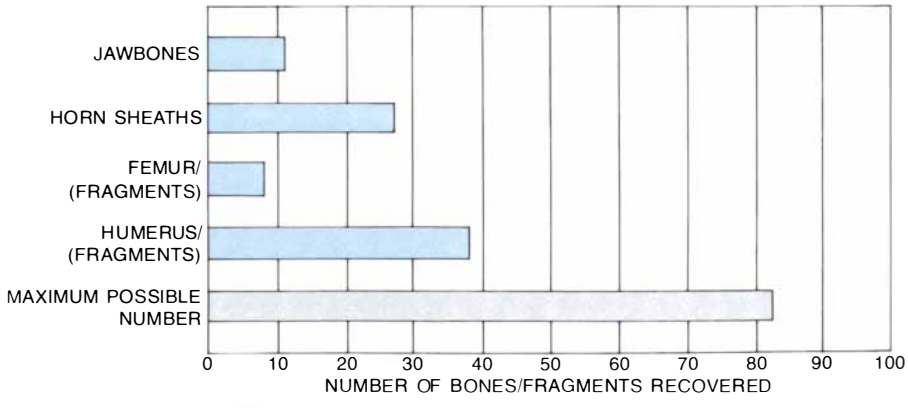
HEAVY STONE TOOLS, made chiefly from quartzite found in the local glacial till, included flake choppers (*a*) and cobble choppers (*b*). The choppers were left mostly unmodified. Both kinds of tools were probably used more for breaking bones than for chopping meat. The evidence of wear on the clublike tool (*c*) suggests that it too was used to break bones. All three tools are shown at two-thirds actual size.

slope, is six and a half hectares in extent. Most of its present surface is mantled by a thin scatter of refuse: butchered bones, cracked rock hearths for cooking fires and miscellaneous artifacts. The preferred camping area was evidently the south end of the bench, upwind of the kill area. Here we uncovered a midden of bones, cracked rocks and artifacts associated with the final butchering of different parts of the slaughtered buffalo. Within the midden the principal artifacts were numerous heavy stone tools.

If historical accounts of Piegan buffa-



COMPOSITION OF BUFFALO HERD is based on an analysis of one bone bed at Head-Smashed-In (Avonlea North 2*B*), where the bones represented 41 individual buffalo. As the upper graph indicates, they were predominantly immature. The estimated age at death, as is shown in the lower graph, places seven of the animals in the fully mature category and only three in old age (more than 9.5 years old). Seven others were less than 2.5 years old and 24 were between 2.5 and 5.5 years old. Because buffalo cows usually calve in May, the animals must have been killed between four and five months later: from mid-September to late October.



PRESERVATION OF BONES in the same Avonlea stratum, North 2*B*, shows that, as was the later practice, Avonlea hunters carried many parts of the slaughtered buffalo away from the kill site for further butchering. The presence of 41 individual animals was established by the analysis of teeth. If the carcasses had been undisturbed, 82 horns, 82 jawbones (upper and lower) and 82 front and rear upper-leg bones should have been found (*bottom bar*). Fewer than half that number of horns and only 11 jawbones were recovered. The number of femur (rear upper-leg bone) fragments was only eight. There were, however, 38 humerus (front upper-leg bone) fragments, suggesting that these bones were used less than femurs as a source of marrow.

A ripple never stops.

It goes all the way to the edge of the water. And then comes back. Every time you reach out from yourself, you make a bright new one. U.S. Swimming and U.S. Diving are a chance for thousands of young people to find that you can reach even farther than you thought. And make ripples of your own. And every time you make a ripple, it touches everyone around you.

PHILLIPS 66

Phillips Petroleum has sponsored United States Swimming for eleven years, and United States Diving for five, helping with operating costs of national and international competitions leading to world championships. We continue to support them. Because their ideals touch the lives of everyone.

How you can tell

They're both IBM Personal Computers. And they're the same. Only different.

The system that's on the left is the ideal solution for a person who wants to be creative, efficient and improve his or her personal productivity.

So is the other one.

The system on the left incorporates the quality, the reliability and the technological excellence that have made IBM a computer leader for over 30 years.

So does the other one.

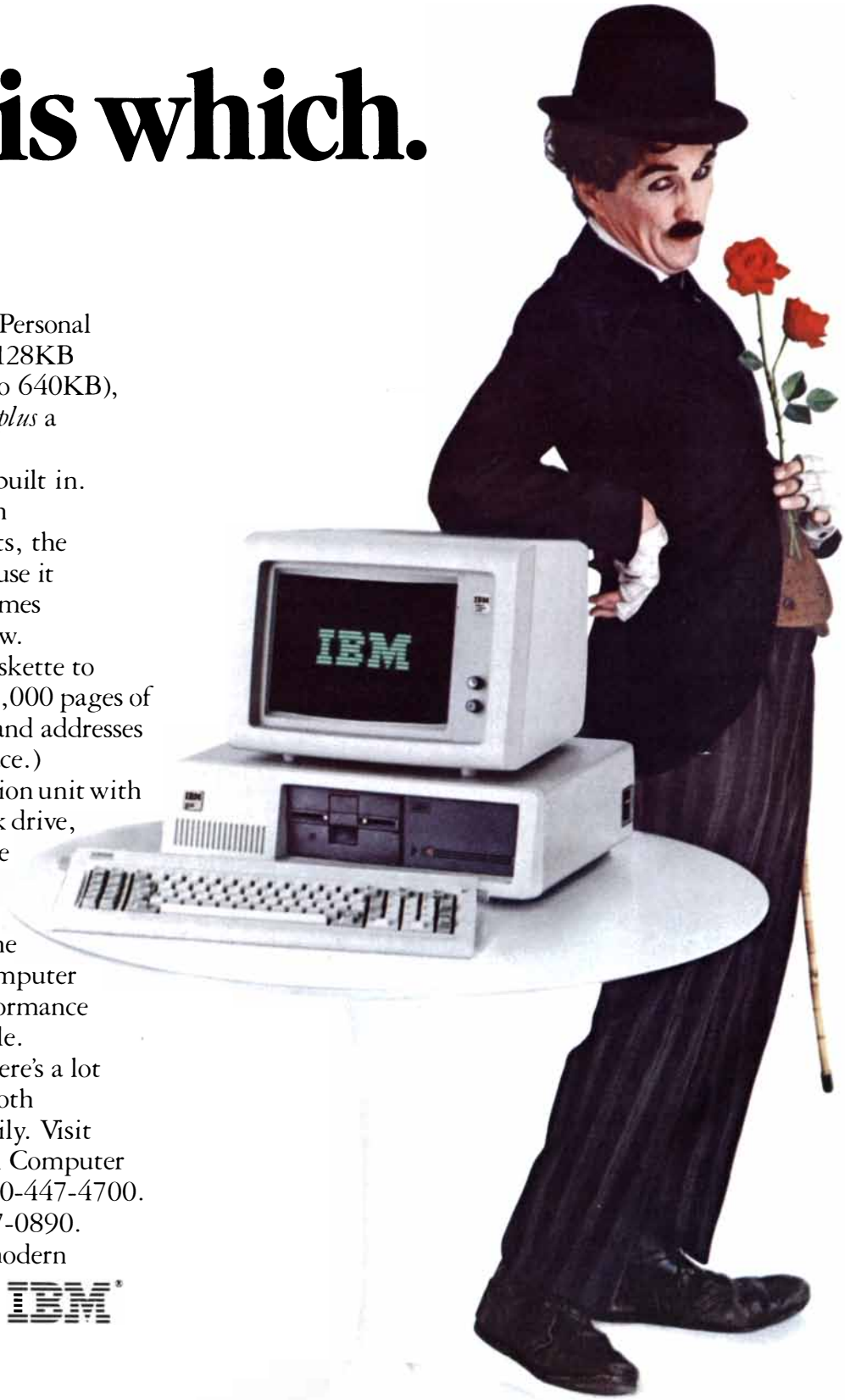
So which is which? Simple.

On the left is the IBM Personal Computer, starting with 64KB of user memory (expandable to 640KB) and two optional 5¼" diskette drives. It can easily satisfy your computing needs at the office, at home or in school. With 5 expansion slots, it gives you room to grow. (You can even make it function like the computer shown on the right by adding an expansion unit that houses one or two 10-million-character fixed disk drives.)

This system can run most of the same software and accept most of the same IBM hardware as the computer on the right. And its price/performance is nothing less than remarkable.

The IBM Personal Computer

which is which.



On the right is the IBM Personal Computer XT, starting with 128KB of user memory (expandable to 640KB), a 5¼" 360KB diskette drive *plus* a standard 10-million-character fixed disk drive that's *already* built in.

For a businessperson with heavyweight data requirements, the XT packs a lot of power, because it can store the facts, figures, names and numbers you need to know.

(Instead of going from diskette to diskette, you can have up to 5,000 pages of text or up to 100,000 names and addresses conveniently stored in one place.)

And by adding an expansion unit with a *second* 10-megabyte fixed disk drive, you get even more high-volume capacity from the system. XT can run most of the same software and accept most of the same IBM hardware as the computer on the left. And its price/performance is nothing less than remarkable.

But for you to choose, there's a lot left (or right) to learn about both members of this growing family. Visit your authorized IBM Personal Computer dealer. To learn where, call 800-447-4700. In Alaska or Hawaii, 800-447-0890.

And see which tool for modern times is right (or left) for you. IBM®

The IBM Personal Computer XT

The experts have had a lot to say about the new Thunderbird.

"Thunderbird is a head turner."
Washington Business Journal, March 1983

And that's not what's best about Thunderbird's design. Its flowing lines help reduce lift on both the front and rear for excellent traction and stability, so Thunderbird's look actually helps the way it drives. It also has one of the lowest drag coefficients of any four-passenger touring coupe anywhere.

"Its performance is as smooth as its appearance."
New York Times, April 10, 1983

With either the standard 3.8 liter V-6, the 5 liter V-8 or the powerful 2.3 liter turbocharged engine, Thunderbird is a performer. And the power is thoughtfully applied, because the Thunderbird 2.3 liter Turbo Coupe is rated at 33 est. hwy., 22 EPA est. mpg.*

"Ford's new Thunderbird Turbo Coupe is pure driving excitement."
Popular Mechanics, April 1983

From the tires to the suspension to the steering, the Thunderbird was designed for the discriminating driver. Radial tires provide great traction on both wet and dry pavement. The rack and pinion steering is quick and precise. Gas-filled struts and shock absorbers give the Thunderbird a smooth ride in normal driving conditions and a supportive ride when either you or the road demand. And all these parts work in concert to make the Thunderbird handle the road with confidence.

"To say that this car is the best new Thunderbird in years is a dramatic understatement."
Road & Track, January 1983

When we say "Quality is Job 1," we are talking about more than a commitment. We are talking about results. An independent survey concluded Ford makes the best-built American cars. The survey measured owner-reported problems during the first three months of ownership of 1983 cars designed and built in the U.S.

*For comparison. Your mileage may differ depending on speed, distance, and weather. Actual highway mileage lower.

Get it together—
Buckle up.

Have you driven a Ford... lately?

Ford

"The new Thunderbird is Detroit's design triumph of the year."

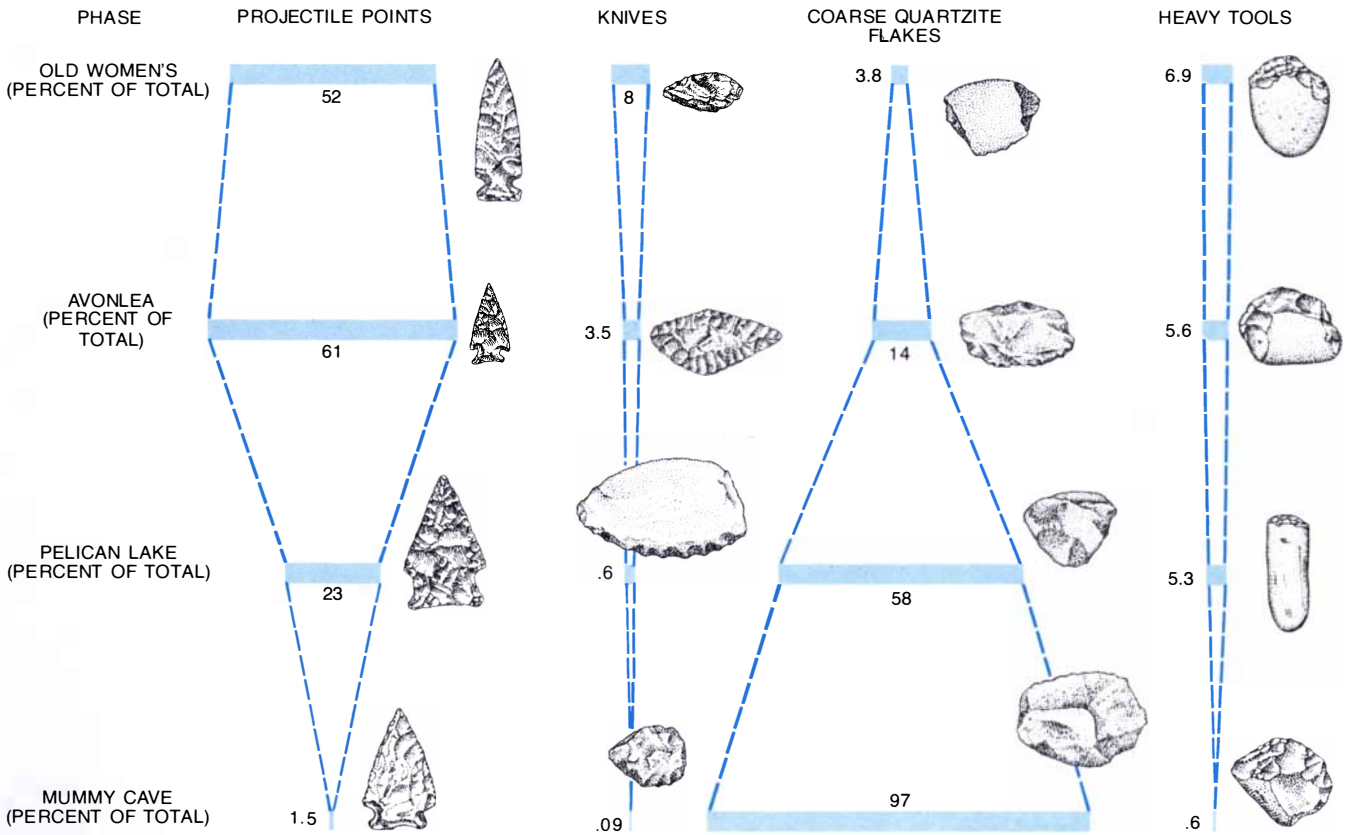
Car and Driver, July 1983

lo hunts are any guide, the various stone tools had served to cut up the animals' four quarters, to cut the meat into strips for drying and to smash the leg bones for their marrow. Most of the stone cores and waste flakes at the camp had come from large, coarse-grained quartzite cobbles; little fine-grained chert waste was found. A small amount of pottery also turned up, along with such trade goods as beads, copper bangles, bottle glass and iron arrowheads.

Among the buffalo bones in the camp were fragments of mandibles, left over from the removal of the animals' tongue (considered a delicacy by buffalo hunters since Paleo-Indian times), the base and frontal bones of skulls (broken to remove the brain), rib bones, bones from buffalo humps and many fragments of limb bone. We also excavated a number of what, on the basis of their contents and of historical accounts, must have been boiling pits. Traditionally such pits were dug, up to two meters in diameter and one meter deep, and lined with a buffalo hide. The skin was then filled with water and cracked marrowbones. Rocks heated in a nearby fire were thrown in until the water boiled. Finally the marrow fat that accumulated on top of the water was skimmed off, ladled into containers and used as a base for pemmican: a mixture of the grease, berries and dried meat pounded to a powder.

Although the camp area may have been used by hunting parties other than those of the prehistoric and modern Piegan at Head-Smashed-In, we found little or no archaeological trace of any of the two earliest peoples who had stampeded buffalo at the site. Head-Smashed-In is, however, only the second buffalo-jump site to be excavated in Alberta, the first having been Old Women's. At least 20 more sites, with their associated hunting and butchering camps, still remain to be investigated. Our site provides a record of use by Great Plains hunters over a period of at least 5,600 years. That is a considerable span of time. Indeed, only one other excavated buffalo-jump site is substantially older: Bonfire Shelter, near the juncture of the Pecos River with the Rio Grande in Texas. Bonfire Shelter is some 10,000 years old, but the history of its use is far briefer than that of Head-Smashed-In. With the exception of Bonfire Shelter, jump sites are typically distributed along the western edge of the plains. Who knows how old some of the other Alberta buffalo jumps may be?

In any event our findings at Head-Smashed-In indicate that substantial numbers of hunters on foot were successful in providing themselves with meat and fat, with hides for robes and tepee covers, with bladders and lengths of intestine for containers, with sinew for sewing, with bone and horn for tools and utensils and with dung and tallow to burn for warmth and light. Moreover, their hunting methods required more sophisticated social mechanisms than many scholars have been prepared to credit even the historical plains Indians with. For all their deceptively simple material culture, these earliest plainsmen were at the same time excellent organizers and daring coordinators when many of the white man's ancestors were still simple hunters and gatherers in the chill forests of Mesolithic Europe.



STONE ARTIFACTS of different kinds varied in number from one phase to another at Head-Smashed-In. In the Mummy Cave strata, for example, of some 1,129 stone artifacts found, 97 percent were flakes of coarse-grained quartzite made from local quartzite cobbles. The Mummy Cave projectile points, 17 in all, were for hafting to the long darts thrown with the atlatl. Only one knife was found in the Mummy Cave strata. Of the 1,149 artifacts from the Pelican Lake strata, more than half were also flakes of local quartzite. Atlatl projectile points, some made from imported obsidian, accounted for another 23 percent of the total. A few knives were present, some also made from imported stone, while heavy stone tools such as choppers and mashers accounted for 5.3 percent of the total. In the Avonlea strata, arrowheads were the most abundant (61 percent of the total) among the 1,735 artifacts found. Knives were far more numerous than they were in the Pelican Lake phase: the total was 60. Avonlea craftsmen imported chert from British Columbia and obsidian from the Yellowstone area. The people of the final phase, Old Women's, left fewer arrowheads than their Avonlea predecessors had left but more knives. Up until historical times they worked mainly in local stone, using chert for points and knives and quartzite for heavy tools.

The Extinction of the Ammonites

Changes in the shells of these nautiluslike marine animals at the end of their long history suggest they were fighting a losing battle against more mobile, shell-crushing predators

by Peter Ward

At the end of the Cretaceous period of the Mesozoic era 65 million years ago many species of plants and animals, including many groups of marine invertebrates, suddenly died out. One of the most important groups of marine invertebrates to be extinguished was the ammonites. The ammonites, like their nearest living relatives the members of the genus *Nautilus,* were chambered cephalopods: mollusks that live in the outermost compartment of a shell they divide into chambers by secreting a series of walls behind them as they grow. Many investigators now believe the extinctions at the end of the Cretaceous period were caused by the direct or indirect effects of the collision of a large meteoritic body with the earth, a possibility first proposed by Luis W. Alvarez, Walter Alvarez and their co-workers at the University of California at Berkeley to account for the abnormally high levels of platinum-group metals found in sedimentary strata dating from this period [see "The Mass Extinctions of the Late Mesozoic," by Dale A. Russell; SCIENTIFIC AMERICAN, January, 1982]. The fossil record suggests, however, that the extinction of the ammonites was a consequence not of this catastrophe but of sweeping changes in the late Cretaceous marine ecosystem.

"Ammonites" is a term reserved for the Jurassic and Cretaceous representatives of the order *Ammonoidea.* The shells of the ammonites differ from those characteristic of the ammonoids throughout most of their 300-million-year history in ways that suggest these slow-moving and probably bottom-dwelling animals were encountering much stronger selective pressures than they had up to that time. The typical ammonoid shell was beautifully engineered for withstanding the pressure of seawater at the depths at which the animals lived but was poorly engineered for escaping or discouraging predators. Most ammonoid shells, like those of the modern nautilus, were planispiral (coiled in a plane), comparatively thin-walled and poorly streamlined. In the late Mesozoic many fast-swimming, shell-crushing marine predators arose, among them the modern bony fishes and many species of air-breathing marine reptiles. Their presence may explain the predominance of three types of shells among the Cretaceous ammonites: streamlined planispiral shells, heavily ornamented or armored planispiral shells and a wide variety of bizarrely shaped shells collectively called heteromorphs.

Much can be deduced about the agility, speed and mode of life of the new species from their shells alone, but a complete understanding of the defensive strategies to which the shell types bear silent witness requires some understanding of the biology of the animals living in them. For the most part only the shells and other hard parts of the ammonites have been preserved; rarely are fossils containing traces of organic material found. Thus the living fossil, the nautilus, has proved to be an invaluable source of information, allowing otherwise inexplicable or apparently maladaptive modifications of the ammonite shells to be explained.

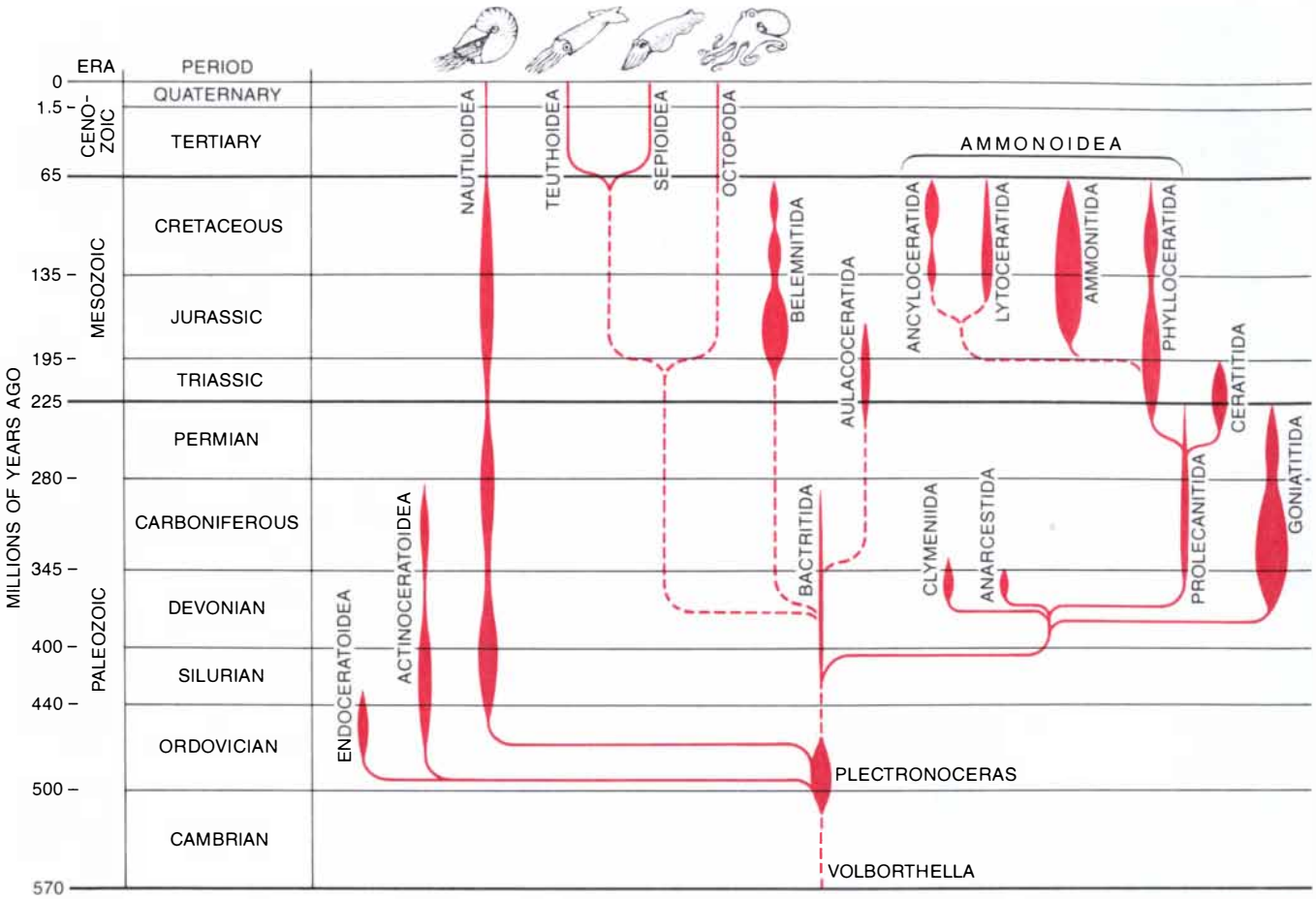
The ultimate fate of the ammonites is still an enigma, in part because ammonite-bearing sediments encompassing the boundary between the Cretaceous period and the Tertiary have been found at only a few sites. In the late Cretaceous both the number of ammonites and the number of species of ammonites dropped sharply. What happened to the remaining, apparently resilient ammonite species is not clear, but studies of the fossils from the stratigraphic sections at Zumaya in Spain suggest they became extinct long before the proposed impact of the meteoritic body. Even if it is assumed that the impact hastened rather than caused the final extinction of the ammonites, however, there are loose ends to the story. Some of the late Cretaceous ammonite species closely resembled the nautiloids, the ancestors of the modern nautilus. Why should they have succumbed when the nautiloids survived?

The nautiloids, some species of which are found in strata dating from the Cambrian period of the Paleozoic era, are the oldest cephalopods. A very restricted group (that is, a group limited in numbers) called the bactritids developed within this subclass in the Silurian period of the Paleozoic; the bactritids may be the common ancestor of all the more recent cephalopods, including the modern cuttlefish, squid and octopus. The ammonoids apparently branched off from the bactritids in the early Devonian period of the Paleozoic some 395 million years ago.

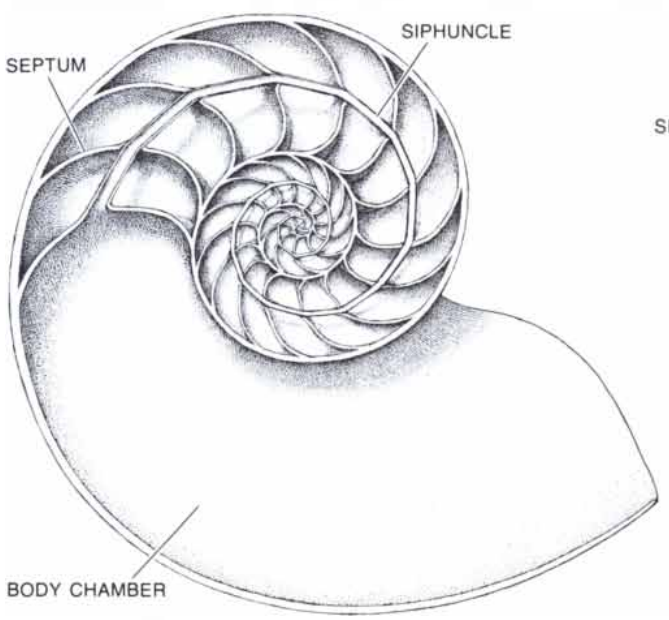
The long evolutionary history of the ammonoids is characterized by explosive radiations and the sudden appearance of many new species, followed quickly by abrupt extinctions. The number of ammonoid species increased rapidly in the Paleozoic, quickly equaling the number of nautiloid species. In the Triassic period of the Mesozoic era, and again in the Jurassic and Cretaceous periods, the ammonoids radiated explosively, eclipsing the nautiloids in number of species. At least three-fourths of the approximately 10,000 known fossil chambered cephalopod species are ammonoids. So diverse are the ammonoids that their fossils are often helpful in dating sedimentary strata.

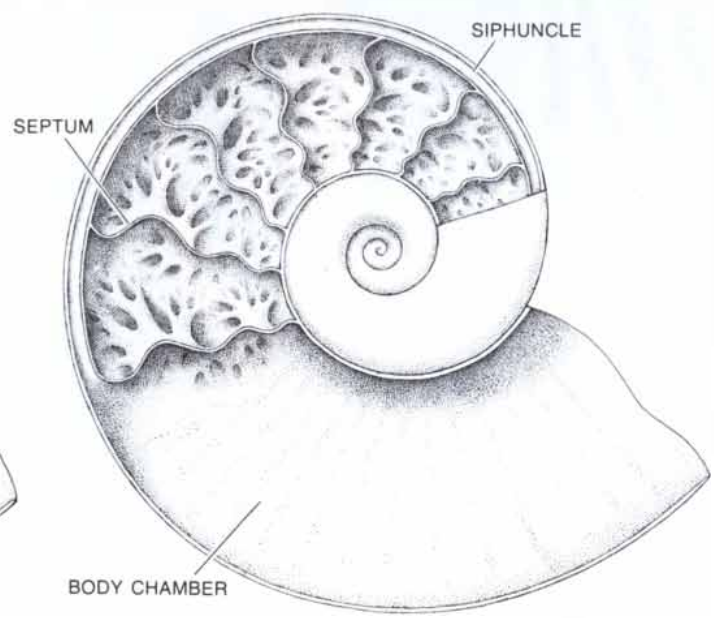
Perhaps the most striking difference between nautiloid and ammonoid shells is the one between the two organisms' septa (chamber walls) and septal sutures (the line of contact between the septa and the inside of the shell), which are the features of the shell that largely dictate its strength. In the modern nautilus the chambers are emptied of fluid as they are walled off, a contrivance that enables the animal to achieve neutral buoyancy (an overall density or weight per unit volume nearly equal to that of the surrounding seawater) and thus to remain at any depth without effort. The weight of the shell and the body tissues is greater than the weight of seawater, so that the chambers are maintained at

CROSS SECTION OF AN AMMONITE FOSSIL exposes the internal chambers of the shell the animal created by secreting walls behind it as it grew. (The body cavity of the shell is missing in this specimen.) Crystals of chert, a siliceous mineral, deposited on the walls during fossilization give them their layered appearance. This specimen is a member of the genus *Placenticeras,* one of the last genera of ammonites to be extinguished. The form of its shell closely resembles that of the modern nautilus, the only surviving chambered cephalopod. One of the puzzles presented by the extinction of the ammonites is why genera such as *Placenticeras* were extinguished when the ancestors of the nautilus survived. The term ammonite refers only to the last representatives of the group called the ammonoids. The shells of the roughly 7,500 known ammonoid species vary widely in shape and size. The ammonoids were named for the ancient Egyptian god Ammon, often represented as the head of a ram, because some ammonoid shells resemble twisted ribbed ram horns. Most ammonoids are smaller than the specimen shown here, which is 24 centimeters in diameter, but fossils nearly two meters in diameter have been found.



SMALL GROUP OF NAUTILOIDS (the ancestors of the modern chambered nautilus) called the bactritids may be the common ancestor of the extinct ammonoids and belemnites and all the modern cephalopods, including the cuttlefish, the squid and the octopus. The small orthoconic (straight-shelled) bactritids developed into ammonoids when their shells rolled first into loose coils and then into progressively tighter ones. The belemnites had an internal chambered shell surrounded by a soft body. Modern cephalopods have either a chambered internal shell, a laminated cuttlebone, a "pen" or, in the case of the octopus, a vestigial skeleton consisting of small horny supports or a simple rod. These internal hard parts are homologues of the external chambered shells of the nautiloids and the ammonoids.

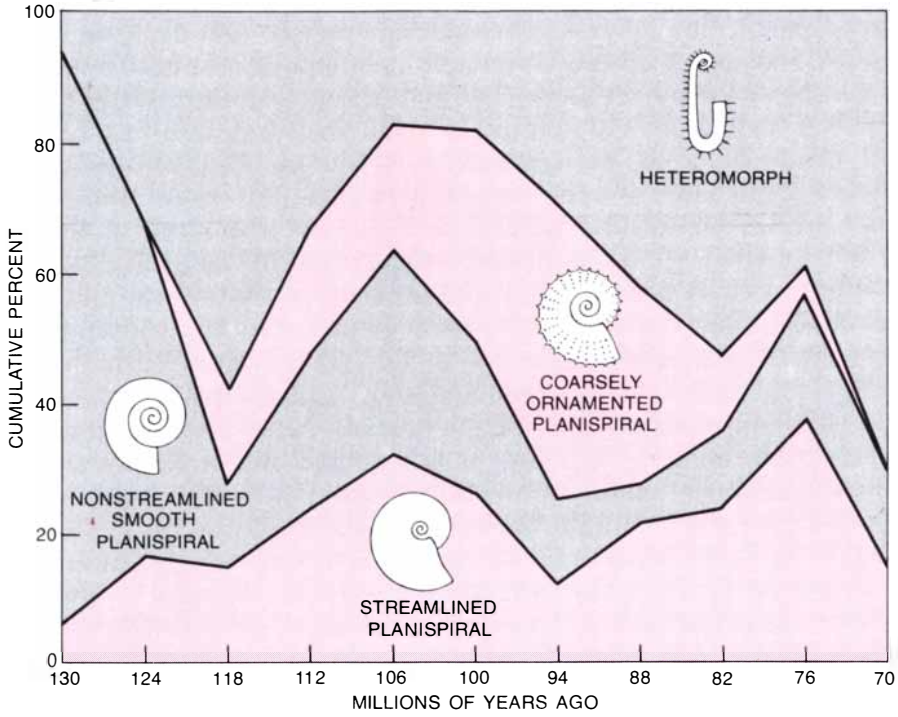




SHELLS OF THE AMMONOIDS differ from those of the nautiloids in two respects. The septa (chamber walls) of the nautiloid shells are smooth, curved surfaces. The septal sutures (lines along which the septa intersect the inner wall of the shell) are gentle curves. The septa of ammonoid shells, on the other hand, are fluted at the periphery, and the septal sutures are folded into complex, frilled curves. The complexity of the septa and septal sutures of the ammonoid shell made it possible for the shell wall to be relatively thin. The other difference between the nautiloids and the ammonoids is the position of the siphuncle, the organ that empties the walled-off chambers of fluid. In the nautiloids the siphuncle generally passes through the center of the whorl; in the ammonoids it is on the outer wall of the whorl.

pressures far lower (less than one atmosphere) than the pressure of seawater (about 40 atmospheres) at the depth where the nautilus is typically found (400 meters). The shells of the nautiloids and the ammonoids were probably also at least partially filled with gas.

The septa of the shells act as braces, giving the shells enough strength to withstand the pressure of seawater at great depths. In most nautiloid shells the septa are smooth surfaces, gently curved in toward the innermost chamber of the shell. The sutures at the intersection of the septa and the shell wall are thickened, but the suture lines are simple curves. In most ammonoids the periphery of the septa is fluted or corrugated. The suture lines are frilled or denticulate (toothed) and of staggering complexity compared with those of nautiloids. Ammonoids and nautiloids are commonly found in the same sedimentary strata, and so they probably lived at similar depths in the ocean. The walls and septa of ammonoid shells are much thinner, however, than those of nautiloid shells of similar diameter. Thus it appears that the architectural complexity of the ammonoid shells made them as strong as nautiloid shells even though they were lighter.



THREE TRENDS IN SHELL TYPE characterize the Cretaceous ammonites. The number of species with streamlined, ornamented or heteromorphic (irregularly coiled) shells increased at the expense of the species with the shell characteristic of most of the earlier ammonoids: a nonstreamlined, smooth, planispiral shell. All three shell types can be interpreted as adaptations to the presence of the more sophisticated marine predators that arose in the Jurassic and Cretaceous periods of the Mesozoic era. Some of the adaptations were more successful than others. Perhaps the most marked (and in some respects the most surprising) trend is the increasing dominance of heteromorph ammonites. The armored ammonites, however, were much less successful; they had almost all been extinguished before the end of the Cretaceous period.

Perhaps as a result the ammonoids produced shell types never evolved by nautiloids, such as shells with a highly compressed or depressed cross section (that is, shells in which either the height or the breadth of the opening in the shell is exaggerated). It is probably also no accident that the variety of shell shapes and the number of ammonoid species increased whenever more complex septal sutures evolved. The very rapidity with which shell shape (and shell ornamentation) changed, however, suggests that both features of the shell were quite plastic and indeed may have had little adaptive significance. Suture lines, on the other hand, are quite conservative, so much so that they serve to establish evolutionary lineages.

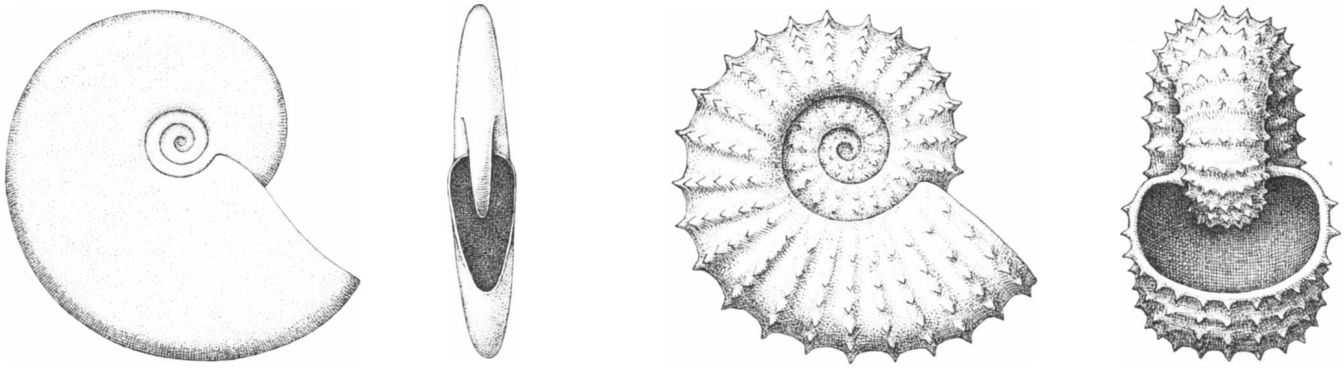
The design of a typical ammonoid shell also suggests that during most of the history of the group shell shape and ornamentation were not dictated solely by their effect on the ability of the animal to elude or discourage predators. All the Paleozoic ammonoids and almost all the ammonoids of the early and middle Mesozoic had planispiral shells, but many of the shells were poorly streamlined and therefore not adapted to fast swimming. Shell ornamentation varied widely, but most shells were smooth or finely ornamented and so gave little protection from predators.

This situation changed markedly in the late Mesozoic, the time of what Geerat J. Vermeij of the University of Maryland at College Park calls the Mesozoic marine revolution. Late Mesozoic radiations of shell-crushing animals such as modern clawed crabs, lobsters, skates and rays, and the arrival of the carnivorous gastropods, bony fishes and many species of large air-breathing marine reptiles, greatly increased the tempo and efficiency of predation in the Jurassic and the Cretaceous. The ammonoids, themselves predators feeding on minute marine animals, small crustaceans and smaller ammonoids, may increasingly have become prey or have lost their prey to more mobile predators. Each of the three trends in ammonite shell type in the Cretaceous is clearly an adaptation to which the selective pressure imposed by the more efficient marine predators had given rise.

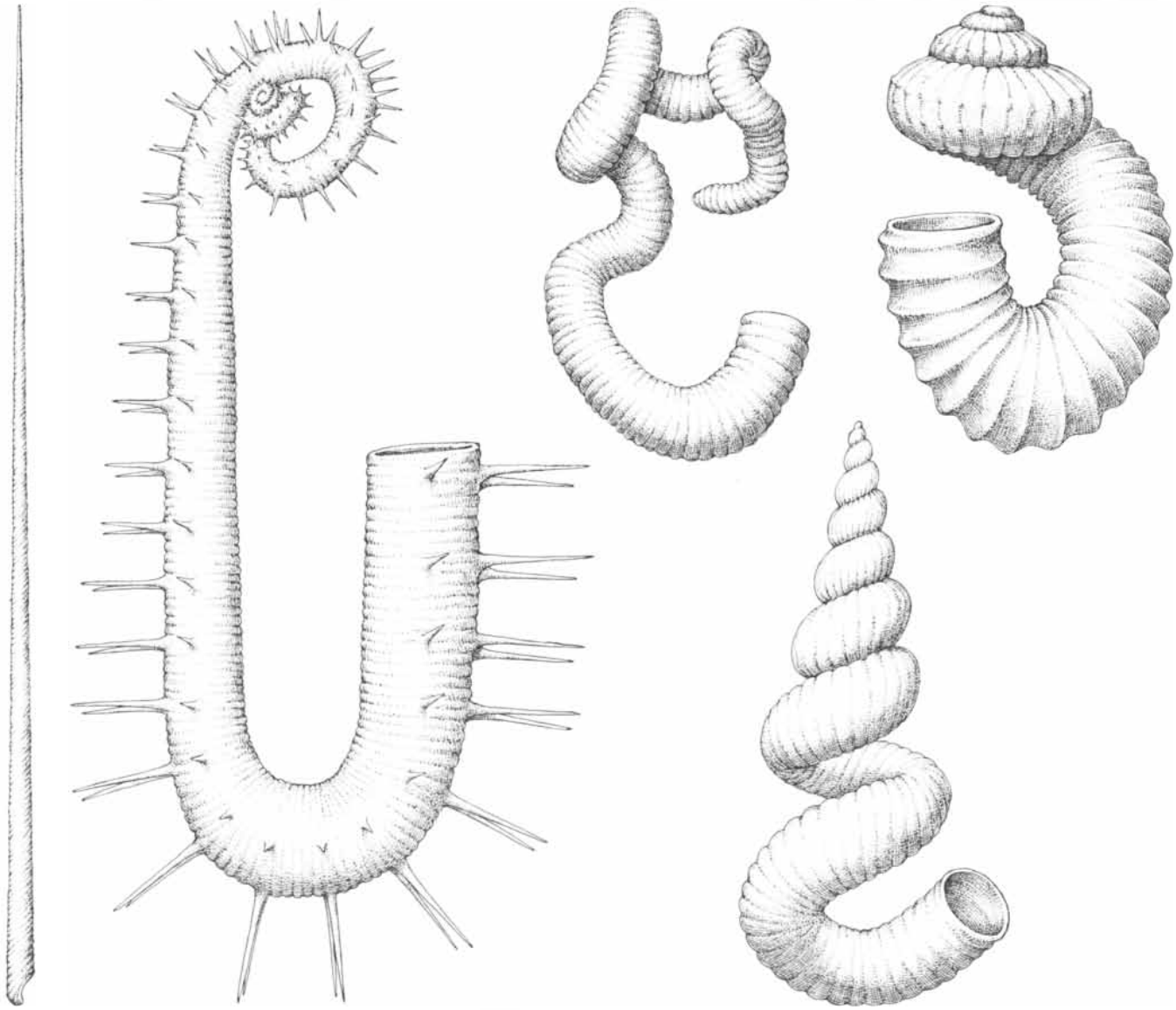
The first trend was toward shell shapes that made the ammonites more agile and faster swimmers. A surprising amount of information about swimming ability can be deduced from shell shape alone. In the 19th century the English mathematician Henry Moseley developed a geometric model for shell coiling based on the logarithmic spiral, a spiral in which the distance from the point of origin increases geometrically with each revolution. Building on this work, David M. Raup of the University of Chicago developed mathematical equations in the 1960's that generate from four parameters of the shell a shape comparable to that of a specimen. When the shell is planispiral rather than helically coiled, only three parameters need be considered: the shape of the closed curve that generates the shell when it is rotated about the coiling axis, often given as the ratio of the breadth to the height of the opening (S), the rate at which the generating curve expands with each revolution (W) and the rate at which the generating curve moves away from the coiling axis with each revolution (D). For example, if the generating curve is a circle, W is large and D is small, the result will be a tightly coiled shell with overlapping whorls.

Raup went on to map ammonoid specimens according to the S, W and D values of their shells. He found that many ammonoid shells were poorly designed for swimming. Two adaptations made the ammonoids (and the nautiloids) free-swimming rather than bottom-crawling: the development of a phragmocone, the evacuated part of the shell that allows the animals to achieve neutral buoyancy, and the development of a hyponome, the funnel-like structure in the body cavity through which water can be forcibly ejected.

One of the problems a swimming ammonoid faces is the problem of attitude control. In an ammonoid the center of buoyancy, which is in the phragmocone, is separated from the center of mass,



STREAMLINED AND HEAVILY ORNAMENTED planispiral shell types are illustrated by these ammonite specimens, a member of the genus *Placenticeras* (*left*) and a member of the genus *Douvilleiceras* (*right*). The smooth exterior and compressed cross section of the *Placenticeras* shell reduced drag, and the tight coiling of the shell increased its hydrodynamic stability; both factors made the animal a more agile and faster swimmer. The *Douvilleiceras* shell is less well adapted for swimming because of the rough exterior, the broad cross section, the comparatively loose coiling and the depressed umbilicus (the cavity around the axis of coiling). The spines and thickened ribs of the shell may, however, have served to discourage crabs, marine reptiles such as mosasaurs and other shell-crushing predators.



HETEROMORPH AMMONITE SHELLS are in some instances so bizarre that they were once thought to be the product of "genetic exhaustion," foretelling the extinction of the ammonites. Even now the variety of the shell shapes precludes simple generalizations about their adaptive significance. The heteromorphs shown here are (*from left to right*) members of the genera *Sciponoceras*, *Anisoceras*, *Nipponites*, *Nostoceras* and (*lower right*) *Didymoceras*. Most of the heteromorphs probably led passive, floating lives. Many early Cretaceous heteromorphs seem to have depended on shell ornament for protection against predators. Late Cretaceous heteromorphs, however, particularly those with a *U*-shaped hook at the end of their shell, may have floated at middle depths in the ocean and so escaped the continental-shelf habitats of their bottom-dwelling ancestors and perhaps also the predators that invaded them in the Mesozoic era.

which is in the body cavity. The animals therefore have great static stability. On the other hand, forward thrust from the hyponome is off-axis from the center of buoyancy and tends to rotate the shell away from its equilibrium position; the opposing force generated by the displacement of the mass tends to reorient the shell. The greater the separation between the center of buoyancy and the center of mass, the greater the restoring force and the greater the dynamic stability of the shell. Dynamic stability would be critical to the agility of the animal and would also limit the speed with which it could swim.

A nautilus shell is a good example of a shell in which the centers of buoyancy and mass are widely separated. Raup found, however, that many ammonoid shells, unlike the involute, or tightly coiled, nautilus shell (high *W,* low *D*), are evolute, or openly coiled (low *W,* high *D*). The center of mass and the center of buoyancy tend to be close together in such shells. As a consequence the thrust generated by the squirting of water out of the hyponome is translated into spinning or pinwheeling motion rather than into forward motion.

John A. Chamberlain of Brooklyn College of the City University of New York extended Raup's work on ammonoid shell types, placing particular emphasis on the hydromechanical design of the shells. To hydrodynamic stability he added the further factor of drag: resistance as the shell is pushed or pulled through water. The shell parameter that has the greatest effect on drag is the shape of the generating curve, *S*. If the ratio of the breadth of the shell opening to the height is small, the curve is compressed and the shell is disk-shaped. If the ratio of the breadth of the opening to the height is large, the curve is depressed and the shell is globular. Clearly the smaller the value of *S* is, the less effort is required of the animal to swim at a given velocity.

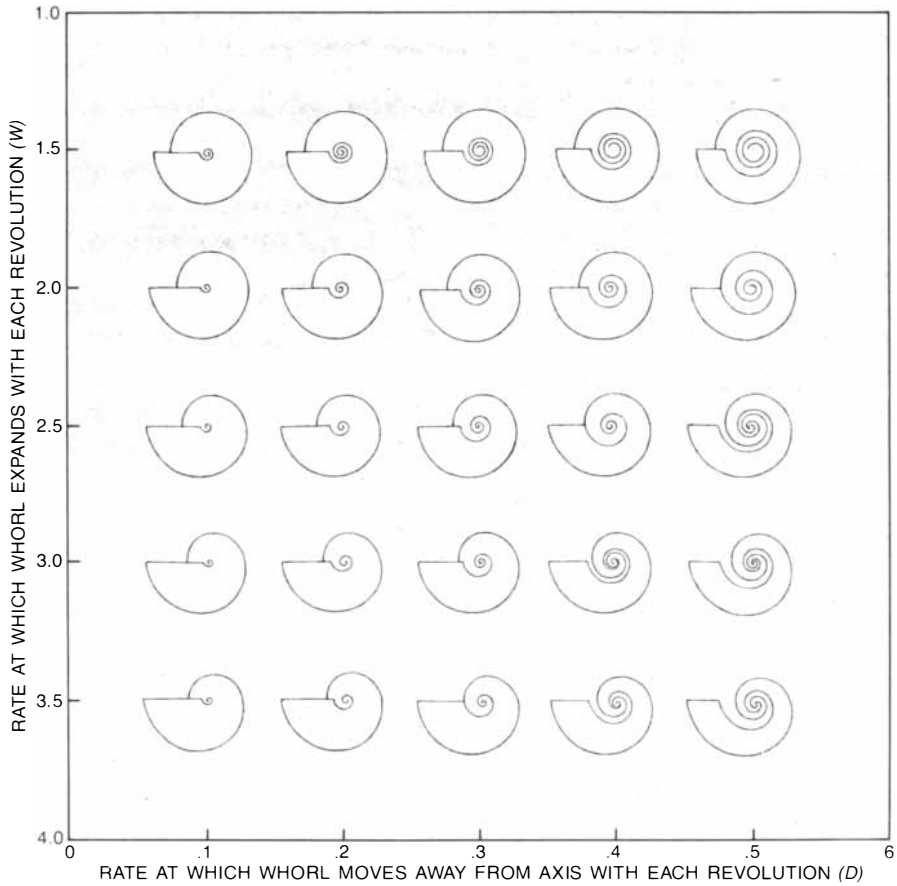
Chamberlain developed equations allowing the swimming velocity of the ammonoids to be calculated from these shell characteristics and others. The shell shape that would enable the animal to reach the greatest velocity would be a compressed shell with overlapping whorls. Chamberlain found that ammonoid shells plotted on *S, W* and *D* graphs clustered around the possible shell shapes best designed for swimming, but that great numbers of shells, translating into thousands of species of ammonoids, had shells only minimally or poorly adapted for swimming. These studies suggest that during most of the history of the ammonoids efficient swimming ability was poorly selected for. In the late Cretaceous period, however, highly streamlined shell shapes increased at the expense of less well streamlined ones both regionally and worldwide. Agility and speed had clearly become advantages.

The second trend in ammonite shells is toward increased shell ornamentation among the nonstreamlined species. Over most of their history ammonoids had smooth or finely ornamented shells. Although Chamberlain and Gerd E. G. Westermann of McMaster University have suggested that some shell ornamentation may actually have decreased hydrodynamic drag, just as the pits on golf balls reduce aerodynamic drag, much ammonoid shell ornamentation seems to have no identifiable purpose. Moreover, the pattern of ornamentation is highly variable within a given evolutionary lineage. It would seem, therefore, that barring substantial changes in roughness the pattern of ornamentation on ammonoid shells was unimportant and evolutionarily quite plastic.

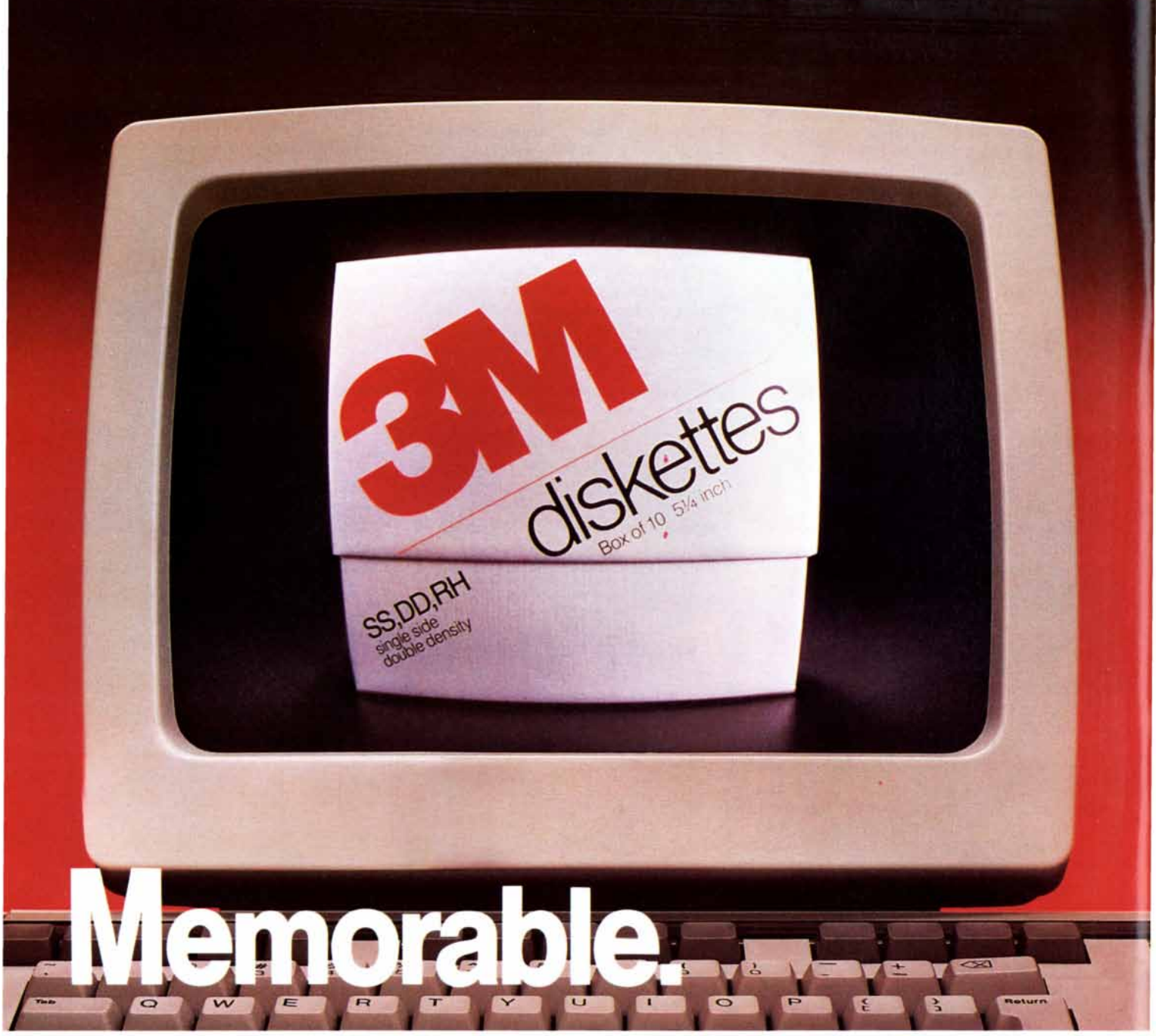
In the Cretaceous period, however, those planispiral ammonites that did not have streamlined shells developed large, robust ribs, spines and tubercles. In mollusks living today this type of shell ornamentation appears to have the purpose of defeating attacks by shell-crushing predators. The trend toward heavily armored shells among the ammonites can probably be interpreted in the same way.

How effective was this particular defensive strategy? Many ammonite fossils from the Cretaceous bear the marks of attacks by predators. Some shells have been cut open by crabs. Other fossils bear the tooth marks of mosasaurs and other marine reptiles. In many instances part of the shell near the opening has been broken off. Assuming the animal was not killed, could it survive such an attack? Once again studies of the nautilus provide clues to the answer.

The phragmocone of the nautilus shell serves primarily to buoy up the heavy calcareous shell rather than the



SWIMMING ABILITY OF THE PLANISPIRAL AMMONOIDS can be deduced from the shape of their shells. David M. Raup of the University of Chicago developed equations that will generate any shell shape based on a logarithmic spiral from four parameters of the shell. These computer-generated line drawings show the variation of shell shape with two parameters: the rate at which the cross section of the shell increases with each revolution (*W*) and the rate at which the cross section moves away from the coiling axis with each revolution (*D*). Low *W,* high *D* (evolute) shells are poorly adapted for swimming; high *W,* low *D* (involute) shells are comparatively well adapted. The center of mass of evolute shells, which is in the body cavity of the shell, tends to be close to the center of buoyancy, which is in the phragmocone: the walled-off part of the shell. The two centers are more widely separated in involute shells. Thrust from the directional water jet in the body cavity tends to rotate the shell away from its equilibrium position (in which the center of buoyancy is directly above the center of mass). The greater the separation of the centers of buoyancy and mass is, the faster the shell will reorient itself. Animals with involute planispiral shells therefore tend to be more agile and faster swimmers.



With 3M diskettes, your computer never forgets.

3M diskettes remember everything, every time. Because at 3M, reliability is built into every diskette. We've been in the computer media business for over 30 years. And we've never settled in. We're constantly improving and perfecting our product line, from computer tape and data cartridges to floppy disks.

3M diskettes are made at 3M. That way, we have complete control over the entire manufacturing process. And you can have complete confidence in the reliability of every 3M diskette you buy.

Look in the Yellow Pages under Computer Supplies and Parts for the 3M distributor nearest you. In Canada, write 3M Canada, Inc., London, Ontario. If it's worth remembering, it's worth 3M diskettes.

3M hears you...

3M

body. The density of the shell is much greater than the average tissue density (2.67 grams per cubic centimeter compared with 1.06 grams for the muscles and digestive gland and 1.03 grams for the body fluids). Eric Denton of the Marine Biological Association of the United Kingdom at Plymouth has estimated that about 80 percent of the phragmocone volume is needed just to buoy up the mass of the shell. Thus any loss of shell material causes a comparatively large decrease in the density of the animal. If enough material is removed, the animal is forced to the surface, where it is at the mercy of surface predators and is buffeted by waves and currents.

Many nautilus shells have healed shell breaks, suggesting that the animals have at least some ability to survive sudden losses in weight. The most obvious compensatory strategy would be to refill walled-off chambers with fluid. Until two years ago, however, it was thought that a nautilus at or near the surface had only the option of increasing or decreasing the rate of emptying chambers, not of filling them.

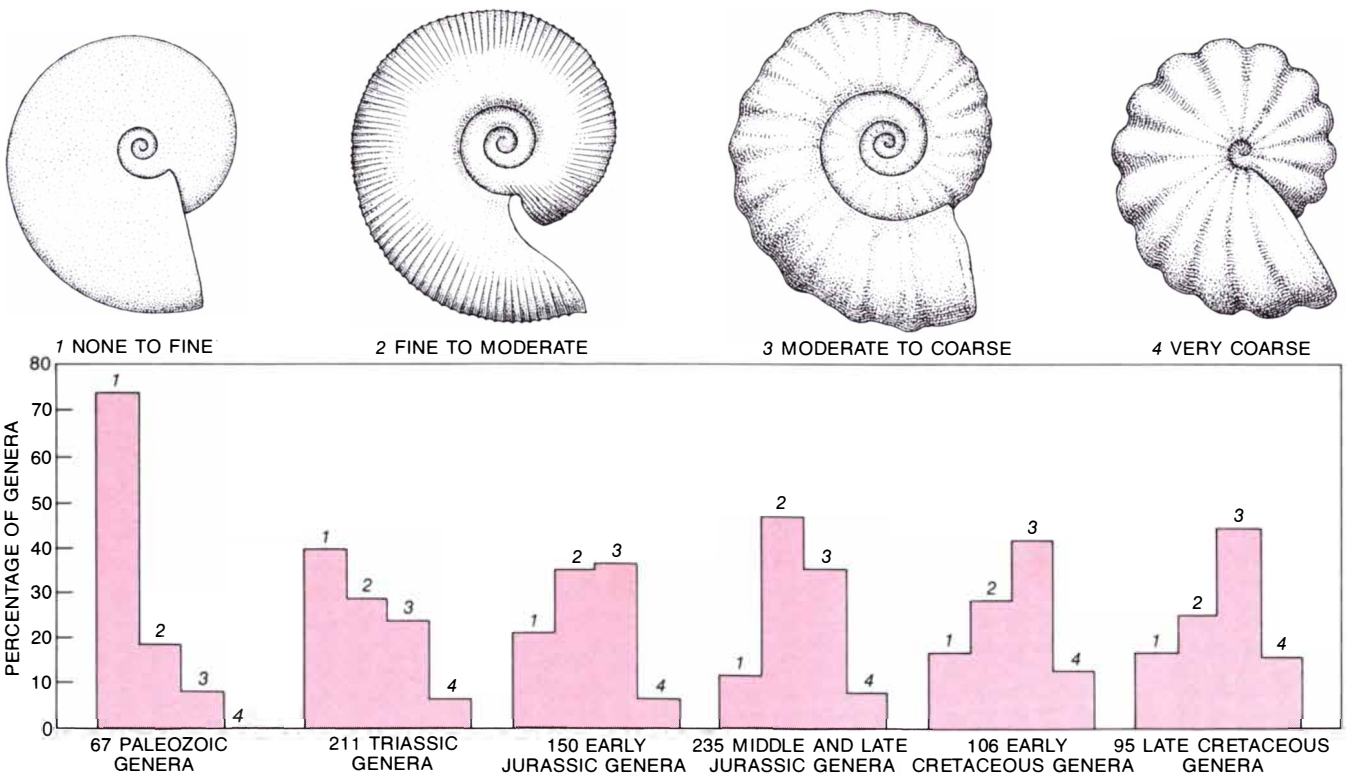
How the nautilus empties walled-off chambers was revealed by Denton and John B. Gilpin-Brown of the Marine Biological Association. They realized in the course of studying modern chambered cephalopods such as the nautilus, the cuttlefish *Sepia* (which has an internal chambered cuttlebone) and the squid *Spirula* (which has a small internal chambered shell) that the chambers in the shell or cuttlebone are originally filled not with gas but with a saline liquid called the cameral fluid. This opened the way to a new interpretation of the siphuncle, the organ that empties the chambers. The mechanism by which the siphuncle empties the chambers was worked out by Denton, Gilpin-Brown, Lewis Greenwald and me.

In the nautilus the siphuncle is a strand of living tissue enclosed in a calcareous tube that spirals through all the chambers of the shell, including the first chamber to arise in the growth of the animal. The substances dissolved in the cameral fluid pass through the porous outer layers of the siphuncle into the cells of the siphuncular epithelium. Enzymes on the folded inner membrane of these cells pump the solute into the fine network of infoldings. When the concentration of ions in the infoldings is sufficiently great, fluid from the chambers is drawn into them by osmosis, draining from there into the blood vessels at the center of the siphuncle.

At the time, never having found a nautilus at or near the surface that was refilling its chambers, we speculated that the part of the siphuncle extending into the first chambers, which are emptied of fluid early, was the vestige of an organ that could both empty and flood the chambers of the ancestral chambered cephalopods. Greenwald and I have since demonstrated that the nautilus itself has this ability. I was recently able to study the phenomenon with freshly captured specimens of *Nautilus macomphalus* in New Caledonia. About one out of 10 nautilus shells in this area shows the scars of large breaks. By simulating such attacks I was able to measure the rate at which the nautilus could refill its shell.

Within the first hour after a nautilus was forced to the surface, liquid slowly began to reenter virtually all the chambers of its shell. The rate of refilling, however, was quite low. The highest rate of weight gain in 25 specimens was less than .5 gram per hour. The total amount of liquid that could be added to the chambers also seemed to be limited. No single chamber was even as much as half refilled and no nautilus (even those having lost as much as 25 grams of shell) ever gained more than five grams in weight. In the nautilus, at least, this adaptation for compensatory buoyancy change seems extremely limited.

What can be said about the ammonites? Many ammonite fossils also show healed shell breaks. In addition the thickened ribs of ammonite shells are oriented radially, so that breaks near the opening of the shell, the shell's most vulnerable part, would be channeled parallel to it and the loss of shell would be minimized. The anatomy and position of the ammonite siphuncle are different from those of the nautilus, but my studies indicate that the rate of chamber emptying and refilling in the nautilus is largely determined by the ratio of the



ROBUST RIBBING, a type of defensive shell ornament, was much commoner in Cretaceous ammonite genera than it was in earlier ammonoid genera. Shell ornamentation is classified as fine or coarse on the basis of the ratio of the width of an outer rib to the shell's diameter.

surface area of the siphuncular epithelium within any given chamber to the volume of the chamber; the ratios are quite comparable in the nautilus and the ammonites. The evidence is therefore inconclusive. Perhaps the ammonites had a refilling system similar in capacity to that of the nautilus; perhaps it was many times more efficient. It is clear, however, that they needed such a system.

The last and most pronounced trend among the Cretaceous ammonites is one toward heteromorphs: species in which the shell forms differ in many ways from the ancestral planispiral form. A few heteromorph species appeared briefly among the thousands of planispiral species in the Triassic and Jurassic periods. Starting about 120 million years ago, however, large numbers of heteromorphs began to evolve. By the end of the Cretaceous period they made up the majority of ammonites, both in numbers and in number of species.

This trend is the most difficult one to interpret. The shell forms of heteromorphs range from openly coiled planispirals to bizarre, seemingly patternless coils. Late in the 19th century and early in the 20th biologists proposed that these aberrant forms were inadaptive end members of the long ammonoid evolutionary history and foretold the final extinction of the ammonites. This notion of "typolysis," or racial senescence, has been discarded; today most workers consider the heteromorphic shell forms to be specialized adaptations to a variety of habitats.

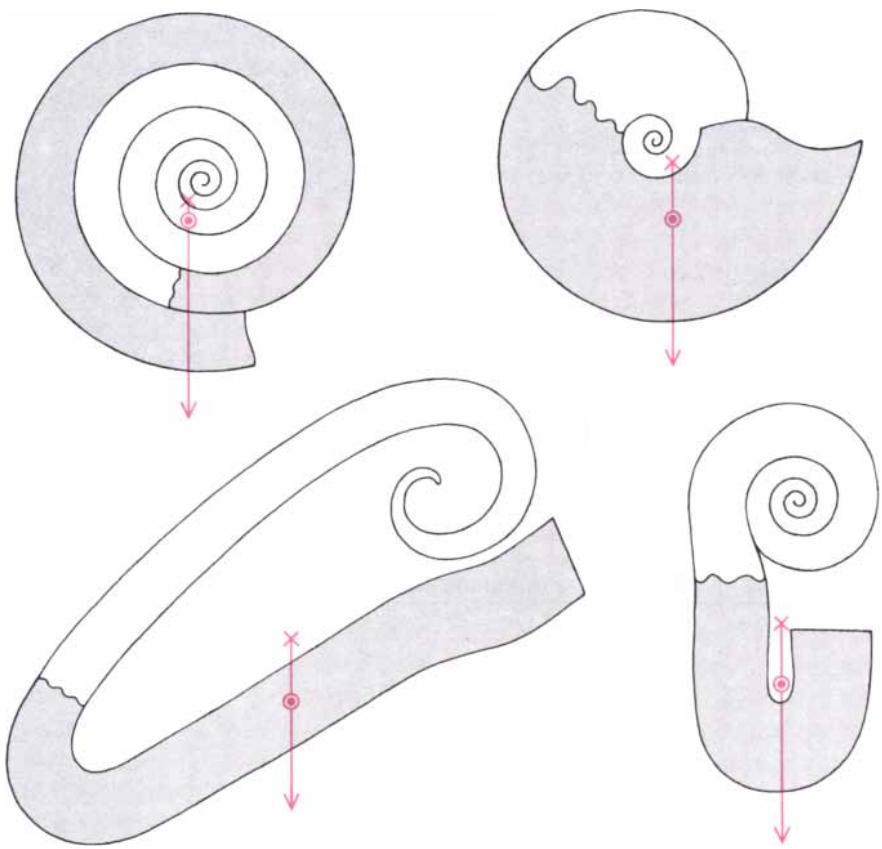
In their diversity of form, however, the heteromorphs defy any simple generalization about the adaptive significance of their shells. Early Cretaceous heteromorph shells ranged from orthocones (straight cones) to openly coiled planispirals to anomalous forms with an extravagant hook at the end of the shell. In the early Cretaceous strata of northern California, perhaps the richest source of early Cretaceous ammonite fossils (soon to be flooded by a dam), many of the heteromorph ammonites are massive and heavily ornamented.

Heavily ornamented planispiral species are found in the same strata. The early Cretaceous heteromorphs, like the heavily ornamented planispiral ammonites, may have arisen from poorly streamlined planispiral species of ammonoids. Jost Wiedmann of the University of Tübingen has shown on the basis of suture lines that heteromorph species in general arose from poorly streamlined planispiral species and often gave rise to planispirally coiled descendants. The plasticity of the shell type suggests that the early heteromorph ammonites, like the ornamented planispiral ammonites, relied for survival primarily on defensive ornamentation rather than on shell form.

By the end of the first half of the Cretaceous many of the larger heteromorph species had disappeared. Although giant forms, such as certain species of the orthoconic genus *Baculites,* reappeared in the late Cretaceous period, late Cretaceous heteromorphs were for the most part smaller and more delicately ornamented than earlier ones. The early Cretaceous heteromorphs, like their ancestors, were probably bottom-dwelling animals, but many of the late Cretaceous species have shell adaptations suggesting that they lived near the surface or at middle depths rather than on the bottom.

Many of the late Cretaceous heteromorph ammonites are helically coiled, and their way of life has traditionally been assumed to be similar to that of the mollusks they most closely resemble: the helically coiled, bottom-dwelling gastropods. The first item of evidence that led to a reinterpretation of their way of life was found by Arthur E. Trueman of the University of Glasgow. In the early 1940's Trueman calculated the centers of mass and buoyancy of a variety of planispiral and heteromorph species of ammonites. His calculations showed that as a rule the heteromorphs had a much greater static stability than the planispirals, largely because the uncoiling of the shell usually separated the center of mass in the body chamber from the center of buoyancy in the phragmocone. Indeed, many of the heteromorphs had such great static stability that they must have been capable of only small changes in orientation.

If the shell of the heteromorph was coiled in such a way that the opening (and thus the body of the animal) faced the bottom, the stability of the shell is not inconsistent with a deep-water existence. An increasing fraction of the heteromorph species that arose in the Cretaceous, however, had a *U*-shaped hook at the end of the body chamber. The phragmocones of these shells were sometimes snail-shaped, sometimes coiled around more than one axis and sometimes nearly patternless in their coiling. In all cases, however, the extreme separation of the phragmocone from the body chamber would have made the shells very stable and would



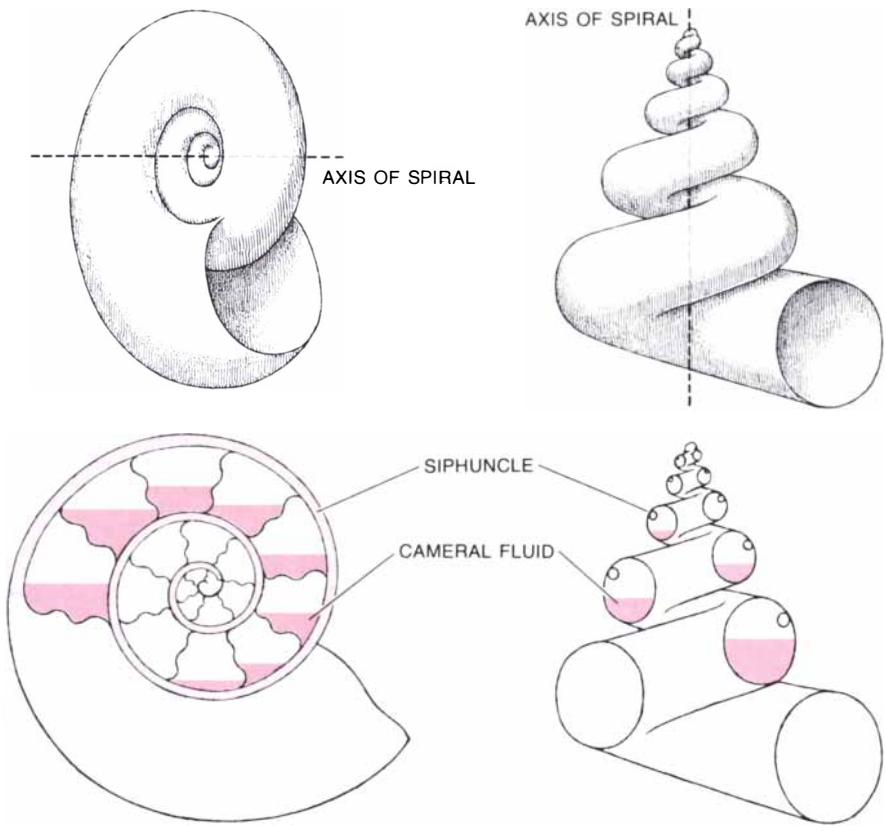
STATIC STABILITY of most heteromorphic shells is even greater than that of involute planispiral shells. Arthur E. Trueman of the University of Glasgow calculated the center of mass and the center of buoyancy for a variety of ammonite shells in the 1940's. The position of the center of mass is dictated by the spatial distribution of the body cavity (*shaded area*) and the position of the center of buoyancy by the spatial distribution of the phragmocone. The static stability of many heteromorphic shells is so great that the animals with these shells were probably capable of only modest changes in orientation. The normal orientation of some of these shells would dictate that the body of the animal face the surface rather than the bottom. This was the first clue that some heteromorphs, unlike their ancestors, were not bottom dwellers.

have dictated that the body of the animal face the surface, an extremely awkward orientation for a bottom dweller.

The next item of evidence toward a reinterpretation of the mode of life of the heteromorphs was provided by Denton and Gilpin-Brown, who pointed out that the siphuncle is positioned in modern cephalopods in such a way that the level of cameral fluid drops below it before the chamber is completely emptied. In the nautilus the siphuncle is in direct contact with the cameral fluid only until the chamber is half empty. After the cameral fluid is "decoupled" (a term introduced by Denton and Gilpin-Brown) the chamber continues to empty because the pellicle, the membrane lining the inside of the chamber, is hydrophilic and acts as a wick to draw fluid up to the siphuncle. The other two modern chambered cephalopod genera, *Sepia* and *Spirula,* also have adaptations for decoupling. It would seem that the chambers could be emptied more efficiently if the siphuncle was oriented so that it was constantly bathed in cameral fluid. Are these adaptations accidental or do they have a functional purpose?

The chambered nautilus lives on the seaward side of reefs where there are often great changes in depth over very short horizontal distances. Bruce Carlson of the Waikiki Aquarium in Hawaii, Mike Weekly of the Seattle Aquarium and I, using remote telemetry to track specimens of *Nautilus belauensis* near the island of Palau in the western Pacific, found that the animals follow the contour of the bottom while foraging, often traveling large vertical distances in a short period. In general the five specimens we tracked moved into shallow water at night and back into deeper water during the day, making daily vertical migrations of as much as 330 meters. *Spirula,* a small squid, also migrates vertically but in mid-water rather than along the bottom.

The process of chamber emptying takes about a month in a small nautilus and three months in larger specimens. It requires energy even if the animal stays at a constant depth, because the hydrostatic pressure of seawater transferred from the body of the animal to the blood in the siphuncle tends to drive fluid back into the chamber, against the osmotic gradient set up by the enzymes in the infoldings of the siphuncular epithelium. As the hydrostatic pressure changes with depth the osmotic gradient must change if the nautilus is to continue emptying a chamber or keep it from being reflooded when the animal moves to a greater depth. It follows that some means of decoupling the cameral fluid from the siphuncle would be an advantage. If when a nautilus changes depth the siphuncle in one of its chambers is decoupled, the salt concentration needs to change only in the fluid absorbed in the chalky tube around the siphuncle and in the wicklike pellicle on the inside of the chamber rather than in the entire volume of cameral fluid.



POSITION OF THE SIPHUNCLE in some heteromorph ammonites may have given them the ability to adjust more easily to changes in depth than planispiral ammonites could, particularly while the animal was growing. Although the anatomy of an ammonite's siphuncle is slightly different from that of a nautilus', the mechanism by which the siphuncle emptied the chambers of fluid was probably substantially the same. Enzymes in the siphuncular epithelial cells establish local osmotic gradients steep enough to draw fluid out of the chambers in spite of the pressure of seawater, which tends to force fluid in the opposite direction. As the pressure changes with depth the osmotic gradient must change if the animal is to continue emptying chambers when it moves to greater depths. If the siphuncle is "decoupled" from fluid in the chambers, however, only the osmotic gradient of the wicklike inner membrane of the shell near the siphuncle need change. In planispiral shells the old chambers rotate up and over as new shell is added at the aperture; the position of the siphuncle in relation to the fluid in any chamber, and thus the degree of decoupling, changes throughout growth. In some heteromorphic shells, such as the torticonic (snail-shaped) shell to the right, the siphuncle in any given chamber remains in a constant position throughout growth and is generally decoupled from the liquid. As a result of this adaptation less energy is required to evacuate chambers.

The decoupling of cameral fluid may have been even more important in ammonites than it is in the nautilus. When a nautilus is mature, virtually all the fluid has been pumped out of its chambers. Recent studies of ammonites, however, suggest that they retained some fluid in their chambers even after they were mature. Richard Reyment of the University of Uppsala has been able to calculate the specific gravity of mature ammonite shells from well-preserved fossils. He found that the shells were much less dense than nautilus shells. Unless the bodies of the ammonites were much denser than the body of the nautilus, 10 to 20 percent of the ammonite phragmocone (compared with 1 or 2 percent of the phragmocone of an adult nautilus) would have had to be filled with fluid to give the animal neutral buoyancy.

The decoupling of cameral fluid in planispiral ammonite species, however, may have been even less efficient than that in the planispiral nautilus. As a planispiral cephalopod adds new shell at the shell opening the older chambers slowly rotate up and over the body chamber. The positions of the older chambers are relatively unimportant in the nautilus both because the chambers are empty and because the siphuncle is centrally located. In the ammonites, however, the older chambers were probably partially filled and the siphuncle was positioned against the outer shell wall. Thus the siphuncle in chambers at the top of the whorl would be decoupled if any fluid had been removed from the chamber, but the siphuncle in chambers at the bottom of the whorl would be

coupled as long as the chamber contained any fluid. The changing position of the siphuncle as the shell grew would have made it even harder for the animal to maintain neutral buoyancy as it changed depth.

One of the major advantages of the heteromorphic shell shapes may have been that the siphuncle in any given chamber remained in a constant position with respect to the cameral fluid as the shell grew. The best examples of this adaptation are the ammonite species belonging to the middle Cretaceous family Turrilitidae and those belonging to the middle to late Cretaceous family Nostoceratidae. In both of these families the shells are helically coiled. In a planispiral shell the axis of coiling is horizontal; in a helicoid shell the axis of coiling is vertical. As a result in the course of shell growth the chambers in a planispiral shell are in effect on a Ferris wheel and the chambers in a helicoid shell are on a merry-go-round.

The siphuncle in a helicoid shell is in a slightly different position with respect to the cameral fluid in successive whorls of the shell but maintains its position as the shell grows; the siphuncle in a planispiral shell does not do so. Moreover, in many species of these two ammonite families the siphuncle migrated high up on the flank of the shell, so that the decoupling of the cameral fluid came soon after the chamber began to be emptied. The migration of the siphuncle, together with the constant position of the siphuncle throughout growth, meant that most of the chambers in the phragmocone were decoupled, even if most of them retained some cameral fluid. Therefore the heteromorphs seem to have gained a more efficient system for the maintenance of neutral buoyancy at the expense of reduced streamlining.

The great stability of the heteromorphic shells and the adaptations they show for the decoupling of cameral fluid have led some workers, such as Andrew Packard of the University of Edinburgh and Herbert Klinger of South Africa, to concur with my supposition that at least some heteromorph species lived at middle depths rather than on the ocean bottom. Many modern cephalopods, such as members of the genus *Spirula* and the cranchid squids, float like balloons at middle depths, moving into shallower waters at night and slowly sinking back into deeper daytime habitats. Some of the heteromorph ammonites may have been capable of such a mode of life and so have escaped from the shallow shelf habitats of the Cretaceous ammonites.

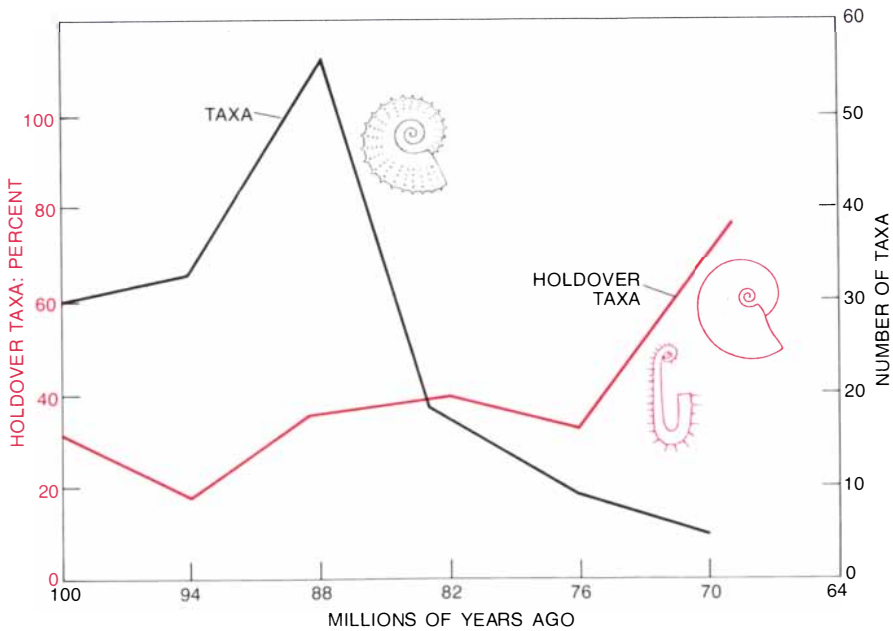
All three shell types (streamlined planispiral shells, heavily ornamented planispiral shells and heteromorphic shells) had appeared at some point in the long history of the ammonoids. What sets the Cretaceous period apart is the sudden increase in the numbers of species with these shell types at the expense of species with poorly streamlined and weakly ornamented planispiral shells, the dominant shell type throughout most of the history of the ammonoids.

In the last stages of the Cretaceous (the Campanian through the Maestrichtian) the number of species of ammonites dropped sharply. There is an interesting pattern to this reduction of diversity. Philip W. Signor of the University of California at Davis and I have analyzed the trends in the origin and extinction rates of families, genera and species of Jurassic and Cretaceous ammonites. The average lifetime for ammonite genera in these periods was about seven million years. William J. Kennedy of the University of Oxford and William A. Cobban of the U.S. Geological Survey have estimated that the average lifetime of ammonite species was between one and two million years. Scattered among these short-lived taxa, however, are a few genera and species that were far more durable; some genera survived for as long as 100 million years. Our studies show that the average lifetime of ammonite genera increased toward the end of the Cretaceous. In other words, the reduction in ammonite diversity was almost entirely due to the extinction of short-lived taxa.

Perhaps not surprisingly, the extinction of short-lived taxa with heavily ornamented and nonstreamlined shells accounts for most of the reduction in diversity at the end of the Cretaceous. That left comparatively few taxa but comparatively long-lived ones, most of which had heteromorphic or streamlined shells. The argument could easily be made that the great reduction in diversity was therefore not necessarily a precursor of the complete extinction of the ammonites.

The fate of the remaining species of ammonites is still not clear. The reason is that the extinction of the ammonites came at a time when shallow ocean basins, the preferred habitat of ammonites, were reduced in area worldwide. Most stratigraphic sections encompassing the transition between the Cretaceous and the Tertiary periods are therefore deep-sea sediments that lack large fossils such as ammonites. So far only two stratigraphic sections that record the final one to two million years of the history of the ammonites have been uncovered. In both of these sections fossils of about 10 species of ammonites have been found in upper Maestrichtian strata. In both roughly half of the fossils belong to genera that have compressed, streamlined shells, such as *Sphenodiscus* and *Pachydiscus*, and half belong to heteromorph genera such as *Scaphites*, *Baculites* and *Diplomoceras*. Unfortunately the stories the sections tell are otherwise contradictory.

At the Stevns Klint section in Denmark, Tove Birkelund of the University of Copenhagen found ammonites of various sizes immediately below strata containing higher than normal concen-



REDUCTION IN DIVERSITY that preceded the complete extinction of the ammonites at the end of the Cretaceous has an interesting pattern. The 300-million-year history of the ammonoids is characterized by the rapid evolution and extinction of many short-lived taxa. The average lifetime of ammonite genera increased during the Cretaceous, however, at the same time that the number of genera dropped precipitously. The reduction in diversity was almost entirely due to the extinction of high-turnover taxa. Why the remaining long-lived (holdover) taxa, some of which closely resembled contemporary nautiloids, became extinct is still unclear.

trations of iridium, one of the platinum-group elements the Alvarezes and their colleagues suggest are derived from a meteorite impact. Recently, however, Wiedmann and I were able to collect large numbers of ammonites from the late Cretaceous section at Zumaya in Spain. As in the Danish section, ammonites are profusely strewn throughout most of the Cretaceous strata; hundreds of fossils can be collected from the beautifully exposed bedding planes.

At about 15 meters below the iridium anomaly in the Zumaya section the number of ammonites gradually falls off. The youngest ammonite in any collection from Zumaya comes from 10 meters below the boundary, even though other large fossils such as echinoids and bivalves are found immediately below and above the boundary. This evidence is negative and could be overturned by the finding of a single new ammonite specimen. Even if a specimen were found immediately below the boundary at Zumaya, however, it would not change the fact the ammonites had virtually disappeared from the region long before the proposed impact of a meteoritic body.

Any hypothesis about the fate of the ammonites must take into account one final question. Why should even the long-lived ammonite species have died out at the end of the Cretaceous when the nautiloids survived? Perhaps no definitive answer will ever be given. My best guess is that the reproductive strategy or perhaps some aspect of the ecology of the adults saved the nautiloids. Plankton, the small floating plants and animals of the sea, had the highest rate of extinction of any group of marine organisms at the end of the Cretaceous; 90 percent of all plankton species were extinguished. Juvenile ammonites hatched from small eggs, with shells no larger than one millimeter in diameter, may have spent their first days or weeks as members of the plankton. The juveniles of nautiloids from the Mesozoic onward seem, on the basis of the form of their shells, to have hatched at a much larger size (from five to 25 millimeters). Juvenile nautiloids probably spent no time as members of the plankton and immediately assumed the near-bottom deep-water foraging mode of life characteristic of the adults. The ammonites may thus have been caught up in the collapse of the plankton ecosystems, either as juveniles or as adults feeding lower down on the food chain than the nautiloids.

For whatever reason, the nautiloids survived the crisis at the end of the Cretaceous and even went on to radiate modestly in the Tertiary period of the Cenozoic era. The low diversity of modern nautiloids suggests, however, that the time for chambered shells, no matter how well engineered, is past.

RENAULT ALLIANCE WATCHWORD: TECHNOLOGY

If you want to invest in European technology but haven't found a car priced within reach—look at Renault Alliance. Independent suspension with unique twin coaxial torsion bars for a quiet, smooth ride. Sedan comfort for five, with Renault's exclusive pedestal seats for extra rear seat leg room. Power front disc brakes. Electronic fuel injection for an outstanding **52** EST HWY, **38** EPA EST MPG.* Renault Alliance. *Built in America* and priced to bring affordability to European Technology: **$5959.**** It's the one to watch.

Alliance 2-door

* Mileage may vary with speed, trip length, weather. Actual highway and CA figures lower. ** Manufacturer's suggested retail price for 2-door. Tax, license, destination charges, optional or regional equipment extra.

Built by American Motors.

RENAULT

THE ONE TO WATCH

Bilateral Negotiations and the Arms Race

A historical review of the negotiating positions of the U.S. and the U.S.S.R. in several major arms-control talks suggests that each side has special problems in dealing with the other

by Herbert F. York

Why is it so hard for the U.S. and the U.S.S.R. to negotiate mutually beneficial arms-control agreements? The question arises most pointedly in the context of the prolonged bilateral talks now under way in Geneva on the limitation of intermediate-range nuclear weapons in Europe and on the reduction of strategic, or long-range, nuclear arms in general. It applies equally, however, to other attempts—past, present and future—by the two superpowers to resort to direct diplomatic means to moderate the arms race and help reduce the chances of nuclear war. In my view there are certain important idiosyncrasies in the negotiating positions of both parties that make it particularly difficult for them to reach such agreements. To show what I mean I shall review here the historical background and current status of several major lines of arms-control negotiations. In so doing I shall draw in part on my experience as a participant in such sessions, particularly in the latest round of the longest-running nuclear-arms-control discussions of all: the sporadic, 25-year-old effort to achieve a comprehensive ban on nuclear-weapons tests.

The first concrete step toward controlling the nuclear-arms race was the moratorium on nuclear testing that was observed by both the U.S. and the U.S.S.R. from 1958 to 1961. Two main factors lay behind this achievement. One was external: public concern expressed in increasingly urgent terms, both in the U.S. and abroad, about the dangers of radioactive fallout from aboveground nuclear tests, aroused largely by the accidental exposures to radioactivity resulting from the U.S. Bravo test in the Pacific in 1954. The other factor was internal: a deepening concern on the part of President Eisenhower and some of his advisers (and apparently also on the part of Premier Khrushchev and some of his advisers) about where the nuclear-arms race was heading, joined with a determination on both sides to find and take a suitable first step in the direction of doing something about it. The moratorium was not the result of a bilateral negotiation; it was supported by nothing more than a pair of matched unilateral public statements to the effect that "we shall refrain from further nuclear-weapons tests if you will."

In President Eisenhower's view the main purpose for declaring a moratorium was to create a political climate conducive to the negotiation of a detailed treaty on the subject of testing. Unfortunately the negotiations became deadlocked at an early stage over an issue that has continued to plague attempts to negotiate such bilateral arms-control agreements ever since. In brief, the American negotiators were not satisfied with the verification procedures the Russian negotiators were willing to discuss, and the Russians in turn charged that the Americans were actually interested only in spying and wanted far too much in the way of intrusions on their national sovereignty. In this case the issue revolved around the problem of detecting and identifying underground test explosions. The U.S. held that the problem could be handled adequately only on the basis of a system of fairly intrusive and mandatory on-site inspections, and the U.S.S.R. was unwilling to accept any such arrangement.

After negotiations on a treaty had been under way for more than a year President Eisenhower became dissatisfied with their pace, and partly in response to pressure from critics within his administration he announced that the U.S. was no longer bound by its pledge not to test but would not resume testing without giving notice. Several days later Premier Khrushchev declared that in that case the U.S.S.R. was also no longer bound by its pledge not to test but would not begin testing again unless the Western nations did so first. A few months later, in early 1960, France conducted its first nuclear test. Even so, neither the U.S. nor the U.S.S.R. resumed testing immediately. Finally, more than a year later, the U.S.S.R. suddenly initiated a major series of nuclear tests, thus ending the bilateral moratorium.

This action on the part of the U.S.S.R. has often been cited as an example of Communist perfidy. It was indeed wrong, I believe, but it was not perfidious, since no agreement—either tacit or explicit—to refrain from such tests existed at the time. In any case the U.S. responded quickly with a major test series of its own. Finally, as a result of the alarm produced by the Cuban missile crisis of October, 1962, negotiations were resumed, and in 1963 President Kennedy and Premier Khrushchev finessed the problem of how to verify a ban on underground tests by negotiating and signing the Limited Test Ban Treaty, which banned tests in the atmosphere, outer space and underwater but allowed them to continue underground.

Following this qualified success the U.S. and the U.S.S.R. continued to explore the possibility of a ban on all nuclear tests, but they were unable to resolve the fundamental issue of verification. Some additional partial measures were eventually achieved, however, including the Threshold Test Ban Treaty of 1974 and the Peaceful Nuclear Explosions Treaty of 1976. In addition the closely related and very important Non-Proliferation Treaty and the treaty establishing a Latin-American nuclear-weapon-free zone (the Treaty of Tlatelolco) were signed, both in 1968. The goal of a comprehensive test ban, however, has remained elusive.

In 1977 President Carter included the negotiation of a comprehensive test ban among his top arms-control priorities. By that time the position of the U.S.S.R. with regard to on-site inspections had evolved to the point where it was willing to accept a voluntary form of on-site

inspection; meanwhile, the U.S. position had evolved to the point where it was willing to accept a carefully hedged form of voluntary on-site inspections instead of mandatory ones. In addition the Russians indicated their willingness to accept a substantial number of specially designed and constructed "national seismic stations" on their territory. Between 10 and 15 of these stations were to be built according to agreed specifications and provided with cryptologic systems that would guarantee that the data stream received from them was continuous and unmodified.

The details of a treaty were only about half worked out when external events slowed the negotiations to such an extent that it became impossible to complete the process before the end of President Carter's term. Among the external factors were unanticipated difficulties in the second phase of the strategic-arms-limitation talks (SALT II), which were going on at the time, the seizure of U.S. hostages in Iran and the Russian intervention in Afghanistan. The Carter round of test-ban negotiations was adjourned indefinitely a week after the 1980 elections.

The Reagan Administration decided immediately after taking office not to resume the negotiations, but it continued to debate for almost a year and a half its reasons for not doing so. One group argued that the administration should simply declare that as long as the U.S. relied on nuclear weapons as an important element of its defense strategy, it would be necessary to continue testing them, and so a comprehensive test ban would not be in the nation's interest for the foreseeable future. A second group argued that the main problem was that there still was no adequate system for verifying a ban on underground tests (the implication being that if there were, the U.S. might then be willing to negotiate an agreement). The second group eventually won the internal debate, and the current official position is that a comprehensive test ban remains a "long-term goal" of the U.S. but that "international conditions are not now propitious for immediate action on this worthy project."

In recent years, including the entire tenure of the Carter Administration, the Joint Chiefs of Staff have consistently and forcefully argued that a comprehensive test ban would not be in the best interests of the U.S., whether or not it could be adequately verified (and they did not believe it could be). In particular, they asserted that as long as the nation maintains a stockpile of nuclear weapons it will continue to be necessary to conduct at least occasional tests to be confident that the weapons in the stockpile are still in working order. The Joint Chiefs based this position on the advice given to them by their own advisers in the Defense Nuclear Agency and on the advice of most of the experts in the nuclear-weapons laboratories. The issue of "stockpile reliability," as it is called, has continued to be the principal basis for the opposition to a comprehensive test ban in both the Department of Defense and the Department of Energy.

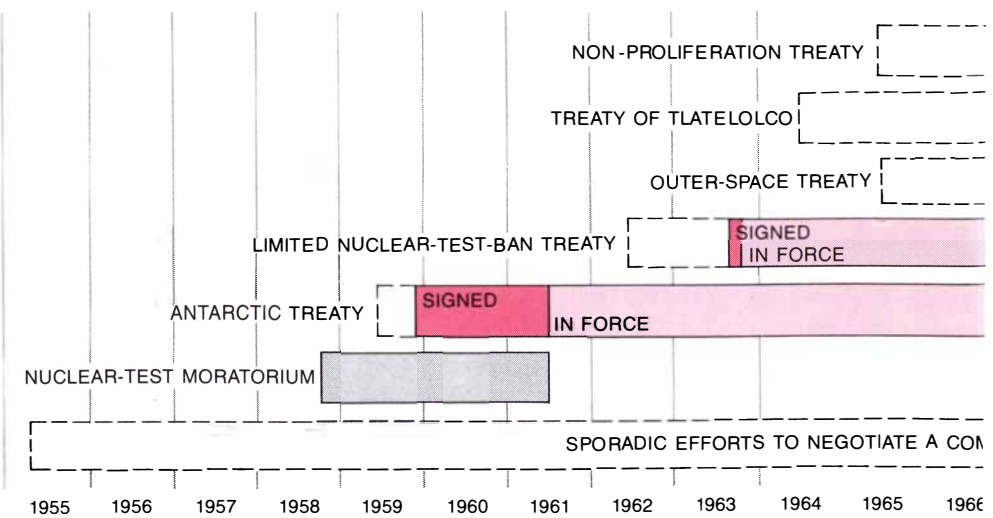
The main argument in favor of a comprehensive test ban in recent years has been that it is an essential element of the nation's nonproliferation policy. In particular, it is usually pointed out that the Non-Proliferation Treaty, which has been signed or acceded to by a large majority of the world's nations, calls for "good faith" negotiations by the superpowers to end the arms race and ultimately to eliminate their nuclear weapons, and the seriousness with which they approach the test-ban issue is widely taken as a measure of their good faith in the matter.

The verification issue remains highly controversial. In brief, large- and moderate-yield nuclear explosions can be readily detected and identified by means of remote sensors but very small ones cannot. The boundary separating the two classes of events is indistinct, however, and that leads to widely varying interpretations of the data, depending on the predisposition of the person interpreting them.

From the beginning of the nuclear age the dominant view in both the U.S. and the U.S.S.R. has been that the interests of both countries and indeed of the world would be best served if there were no other nuclear powers, or at any rate as few as possible. This is one of the rare instances in which both the Americans and the Russians seem to be fully aware that their interests are exactly parallel.

The U.S. has devised a number of specific policies and actions designed to promote the goal of the nonproliferation of nuclear weapons, sometimes unilaterally and sometimes in concert with other nations. Among the measures taken were the creation of the International Atomic Energy Agency, the passage by Congress of the Nonproliferation Act of 1978 and numerous diplomatic initiatives involving such matters as severely limiting the reprocessing of spent fuel from nuclear reactors and placing restrictions on the sale of nuclear-power equipment. Last but certainly not least there is the Non-Proliferation Treaty of 1968, which went into force in 1970.

In essence the Non-Proliferation Treaty can be viewed as an attempt to divide the nations of the world permanently into two categories: one consisting of those nations that already had nuclear weapons and that were pledged not to help anyone else obtain them, and the other made up of those nations that did not have nuclear weapons then and promised to forgo them forever. In return for the promise not to acquire nuclear weapons the non-nuclear nations exacted two promises from those signatories that already had them. One promise was that the "haves" would help the "have-nots" acquire the technology needed to enable them to benefit fully from the peaceful applications of nuclear energy; the other was that the "haves" would undertake serious negotiations to



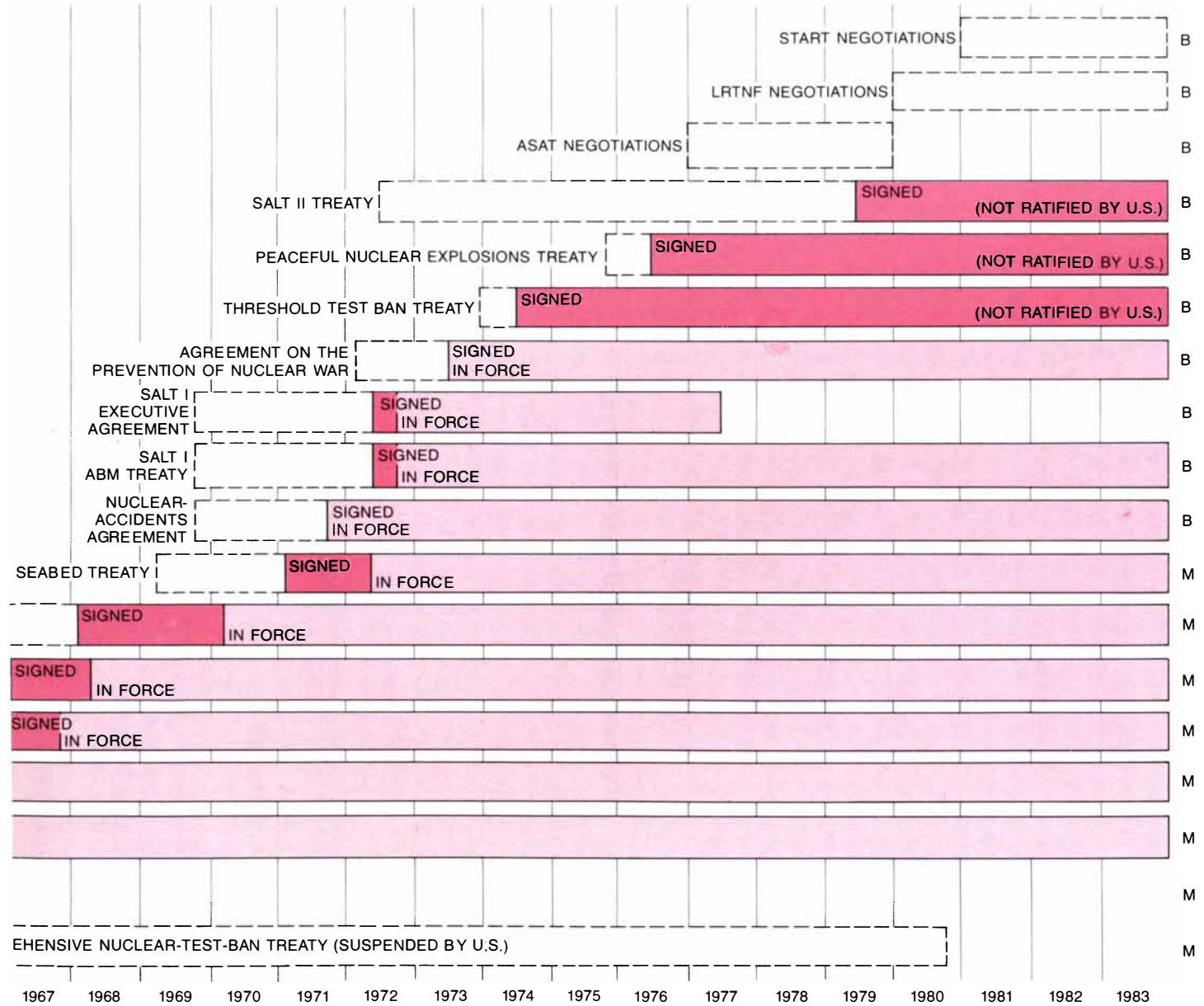
CHRONOLOGY of major nuclear-arms-control negotiations held since 1955 is displayed in the chart on these two pages. The part of each bar represented by the broken outline shows the duration of the negotiating period, the dark-colored part corresponds to the interval between the signing of a treaty and its ratification and the light-colored part is the period during which an agreement is in force. The capital letters at the extreme right indicate whether an agreement is multilateral (*M*) or bilateral (*B*) between the U.S. and the U.S.S.R. Three bilateral treaties

end the nuclear-arms race and eventually eliminate their own nuclear weapons. The treaty also calls for a review of the overall situation every five years. At both of the first two review conferences (in 1975 and 1980) many participating countries complained that neither of the superpowers was living up to the special obligations described above. In spite of these complaints there have been no defections from the treaty, and more importantly there has been no further nuclear-weapons proliferation since the treaty was signed.

There are of course cases where further proliferation could happen soon (India, Pakistan, Israel, South Africa, Argentina and Brazil, for example), but so far even those countries that have evidently advanced quite far down the road toward a nuclear-weapons capability have refrained from testing or otherwise overtly establishing themselves as nuclear-weapons states. (This observation applies even to India, which exploded a nuclear device 10 years ago but has not created a nuclear-weapons force.) Surely the policies and actions described here, including in particular the Non-Proliferation Treaty, must be viewed as a large part of the reason for the long and quite unexpected delay in the appearance of additional nuclear powers beyond the five that have had a nuclear-weapons force since China became a member of the club in 1964.

In spite of this generally successful record it must be noted that some very important nations have refused to sign the Non-Proliferation Treaty, including China, France, Cuba, India, Argentina, Brazil and Israel. In the case of France and China the omission is particularly serious, but at least each of them has pledged to live up to the spirit of the treaty even while refusing for political reasons to formally adhere to it.

President Johnson early in his term of



remain unratified by the U.S. Senate: the Threshold Test Ban Treaty (signed by President Nixon in 1974), the Peaceful Nuclear Explosions Treaty (signed by President Ford in 1976) and the SALT II Treaty (signed by President Carter in 1979). The U.S. and the U.S.S.R. are currently engaged in two nuclear-arms-control negotiations in Geneva: the Strategic Arms Reduction Talks (START) and discussions on the limitation of intermediate-range nuclear weapons in Europe. (Such weapons are technically known as long-range theater nuclear forces, or LRTNF.) Negotiations aimed at achieving a comprehensive nuclear-test ban and an agreement to forestall the further development and deployment of antisatellite (ASAT) weapons have apparently been abandoned by the Reagan Administration.

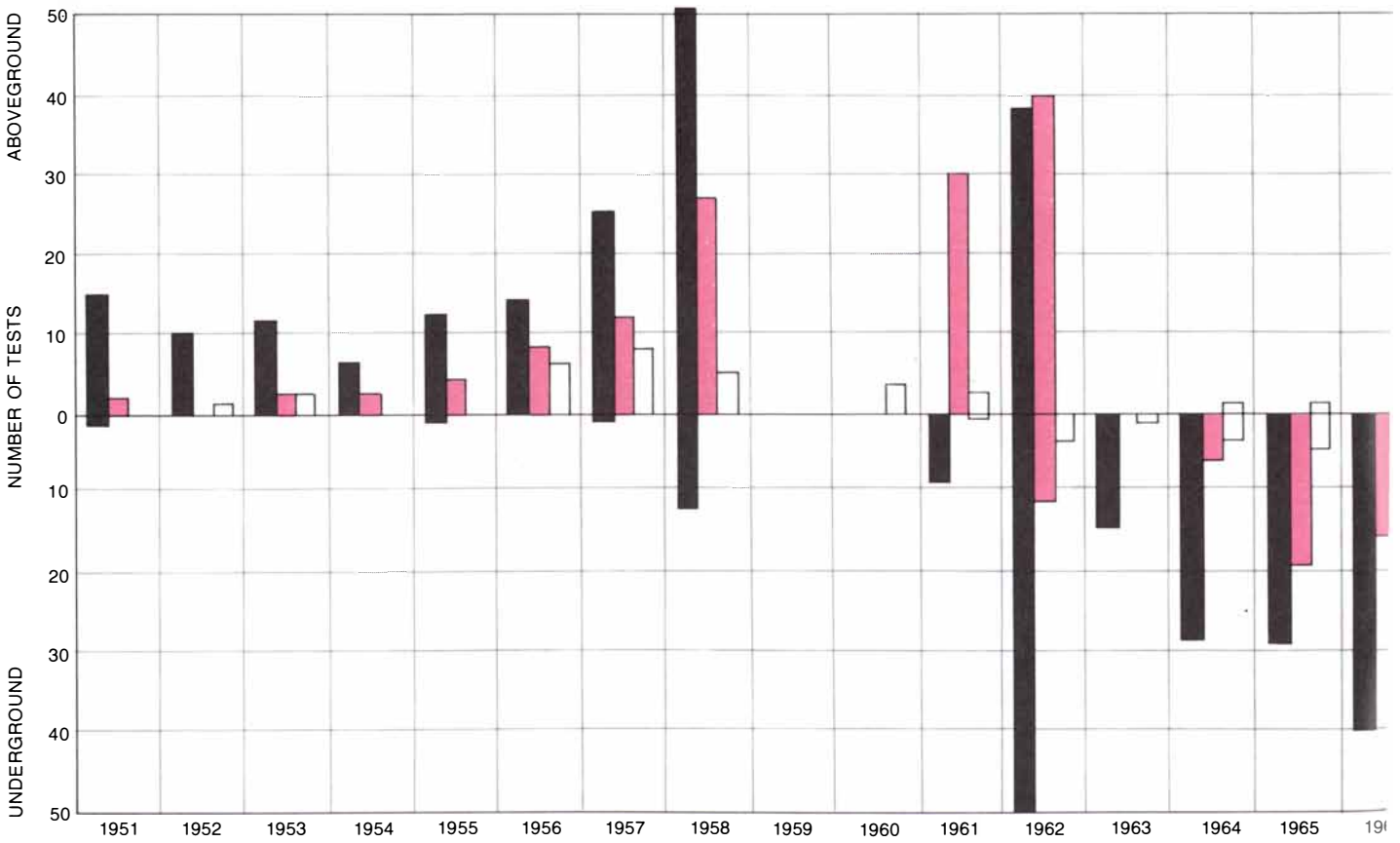
office proposed a freeze on the further development or deployment of strategic delivery systems. After some discussion of the proposal at the Geneva arms talks, President Johnson met with Premier Kosygin in Glassboro, N.J., where they discussed the matter privately. It was on this occasion that Secretary of Defense Robert S. McNamara, who was also present, first formally raised the idea of initiating such a freeze by prohibiting the deployment of anti-ballistic-missile (ABM) systems. Premier Kosygin rejected the idea on the ground that ABM weapons were purely defensive and that it was, after all, only offensive weapons that threatened the lives of many millions of people. Secretary McNamara and other Americans, however, persisted in arguing at various public and private meetings that the development and deployment of ABM systems stimulated the arms race just as much as the development and deployment of offensive systems because of an "action-reaction cycle" in which the development of defensive weapons promoted the development of new offensive weapons. Eventually the Russians came around to this point of view.

President Johnson's attempts to initiate formal bilateral negotiations on the limitation of strategic arms were thwarted by the Russian intervention in Czechoslovakia in 1968. Only after President Nixon took office in 1969 and the international scene had calmed down was it possible to get what is now known as the SALT process under way. The first series of these talks (SALT I), concluded in 1972, resulted in two achievements: a treaty that severely limited the deployment of ABM systems and an executive agreement that temporarily froze the deployment of land-based and sea-based offensive missiles at numbers equal to those already deployed plus those whose deployment was under way at the time the agreement was signed. The net result was a rough strategic balance that was intended not to be an end in itself but to serve as the basis for further negotiations whose ultimate aim was to produce a situation of actual overall parity at a much lower level of total deployments.

One of the principal residual problems of the SALT I agreements was that the U.S.S.R. was left with a substantial number of very large missiles (designated SS-18's by Western sources), whereas the U.S. had no missiles of comparable size. In the early 1970's, before highly accurate MIRV's (multiple independently targetable reentry vehicles) were fully developed and widely deployed, this imbalance did not seem serious to most observers, but in recent years, with the perfection of high-multiplicity MIRV systems and the achievement of very high accuracies by the U.S.S.R. as well as by the U.S., the issue of the SS-18's has come to be widely seen as a serious matter. The new developments increase the vulnerability of the land-based component of the U.S. "triad," the leg on which U.S. defense policy places the most reliance.

The next step after SALT I was the Vladivostok Agreement of 1974, signed by President Ford and President Brezhnev. In essence it was intended to establish general guidelines for the detailed SALT II negotiations, which had already started in Geneva. The guidelines called for an "equal aggregate limit on delivery vehicles" of 2,400 and an "equal aggregate limit on MIRV systems" of 1,320. The effort to transform the Vladivostok guidelines promptly into a formal treaty ran afoul of both technical and political problems. The technical problems had to do with cruise missiles and the Russian "Backfire" bomber; the political problems arose from increasing disillusionment about détente and the challenge to President Ford's nomination by the right wing of the Republican party.

In 1977 the SALT II negotiations became the principal element of Presi-



NUCLEAR TESTING by the U.S. (*black bars*), the U.S.S.R. (*colored bars*) and all other nations (*white bars*) is charted from 1951 through 1982. The gap at the left reflects the moratorium on nuclear-weapons tests that lasted from 1958 to 1961. The net effect of the Limited

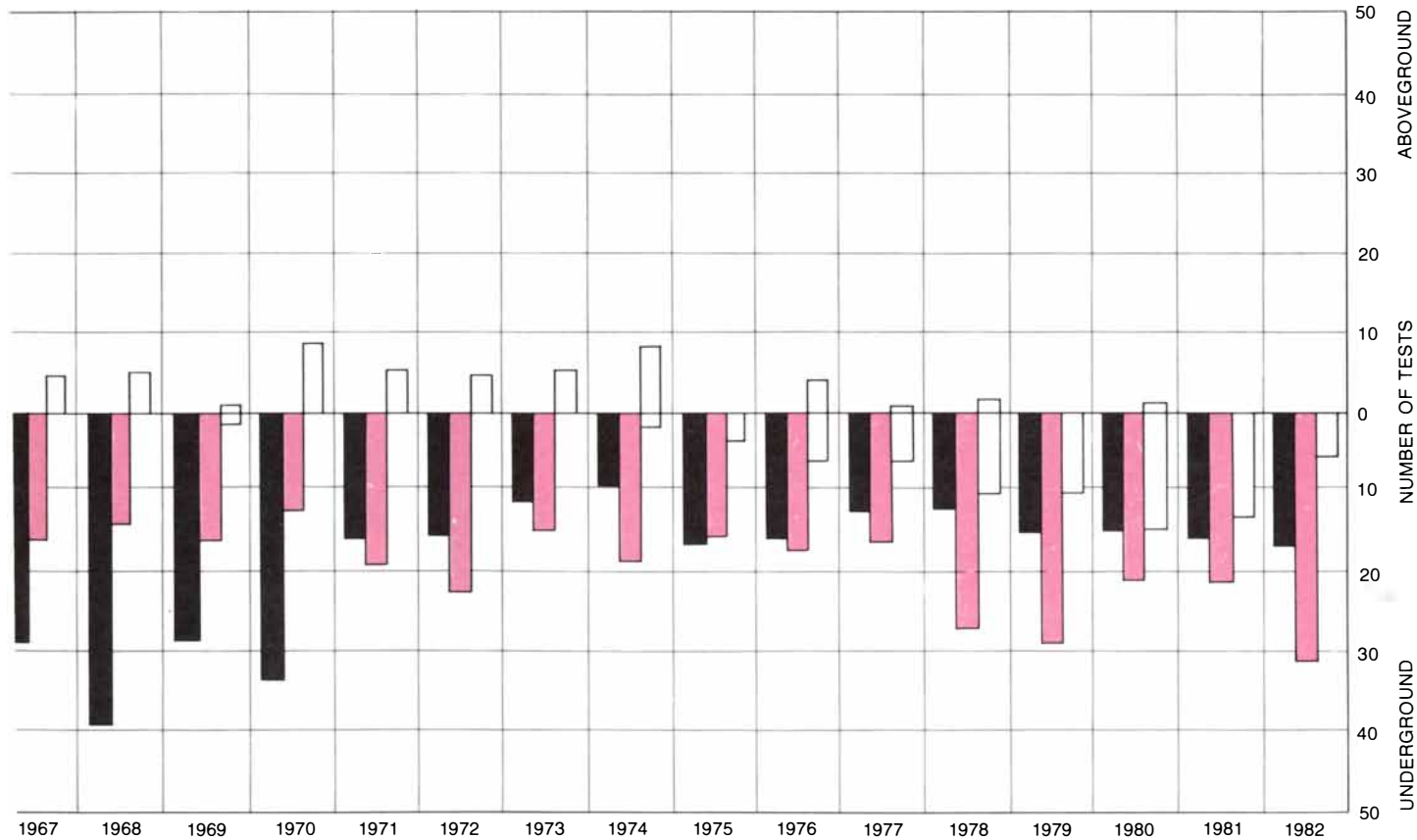
dent Carter's arms-control policy. At first President Carter proposed some reductions in the number of deployed systems below the Vladivostok aggregates, a 50 percent cut in the Russian heavy missiles (modern versions of which were barred to the U.S. entirely) and limits on tests, improvements and numbers of MIRVed intercontinental ballistic missiles (ICBM's). The latter provisions were intended to forestall any further worsening of the problem of ICBM vulnerability and generally reduce technological pressures on the arms race. The U.S.S.R., however, insisted on staying within the Vladivostok framework. The SALT II negotiations were completed in Geneva and in a series of high-level meetings over the next two years, and the resulting treaty was signed by President Carter and President Brezhnev in Vienna in 1979.

The SALT II Treaty basically kept the Vladivostok framework. It set an overall limit on strategic nuclear delivery vehicles of all kinds at 2,250 for each side, and within that limit it provided a nested series of sublimits, setting a ceiling of 1,320 on MIRVed systems of all kinds (including heavy bombers with long-range cruise missiles), a ceiling of 1,200 on MIRVed ballistic missiles and a ceiling of 820 on MIRVed ICBM's. It also limited each side to only one new type of ICBM, banned major changes in existing systems and set specific limits on the number of reentry vehicles that could be placed on the one new ICBM and on each type of existing ICBM. In addition temporary limits on ground-launched cruise missiles (GLCM's), sea-launched cruise missiles (SLCM's) and mobile ICBM's were intended to provide time for the negotiation of longer-term agreements on these systems.

Much of the criticism of the SALT II Treaty in the U.S. grew out of widespread frustration over the nation's international troubles, exaggerated fears of nuclear inferiority (stimulated by right-wing critics at home) and lack of confidence in President Carter's competence in security matters generally and his commitment to military programs in particular. In addition the impending presidential election made Republican senators reluctant to hand a major foreign-policy victory to a weakened opponent. In spite of broadly based satisfaction with the overall terms of the treaty itself, there were several particular treaty issues that raised serious questions in the minds of those senators and other political figures who took an extremely cautious view of the entire arms-control process.

One such issue was that SALT II, like SALT I before it, did nothing to alleviate the heavy-missile problem other than to put a rather high cap on the number of warheads each type of missile could carry. A second issue involved the Backfire bomber, an aircraft that is technically capable of reaching the U.S. under certain unusual circumstances. Some American observers asserted that the Backfire was therefore an intercontinental bomber that must be included under the ceilings. The U.S.S.R. contended (and many American observers agreed) that the Backfire's mission was only that of an intermediate-range bomber, and so it should not be included, particularly since the U.S. medium-range aircraft in Europe capable of reaching the U.S.S.R. had been excluded at Vladivostok over the strong objections of the U.S.S.R. A third issue involved the encryption of certain test data broadcast by Russian missiles during test flights. This last subject is a rather arcane one that cannot be usefully elaborated in an unclassified discussion. Suffice it to say that most of the professionals who were then involved believed the matter had been adequately handled.

On the Russian side the principal issue raised after the Vladivostok meeting concerned cruise missiles, which the U.S.S.R. wanted sharply constrained. (To avoid limitations on exist-



Test Ban Treaty of 1963 was not to diminish the rate of nuclear testing but merely to drive most of it underground. (Only France and China have tested in the atmosphere since then.) The figures were supplied by the Stockholm International Peace Research Institute.

Medicine is always changing, now there's a text that changes right along with it.

SCIENTIFIC AMERICAN *Medicine.*

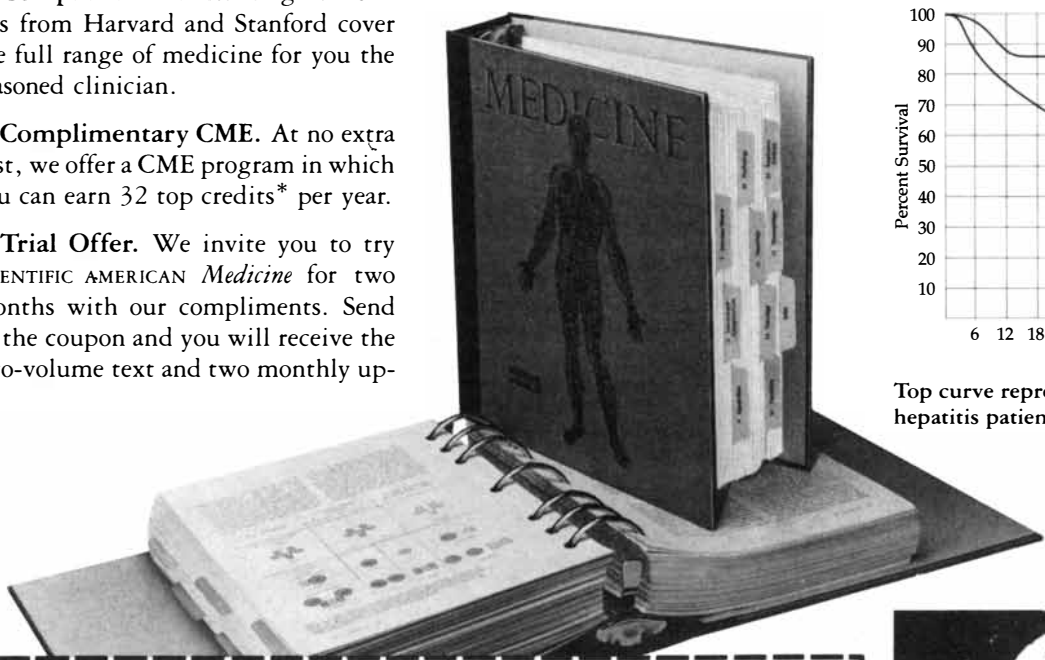
The answers that you get from SCIENTIFIC AMERICAN *Medicine* are current, because each month new chapters replace the old. You will know where to look for the answers, because this advanced text follows the familiar structure of medical knowledge, changing as medicine changes.

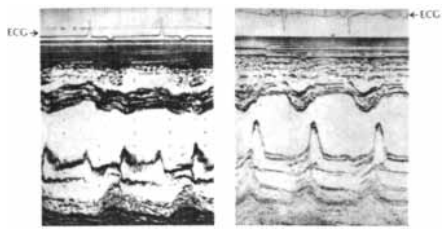
Comprehensive. Leading authorities from Harvard and Stanford cover the full range of medicine for you the seasoned clinician.

Complimentary CME. At no extra cost, we offer a CME program in which you can earn 32 top credits* per year.

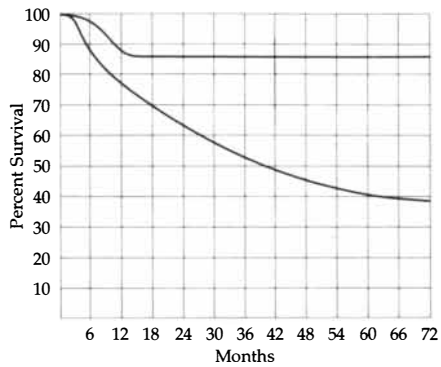
Trial Offer. We invite you to try SCIENTIFIC AMERICAN *Medicine* for two months with our compliments. Send us the coupon and you will receive the two-volume text and two monthly updates. You may also take a CME test for credit. At the end of 60 days, if you decide to continue the subscription, you will owe us $220 for the first 12 months (current renewal is $170); otherwise, return the books; there is no charge.

Please mail the coupon today so that we can put medical progress to work for you.





Echocardiograms from patients with aortic regurgitation.



Top curve represents survival in chronic hepatitis patients treated with steroids.

CT scan reveals large meningioma and mild hydrocephalus.

SCIENTIFIC AMERICAN MEDICINE

415 Madison Avenue, New York, New York 10017

Please enroll me as a subscriber to SCIENTIFIC AMERICAN *Medicine*. On receipt of this coupon you will send me the advanced two-volume text described in your announcement and update it regularly by sending me new monthly subsections. I understand that the annual subscription of $220 for SCIENTIFIC AMERICAN *Medicine* is tax deductible. If I am not entirely satisfied, I may cancel at any time during the first 60 days, returning all materials for a *complete refund*.

☐ Please enter my subscription for SCIENTIFIC AMERICAN *Medicine*
☐ I shall also enroll in the CME program
☐ I enclose a check made out to SCIENTIFIC AMERICAN *Medicine* for $220*
☐ Bill me ☐ VISA ☐ MasterCard

Expiration Date_____ Account Number_____

*Please add sales tax for California, Illinois, Massachusetts, Michigan, Ohio and New York

Name_____ MD Specialty_____

Address_____

City_____ State_____ Zip_____

Signature_____

Please allow six to eight weeks for delivery. All payments must be in U.S. dollars. CME is available outside the U.S. and its possessions for an additional $65. Surface routes used unless airmail delivery is prepaid. 7E

You may also order your trial copy by calling toll-free 1-800-345-8112 (in Pennsylvania, 1-800-662-2444).

*As an organization accredited for continuing medical education, the Stanford University School of Medicine designates this continuing medical education activity as meeting the criteria for 32 credit hours in Category 1 for Educational Materials for the Physician's Recognition Award of the American Medical Association, provided it has been completed according to instructions

This program has been reviewed and is acceptable for 32 prescribed hours by the American Academy of Family Physicians.

This program has been approved by the American College of Emergency Physicians for 32 hours of ACEP Category 1 credit

ing Russian cruise missiles the Russian negotiators insisted that any limits apply only to missiles with a range of more than 600 kilometers.) The issue took on added urgency with the discussion among the member states of the North Atlantic Treaty Organization (NATO) of the possible deployment of ground-launched versions of such systems in Europe, together with President Carter's decision to cancel the B-1 bomber and to emphasize the deployment of air-launched cruise missiles (ALCM's) on bombers based in the continental U.S.

In the case of long-range ALCM's the principal issue was not a ban but how the missiles were to be counted. Was a bomber carrying ALCM's to be counted as a single delivery vehicle no matter how many missiles it carried (as is the rule for a bomber carrying bombs or short-range cruise missiles) or was each ALCM to be counted as an individual delivery vehicle (as in the case of submarine-launched ballistic missiles)? The U.S.S.R. finally agreed to a complex compromise counting only the bombers, with the provisos that no existing type of bomber could be equipped with more than 20 cruise missiles and that the average number of cruise missiles on all bombers so equipped could not exceed 28. In addition if the number of bombers equipped with cruise missiles were to exceed 120, then the number of MIRVed missiles would have to be correspondingly reduced.

With regard to ground-launched and sea-launched cruise missiles the U.S. sought to have no limits applied, because other intermediate-range systems (such as the new Russian SS-20 missile) were not being limited in the agreement; the U.S.S.R. wanted a total ban. In the end testing and development were permitted, but deployment was suspended until the end of 1981 in order to allow further negotiations.

Eventually all these issues were resolved to the satisfaction of the two presidents and most of their advisers, but they continued to provide the basis for opposition to the treaty within the U.S. body politic, and as a result the ratification process was delayed. Ultimately external events—the matter of the "Russian Brigade" in Cuba, the hostage crisis in Iran and the Russian intervention in Afghanistan—overtook the process and brought the attempt to ratify the treaty to a full stop. Carter Administration officials involved in the effort (including myself) remain convinced that for all the troubles the treaty had on Capitol Hill, it would in the end have been ratified but for the Russian intervention in Afghanistan.

During the presidential campaign of 1980 Ronald Reagan and his supporters severely criticized SALT II, calling it "fatally flawed," sometimes on the basis of the issues I have cited. Immediately after the election President Reagan withdrew the SALT II Treaty from any further consideration by the Senate, but he declared the U.S. would abide by it as long as the U.S.S.R. did, and he initiated a new round of negotiations, called START (Strategic Arms Reduction Talks), as a means for generating a treaty more to his liking and that of his supporters. He also placed special emphasis on the need for major reductions in the number of deployed systems, in particular those that have very short flight times (both land-based and sea-based ballistic missiles) and are therefore felt to be particularly destabilizing.

Specifically, it has been reported that the opening U.S. negotiating position at START called for an overall reduction in the number of ballistic delivery systems by more than 50 percent (to 850 ballistic missiles bearing not more than 5,000 reentry vehicles altogether) and also a reduction of 50 percent in heavy ICBM's. In addition the U.S. position is said to be that consideration of limitations on bombers and cruise missiles must be deferred until a later time. It has also been reported that the original position of the U.S.S.R. called for a reduction in the number of delivery vehicles of all types (including bombers) to 1,800 for each side, a figure first proposed by President Carter in 1977 and forcefully rejected by the U.S.S.R. at that time. Recently President Reagan has said he would be more flexible on some of these issues, and he has specifically stated that the total number of ballistic missiles could be somewhere between the American and Russian opening figures.

From the point of view of the U.S.S.R. the main fault in the U.S. position is that it places sole emphasis on those deployments in which the Russians have an advantage and ignores those in which the U.S. has an advantage. From the American point of view the main fault in the Russian position is that it apparently continues to ignore the very important heavy-missile problem.

In addition to the issues I have been describing, which have for some years formed the basis for controversy both within the U.S. national-security community and between the U.S. and the U.S.S.R., two other issues have become increasingly important. One is the issue of mobile missiles, which has arisen mainly because of some of the proposed deployment modes for the MX, the projected successor to the Minuteman ICBM. The other is the matter of "reload capability." It is easy to count missile silos, but it is not easy to count the missiles themselves. Therefore if either side were to build and hold in reserve a number of missiles comparable to the number of silos, a new and serious source of potential instability would result. It remains to be seen whether the current situation will become deadlocked or whether there will be progress in overcoming these problems, but I for one am not optimistic.

There has been a great deal of public discussion in the U.S. of American concessions—real and imagined—made in the course of postwar arms-control negotiations with the U.S.S.R. Western folk history, however, contains virtually nothing about Russian concessions, even though the U.S.S.R. has made a number of important ones. One such concession has to do with the definition of the term "strategic delivery system." It has always been the U.S. position that a strategic delivery system is one that is deployed either in its home territory or at sea and that can reach the home territory of the other country from that deployment site. On the other hand, the Russian position has always been that a strategic delivery system is a system that is able to reach either home territory from its deployment site no matter where the site is.

This difference in viewpoint arises from the very different geopolitical situations of the two superpowers, and it shows up most sharply in the case of "forward-based systems," that is, those medium-range U.S. systems that are currently deployed in Europe and that can reach the U.S.S.R. only when so deployed. The U.S. has consistently refused to count such systems in the SALT totals, and the U.S.S.R. has consistently contended that they should be included. So far the Russians have accepted the American view in this matter. (Such systems are evidently now included in the separately organized talks in Geneva on intermediate-range weapons.)

A second Russian concession involves the British and French nuclear forces. The U.S.S.R. contends that the long-range delivery systems of these two NATO countries should be included in the SALT totals. The U.S. contends that SALT is strictly bilateral and so only the forces of the U.S. and the U.S.S.R. should be counted. In the SALT I agreement the Russians said they would accept the U.S. position provided that the British and French together did not deploy more than nine ballistic-missile submarines (more precisely, that the total number of submarines deployed by the U.S., Britain and France not exceed 50). The U.S. refused to acknowledge even this limitation, but the matter remains moot because that number has not been exceeded.

A third major concession by the U.S.S.R. involves the procedure for counting ALCM's on U.S. bombers. As long as the total number of these cruise

missiles remains less than 3,000 and certain counting rules are satisfied, only the number of bombers so equipped, but not the number of cruise missiles, need be counted and limited under the SALT ceilings. As in the case of the much more widely reported U.S. concessions, the U.S.S.R. has apparently made these concessions and others in a serious spirit of compromise in order to produce a mutually beneficial result.

Just a few weeks before the 1980 presidential elections the U.S. and the U.S.S.R. initiated negotiations designed to limit or eliminate intermediate-range missiles in Europe (technically known in the West as long-range theater nuclear forces). These negotiations are still in progress. Both general and particular factors contributed to the negotiations. The general factor is that there are a great many nuclear weapons (10,000 or more) deployed in or aimed at Western Europe, and yet very few of them are included in the START negotiations. The particular factor arises out of the Russian deployment of the SS-20, the first new weapon in its class in about 20 years. The deployment of the SS-20 began in 1977 and has been proceeding steadily ever since. By 1978 the situation had reached the point where many people in the Western countries became convinced that some kind of reply was necessary, at least for political reasons if not for strictly military ones.

At about this time Chancellor Schmidt of the Federal Republic of Germany made a speech in which he focused special attention on the situation; he asserted there was a need for some sort of highly visible land-based NATO system that would roughly counterbalance the SS-20. In December, 1978, in response to this growing concern, the NATO Council adopted what has become known as the "two-track" approach. One track called for the development and deployment of such a NATO system, and the other called for negotiations designed to make such a system unnecessary. One result of this dual approach was the decision by the U.S. and its NATO allies to deploy on land in Europe 572 intermediate-range missiles of two new types: the ground-launched cruise missile and the Pershing II, a modernized, longer-range version of the Pershing IA missile. As of this writing, neither has been deployed but the latter is expected to be later this year.

The other result of the two-track approach was the initiation of strictly bilateral talks between the two superpowers on this subject in Geneva in late October, 1980. The talks had hardly begun when the U.S. election results came in and both governments knew they would have to wait until the dust settled before anything could be accomplished.

After some months of study the Reagan Administration resumed the negotiations and proposed what is known as the "zero-zero option." This proposal called for the elimination of all Russian medium-range missiles, including the SS-20's (or at least those west of the Urals), in return for a promise by the Western countries to forgo their plan to deploy a counterbalancing force. The response of the U.S.S.R., coming early in the new Andropov administration, proposed that the U.S. eliminate its plans to deploy any such missiles, and that the Russians reduce their SS-20's to a number (162) that would match the corresponding forces belonging to Britain and France.

Considered abstractly, the zero-zero option is clearly a desirable and reasonable proposal. It eliminates an entire class of weapons, one that may have filled a real gap in the 1950's but whose mission can be readily accomplished by other weapons each side now has in abundance. Considered concretely, however, the U.S. proposal calls for the U.S.S.R. to give up weapons it has already bought and paid for, whereas the proposal calls for the U.S. merely to forgo certain of its future plans. Therefore, desirable and reasonable as the zero-zero option may seem, in the current very bad political climate it will probably prove impossible to overcome the difficulty stemming from the asymmetry in the concrete situation. As of this writing each party has stuck with its original position, although President Reagan has indicated there might be some room for compromise on the American side.

From 1958 until about 1977 the principal method used by the U.S. to inhibit the development and deployment of devices suitable for conducting warfare in or from outer space was to practice moderation in its own programs and to urge the U.S.S.R. to do the same. Throughout that period the U.S. deployed space systems that performed important support functions (such as reconnaissance, surveillance and communications), and the military gradually developed an increasing reliance on such systems. Proposals for developing a general-purpose antisatellite (ASAT) system were frequently made in the U.S. by military and industrial organizations, but they were turned down by higher authorities. The basic argument was that the nation's space assets, as they are called, had become so valuable that a world in which neither superpower had antisatellite weapons was better than one in which both did, and that the U.S. therefore should not set a precedent by pushing ahead with the development of an ASAT system of its own. There was only one minor exception to this policy, and that was the development and deployment of an ASAT system of very

limited capability on Johnston Island in the early 1960's because the U.S. suspected the U.S.S.R. was developing a system that involved stationing extremely powerful nuclear weapons in orbit around the earth. The Russian ASAT development never did come, however, and after only a few years the U.S. decommissioned its specialized ASAT system.

In spite of U.S. restraint the U.S.S.R. started in 1967 to test a general-purpose ASAT system of limited capability. Evidently the Russians gave this development a lower priority than most parts of their space program, and it proceeded rather slowly. On occasion the U.S. pointed out that it was deliberately practicing moderation in this area and urged the U.S.S.R. to do the same. That may have had some effect, but the Russian program continued nonetheless.

Finally in 1977 the Carter Administration decided that something more specific had to be done by way of response to the Russian ASAT development, and a three-pronged program was initiated. One element of the program was the decision to begin a full-scale effort to develop an American ASAT system. (A contingent development had already been started during the Ford Administration.) A second was a plan to explore and develop means for defending American satellites against a possible attack by Russian ASAT weapons. The third was the initiation of negotiations designed to forestall further development and deployment of ASAT weapons by either side, if possible.

The first formal negotiations on ASAT systems took place in Helsinki in 1978. Two further negotiating sessions were held in 1979, after which the negotiations were adjourned indefinitely; to this date they have not been resumed. There were both internal and external reasons for the failure to accomplish anything. Internally the problem was twofold. First, the U.S. Government was unable to reach a unified position with respect to what ought to be done. On the one hand, top officials of the Air Force and the Department of Defense placed such a high value on the nation's existing space assets that they were willing to forgo development of an ASAT system if this would ensure that the Russians also did so. The position of the Navy, on the other hand, was that Russian ocean-surveillance satellites presented such a serious threat to the U.S. fleet that the nation needed an ASAT system of its own no matter what the Russians did. Furthermore, officers in the middle levels of the Air Force did not like having any artificial "political" barriers placed in the path of space developments of any kind. On top of these differences the fact that the U.S.S.R. had

already conducted more than a dozen ASAT tests in the preceding decade raised strong pressures for at least an equivalent number of similar tests by the U.S.

The second problem internal to the negotiations was that the Russians also seemed to be ambivalent about the issue. In the negotiations they indicated that in their view there could be serious and valid reasons for possessing an ASAT capability, and they also raised a series of questions about the U.S. space shuttle and what role it might have in this connection. In addition to all these problems relating directly to the substance of the ASAT negotiations, the same general deterioration of the international climate that interfered with SALT II and the comprehensive-test-ban negotiations also operated as a factor strongly inhibiting further progress in this area.

In addition to these so far futile attempts to forestall the development of antisatellite systems, the U.S. and the U.S.S.R. have successfully negotiated more limited agreements in the area. The most important are the clauses in the Limited Test Ban Treaty prohibiting nuclear explosions in outer space, the Outer Space Treaty of 1967 and the clauses of the SALT I Treaty that legitimize and protect reconnaissance satellites used for monitoring arms-control agreements and that prohibit the development and deployment of space-based ABM systems. The Outer Space Treaty prohibits stationing "weapons of mass destruction" in outer space or on celestial bodies. The phrase in quotation marks is always interpreted as including nuclear weapons and excluding non-nuclear ones.

More recently, in 1981, a proposal for an agreement designed to forestall preparations for warfare in space was placed before the United Nations by President Brezhnev. In brief, the proposal called for a prohibition on the deployment of weapons of any kind—not just weapons of mass destruction—in orbit around the earth, on celestial bodies "or in outer space in any other way." The proposal seems carefully to avoid mentioning ground-based ASAT systems of the type both nations are developing. Except for the Brezhnev proposal in 1981 nothing further of a formal nature has happened in this area since the adjournment of the ASAT negotiations in 1979.

There has been much talk lately about the possibility of orbiting "directed-energy weapons" in space. This talk has usually involved three classes of weapons: conventional optical lasers, particle-beam devices and a new category of systems, cryptically referred to by their advocates as "third-generation nuclear weapons," that is known to include X-ray lasers powered by nuclear explosions. These three very different classes of weapons are in very different stages of research and development. The first class, optical lasers, is by far the most advanced. No such system has yet been designed in detail, but presumably one would consist of an assemblage of subsystems some of which would be similar to, although bigger or more capable than, devices that have already been operated in laboratories on earth.

A laser-weapon system that could destroy "cooperative" targets could probably be deployed in space before the end of the century, although at great cost. (I am referring here to high-energy systems that physically destroy their target, not to low-power systems that blind optical sensors or otherwise cause limited special damage.) The two other classes of directed-energy weapons are still only in the research stage. No systems development for either one has yet been carried out or is currently planned, and in my judgment there is no chance whatever that a practical operational device of even limited capability will be deployed in space during this century.

Although the development of such systems is not now prohibited by any international agreement, their development is strongly inhibited by an even more powerful factor: their extremely high cost. The best estimates available indicate that the development cost alone of a "laser battle station" would be about 10 times as much as that of other roughly similar modern high-technology systems (that is, tens of billions of dollars as opposed to billions of dollars), and that the deployment of a system capable of intercepting more than a small fraction of the Russian strategic force would cost a large fraction of a trillion dollars. These huge costs have, so far at least, boggled the minds of responsible officials, and in spite of President Reagan's "Star Wars" initiative there are still no serious plans for the full-scale development of any such battle stations based on any of the various hypothetical types of "killer beams."

The U.S. and the U.S.S.R. each have unique characteristics that make them particularly difficult as negotiating partners when they are dealing either with each other or with third parties. In the case of the U.S. the most serious of these special difficulties arise from certain fundamental mechanisms of the American system of government. These are the requirement for a two-thirds vote in the U.S. Senate for ratification of a treaty and the exceptionally long presidential campaign that the nation goes through every four years.

It was the requirement for a two-thirds vote in the Senate that kept the U.S. out of the League of Nations after World War I, prevented the U.S. from acceding to the Geneva Protocol on chemical warfare of 1925 until fully 50 years had passed and more recently has prevented the U.S. from ratifying the Threshhold Test Ban Treaty, the Peaceful Nuclear Explosions Treaty and the SALT II Treaty. It seems likely that each of these treaties would have been ratified in a timely fashion if only a simple majority were required. Indeed, this particularly difficult and awkward situation is the purpose of the rule. The idea of the country's founding fathers was that the U.S. should avoid "foreign entanglements." When the country was actually isolated by two great oceans, that probably made good sense. In a world that is tightly integrated by high technology and in which Russian missiles in Siberia are less than a half hour away from their targets in the U.S., however, it is a drastically different matter.

The problem is not just one of failing to ratify certain treaties. More important, I think, is the effect this factor has on the negotiating process. Every president early in his term discovers that arms control is even more controversial than he thought it was, and that the ultimate measure of the acceptability of what he negotiates is getting the two-thirds vote in the Senate. Accordingly arms-control policy is developed not with an eye to a national consensus or even to a majority of the Congress, but rather with the objective of somehow capturing the support of those five or six senators who are two-thirds of the way over toward the "no" end of the political spectrum. For good or ill this factor has greatly colored the policies of every president from Kennedy to Carter, and the negotiating instructions to our delegations overseas have always been characterized by extreme caution and conservatism. Contrary to the common belief, this often means that as time goes on in a negotiation the U.S. position undergoes sudden changes, not in response to what the other side may have proposed but in a difficult and sometimes futile process of presidential maneuvering to please a few key senators and those members of the executive branch, particularly in the uniformed military, who have special influence with those senators.

The problem presented by the quadrennial presidential campaign is also serious. Because arms-control policy is intrinsically controversial, all new presidents soon discover that it is absolutely essential to consult all interested elements of the executive branch before they can finally establish arms-control policy and work out detailed negotiating instructions. This process typically takes up most or all of the first year of a new president's term. Later, in the fourth

year of his term, the president finds himself faced with a primary campaign within his own party, followed by the general campaign in which he must face the candidate of the opposing party.

The problems created by the exceptionally long American presidential campaign become evident when one considers the problems that first President Johnson and then Vice-President Humphrey had with this kind of issue in 1968, the problems that President Ford had over the SALT II negotiations and the Panama Canal negotiations during his primary campaign against Ronald Reagan in 1976 and the problems that President Carter had first with Senator Kennedy and then with Ronald Reagan in 1980 (these last being of course greatly exacerbated by the events in Iran and Afghanistan). In sum the U.S., at least in this era of four-year presidencies, is only in a position to negotiate seriously for two years of every four and even then in a way that forces the president to focus special attention on those few people who are two-thirds of the way over toward a "no" vote.

In addition to these peculiarly American problems the bureaucratic difficulties that plague all complex societies also have a strong negative influence on the ability of the U.S. to negotiate. This is primarily because the "nay-sayers" have only to stop or slow the process in any way at all in order to achieve their goals, whereas those who want to help the president achieve his arms-control goals must find a genuinely suitable pathway through what is often uncharted territory.

Perhaps the most serious problems with the Russians as negotiating partners are their penchant for secrecy and their tightly controlled political system. These two problems together are at the root of the difficulties Americans always have in dealing with the verification problem. The U.S. has extraordinarily powerful and sophisticated "national technical means" of verification, including observation satellites, seismic stations all over the world and other ways of eavesdropping. With these the U.S. can and does learn a great deal about what is going on in the U.S.S.R., and most people who are closely acquainted with these technical means and their output hold them to be adequate for verifying all the treaties that have been signed so far. Nevertheless, it is necessary and prudent for the U.S. Government, meaning particularly the intelligence community, to classify the details of these systems and to keep secret the evaluations of their performance.

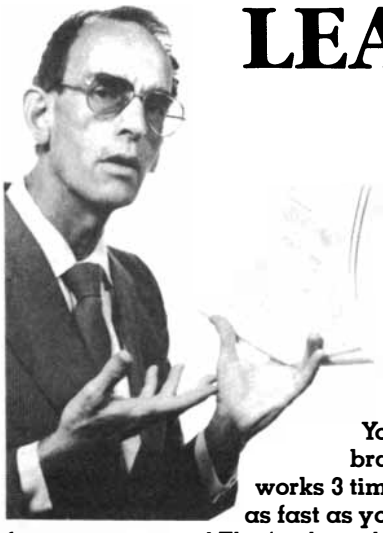
Given this genuine need for secrecy on the part of the U.S. and given the fact that there are always some people inside the system who are not fully satisfied with the performance of the national technical means of verification, it should come as no surprise that those officials and other members of the American body politic who hold extremely negative views of the U.S.S.R. in general and take a cautious approach to arms control in particular are doubtful about the ability of the technical means to uncover every deception that might be invented. The U.S.S.R. is, after all, a huge country with large areas entirely off-limits to foreigners, and it is not just paranoia to suppose that it might be doing something in such places that is significant but not known to the U.S. intelligence community.

The political control that extends throughout all levels of life in the U.S.S.R. makes the problem much worse. It is trite but true to say there are no organized opposition parties, no public-interest groups, no lobbies and no "whistle blowers" of the kind that in most other industrial societies are capable of uncovering and publicizing government misdeeds, including treaty violations. In my discussion of the test ban I mentioned that one of the general problems that has persisted throughout the entire postwar period of bilateral negotiations is that the Americans always ask for more intrusive means of verification than the Russians are willing even to discuss, much less accept, and the Russians are always complaining that the Americans persist in trying to spy on them, to undermine their sovereignty and to otherwise interfere in their internal affairs.

This problem will, I believe, continue into the indefinite future, and important elements of the American body politic will continue to harbor grave doubts about the adequacy of any conceivable verification system. I see no easy way of dealing with this difficulty until and unless there are substantial changes in the political behavior of the U.S.S.R., and I see no reason to expect that in the foreseeable future.

The situation is not totally bleak. The views of the Russian leaders on matters of secrecy and sovereignty have been evolving, and they have relaxed some of their earlier positions on related questions. For example, their acceptance of reconnaissance by satellite, their agreement in principle to exchange geophysical data in connection with the Threshold Test Ban Treaty, their acceptance of certain special on-site activities by foreign observers in the Peaceful Nuclear Explosions Treaty and their acceptance of special seismic stations and a carefully hedged system of voluntary on-site inspections in the comprehensive-test-ban negotiations all attest to this evolution. Whether it is proceeding at a pace that can keep up with American suspicions remains to be seen.

LEARN MATH — *EASY!*



Your brain works 3 times as fast as your fingers can write! That's where the Calculator comes in — you can go three times as fast with your machine doing the dirty work.

It's easier and more interesting. And you'll understand it better when it's fun. (If you haven't yet tried out a modern scientific-statistical calculator, you're in for a pleasant surprise — see below!)

WHY MATH? To get a promotion or a new job. Just to hang on to that job you've got. To quicken your mind. To understand this world you live in. To impress people. Just for some fun you'll feel good about. (Read those letters below to see how it has worked for others.)

Do it at home... You can start right away and go as fast as you like! Put it aside while you're busy with something else — in short, *set your own pace!*

Lots of us like to avoid being compared with the other members of a class — we like to set our own standards. Too, we like to save the time and expense of going to a school or seminar. (Best of all, it's a lot cheaper to study at home where the rent is already paid — *read on!*)

Let's be honest. You wouldn't expect to learn to play baseball or chess by watching an expert do it. Math is the same — you'll need to do some work. BUT — with my calculator method, you'll see it's a whole new ball game!

THIS METHOD IS FRIENDLY! You can use it on your own. You follow interesting examples step-by-step with calculator keystrokes — instead of algebra.

Let me introduce myself — I'm Dr. George McCarty and I teach at the University of California. Tens of thousands of people like yourself have already used my guidebook to teach themselves calculus. Recently I have teamed up with another professor. We put those same tested and proven techniques to work for you in a new *Statistics Guidebook.*

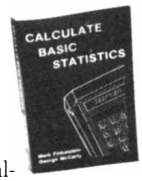
Even if you've had trouble with math, this method will work for you. Choose the one you want to learn, calculus or statistics (or both) and start *today!*

As pennywise Ben Franklin said, "An investment in knowledge pays the best dividends."

CHOOSE STATISTICS

It's used everywhere — to set insurance rates and to assess a drug's effectiveness, to detect a crooked roulette wheel and to measure lightbulb lifetimes, to audit the books and to find your position at sea.

People have always known that their experience was not a perfect guide to the future. Statistics shows us that uncertainty is not only inevitable but it itself is measurable.



You'll find out about this in my guidebook. You'll read informal explanations with detailed calculations for topics like "confidence intervals" and "contingency tables."

YOU'LL BE DOING Inference and Hypothesis Testing, the Chi-Square Distribution, ANOVA, Regression and Correlation, Non-Parametric Methods — they're all here.

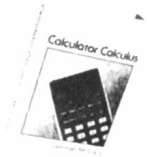
SUPPOSE YOU HAVE ALREADY STUDIED STATISTICS. You'll use Quick-Reference Guides to go straight to a topic you want to refresh yourself on — then get *right-now* answers in your own field, business, biology, science, psychology, education.

The Guidebook is guaranteed to work with any calculator or computer. If you would like to start out with a fancy new machine, order my Statistics Kit which includes the guidebook and a TI-35 calculator which finds means and standard deviations at the touch of a button. It has an LCD display, 1000 hour batteries — the works.

PHONE MC or VISA ORDERS TO
(714) 831-2637
Ask for our Catalog of books and calculators.

CHOOSE CALCULUS

The math of science and engineering — satellite orbits and compound interest, bacterial growth and radioactive decay, marginal profits and reaction rates.



You'll find out about these concepts when you use the Calculus Kit. This Kit contains my guidebook and a TI-35 calculator which finds log and trig values at the touch of a button. (It's modern, too, with LCD display and 1000 hour batteries.)

In the guidebook you'll learn both differential calculus and integral calculus — *even differential equations!*

NEED TO EVALUATE functions, areas, volumes — solve equations — use curves, trig, polar coordinates — find limits for sequences and series? It's all here!

If you're in the biological, social or physical sciences, you'll be doing Bessel functions, carbon dating, Gompertz' growth curves, half-life, future value, marginal costs, motion, cooling, probability, pressure — and plenty more.

Important numerical algorithms are here, too: rational and Padé approximation, bracketing, continued fractions, Euler's method, Heun's method, iteration functions, Newton's method, predictor-corrector, successive substitutions, Simpson's method and synthetic division.

If you already have a scientific calculator, you can get just the *Calculus Guidebook.*

George McCarty

P.S. — YOU *CAN* DO IT! I'm certain I can show you this easy way to success with math, so *I guarantee it to you unconditionally* — if you are not satisfied just send it back for a prompt refund!

LOOK AT WHAT THEY SAY

- "...*excellent diagrams and clear explanations.*" —POPULAR SCIENCE
- Professor John Ball of Harvard College writes: *"I wish I had had as good a calculus course."*
- S.C. McCluney, Jr. of Philadelphia writes: *"With your book and a calculator the whole idea becomes clear in a moment, and is a MOST REFRESHING EXPERIENCE."*
- Professor H.I. Freedman of the U. of Alberta, states, *"There can be no question as to the usefulness of this book...lots of exercises...very clearly written...easy reading."*
- "...*straight-to-the-point explanations...*" —HP Key Notes
- Tektronix Engineer Bill Templeton says, *"The best, most clearly written book I have seen for improving your math skills."*

TAX DEDUCTIBLE FOR PROFESSIONALS

YES, I want to learn math **fast** and **easy** with your *new method.* If I am not more than satisfied I can return it for a quick refund. RUSH me the guidebook or complete kit I select below (kit contains the guidebook and a modern TI-35 calculator).

☐ Send **FREE** Catalog of books & calculators

	STATISTICS GUIDEBOOK	KIT
How many?	☐ $14.95	☐ $39.95
Handling/Shipping	1.00	2.00
Tax (within Calif.)	.90	2.40
TOTAL		

	CALCULUS GUIDEBOOK	KIT
How many?	☐ $19.95	☐ $44.95
Handling/Shipping	1.00	2.00
Tax (within Calif.)	1.20	2.70
TOTAL		

For AIR SHIPMENT add $3.00 per item

Phone (714)831-2637 (MC or VISA only)

Enclosed is ☐ Check, ☐ M.O.; or charge my MC/VISA... exp._____

Card #_____

Name _____

Address _____

City _____

State, Zip _____

OUTSIDE USA, **surface shipping is $2.00 per book or $5.00 per kit. Air shipment is $5.00 per book or $10.00 per kit. U.S. FUNDS PLEASE.**

EduCALC Publications, Dept. AO
27953 Cabot Road
South Laguna, CA 92677

1982

THE AMATEUR SCIENTIST

Thinking about physics while scared to death (on a falling roller coaster)

by Jearl Walker

The rides in an amusement park not only are fun but also demonstrate principles of physics. Among them are rotational dynamics and energy conversion. I have been exploring the rides at Geauga Lake Amusement Park near Cleveland and have found that nearly every ride offers a memorable lesson.

To me the scariest rides at the park are the roller coasters. The Big Dipper is similar to many of the roller coasters that have thrilled passengers for most of this century. The cars are pulled by chain to the top of the highest hill along the track. Released from the chain as the front car begins its descent, the unpowered cars have almost no speed and only a small acceleration. As more cars get onto the downward slope the acceleration increases. It peaks when all the cars are headed downward. The peak value is the product of the acceleration generated by gravity and the sine of the slope of the track. A steeper descent generates a greater acceleration, but packing the coaster with heavier passengers does not.

When the coaster reaches the bottom of the valley and starts up the next hill, there is an instant when the cars are symmetrically distributed in the valley. The acceleration is zero. As more cars ascend, the coaster begins to slow, reaching its lowest speed just as it is symmetrically positioned at the top of the hill.

A roller coaster functions by means of transfers of energy. When the chain hauls the cars to the top of the first hill, it does work on the cars, endowing them with gravitational potential energy, the energy of a body in a gravitational field with respect to the distance of the body from some reference level such as the ground. As the cars descend into the first valley much of the stored energy is transferred into kinetic energy, the energy of motion.

If the loss of energy to friction and air drag is small, the total of the potential and kinetic energies must remain constant throughout the descent and even throughout the rest of the ride. The coaster gains kinetic energy and speed at the expense of potential energy. If the first valley is at ground level, the transfer is complete, and for a moment the coaster has all its energy in the form of kinetic energy.

Without energy losses the coaster could climb any number of hills as high as the one from which it is released (but no higher). To be sure, friction and air drag do remove energy from the coaster, and its total energy content dwindles. It can no longer climb high hills, which is why the last stages of the track consist only of low hills.

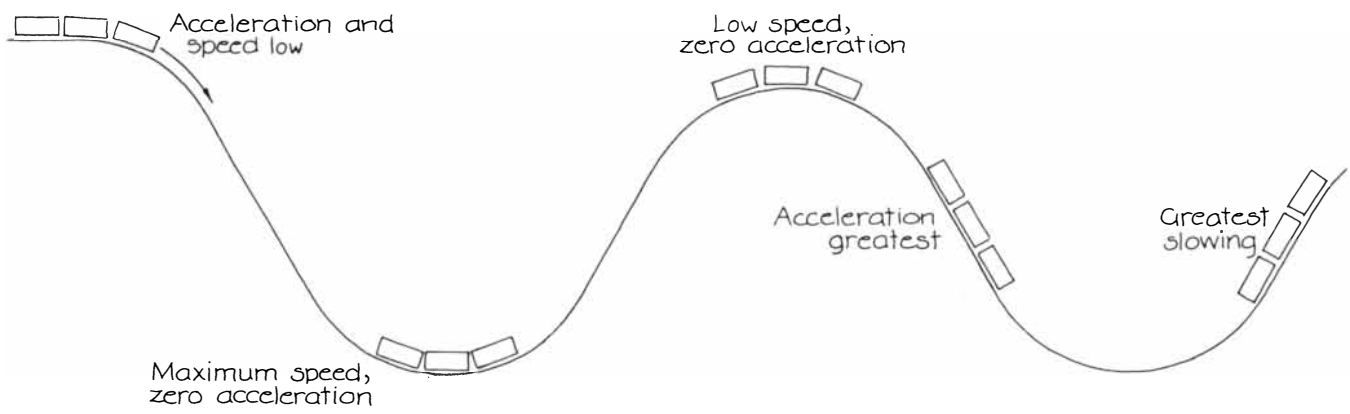
The length of a ride on a roller coaster depends on the speed. If the ride is to be fast, the launching hill should be high so that the total energy is large. The rest of the track should be low so that most of the energy remains kinetic.

The choice of a seat on a roller coaster makes a difference in the ride. Some people prefer the front seat because the descent from the launching site presents the pleasingly frightening illusion of falling over the edge of a cliff. Other people prefer the psychological security of the rear seat.

The choice of a seat also determines the forces felt by the passenger. Consider the first descent. The front car starts down slowly because little of the coaster's energy is then kinetic. The speed of the cars increases as an exponential function of time, so that the rear car starts down at a much higher speed than the front car did. Although the passengers in the front car get an unobstructed view of the descent, the passengers in the rear car have a stronger sense of being hurled over the edge.

At the edge one force on the passenger is from the change in the direction of his momentum vector. Initially the vector is horizontal, but soon it points toward the valley. The force necessary to effect this change in direction is delivered by the safety bar or seat belt that keeps the passenger in the car. That force, which points downward and back toward the hill, is part of the thrill of the ride. A passenger in the rear feels the force more than a passenger in the front because the size of the force is proportional to the momentum, which is greater for the passenger in the rear.

The story is different in the valley. Again a force from the coaster is necessary to redirect the passenger's momentum. This time the momentum is initially downward toward the bottom of the valley and then is redirected toward the top of the next hill. The front passenger has a large momentum and is subjected



The energetics of a roller coaster

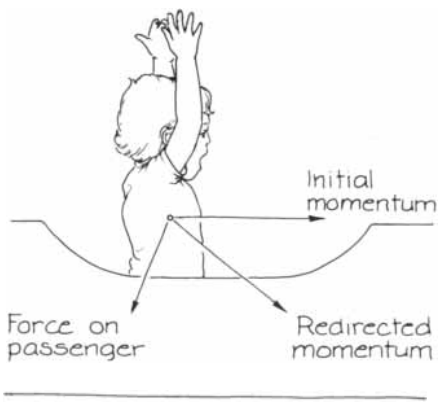
to a large force. By the time the rear car reaches the bottom of the valley the movement of the front cars up the next hill has slowed the coaster. A passenger at the rear has less momentum and is subjected to a smaller force.

At the crest of the hill the passenger gets a force leveling his momentum vector. At the rear of the coaster the force can be considerable if the front is already well down the next slope. To a passenger at the rear who is loosely held in place by a safety bar a fast trip over a hill provides a brief sensation of being lifted from the seat. He arrives at the crest with a large momentum. Until he encounters the safety bar and is redirected he continues to travel upward even though the coaster has leveled out below him. The faster the coaster goes over a hill, the greater the sensation of being thrown free.

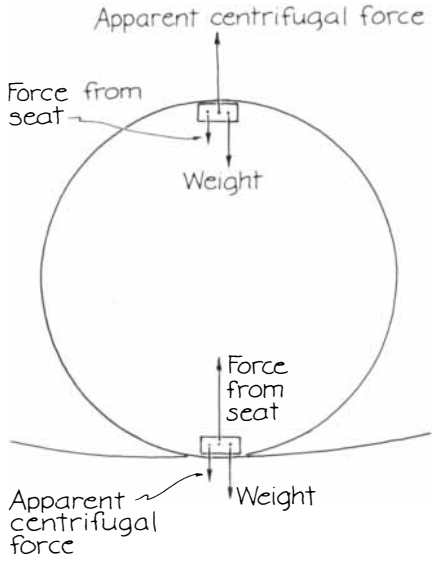
The brave passenger is one who rides the roller coaster without holding on. I tried this once while arriving at the crest of a hill at high speed. I avoided being thrown free of the coaster by catching my thighs on the safety bar at the last instant. Thereafter I kept a tight grip on the safety bar.

Roller coasters such as the Big Dipper have been around for more than 50 years. Recently a new type of coaster has appeared. The principles are seen in the Double Loop and the Corkscrew. The Double Loop at Geauga Lake begins like the Big Dipper in that a chain pulls the cars to the top of the first and highest hill. After the coaster travels over a few smaller hills (and before it loses too much of its energy to friction and air drag) it runs through two vertical loops. The ride is splendidly unnerving. In the times I managed to open my eyes while traveling through the loops I saw the world turn upside down, the ground race up toward me and the world turn upside down again.

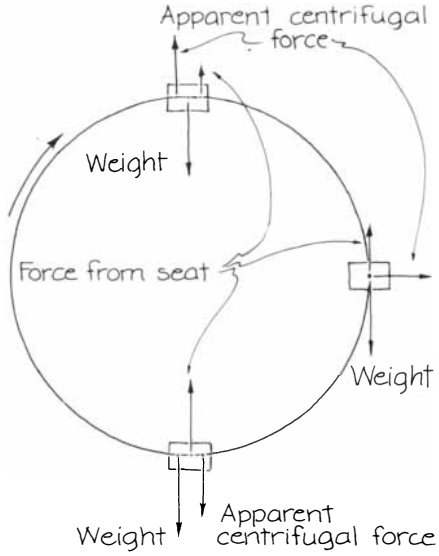
The coaster on the Double Loop is held onto the track by a double set of wheels, one set on the top of the rails and the other set on the bottom. When the coaster is on the normal section of the track, its weight rests on the top set of wheels. When it is in the loop, the other set of wheels can come into play. They keep the cars from flying off the track.



Forces that redirect momentum



Forces in a coaster that loops



What you feel in a Ferris wheel

When the coaster enters a loop, I sense three forces. One is my weight, which of course is directed downward. Another is the force from the seat. The third is the apparent centrifugal force downward, which seems to add to my weight; it makes me feel as though I am being pushed into the seat. At the top of a loop the apparent centrifugal force is upward, and I feel light.

The centrifugal force is a fiction. No outwardly directed force is at work. The notion of a centrifugal force is useful, however, since it easily explains what a passenger feels. The perspective of someone on the ground is more to the point: a combination of real forces causes the rider to move in a circle instead of a straight line.

If the circular motion is to be maintained, the net force must be toward the center of the circle. At the bottom of a loop the passenger's weight vector is downward (and therefore away from the center of the loop). An upward force acts on the passenger from the seat. Since the push from the seat is greater than his weight, the net force points toward the center of the loop and he begins the circular motion. From the passenger's perspective the large push from the seat is sensed as a centrifugal force pressing him into the seat.

At the top of the loop the forces have changed. The passenger's weight is still the same and is still pointed downward, that is, toward the center of the loop. The push from the seat is also downward. The two forces combine in the net force that makes the rider continue in the circle.

This time the force from the seat is smaller. One reason is that at the top of the loop the coaster has less kinetic energy and so is traveling slower. Moreover, the force from the seat is now augmented by the rider's weight vector instead of having to oppose it. The rider senses the force from the seat as a small centrifugal force.

How high must the coaster be at the start of its journey (with essentially no initial speed) if it is to have at the top of the loop the speed that will hold it firmly on the track? To answer the question I made two assumptions. The first was that the coaster has only one car. The second was that the energy losses from friction and air drag are negligible. With these assumptions I found that the first hill must be higher than the top of the loop by at least half the radius of the loop.

The first assumption is a convenient simplification. If the coaster is long, one must consider the rise and fall of its center of mass rather than considering only one car. Since only part of the coaster is at the top of the loop at any given instant, the center of mass never reaches that height, and so less energy is actually required to keep the coaster on the track than would be needed if there were only one car.

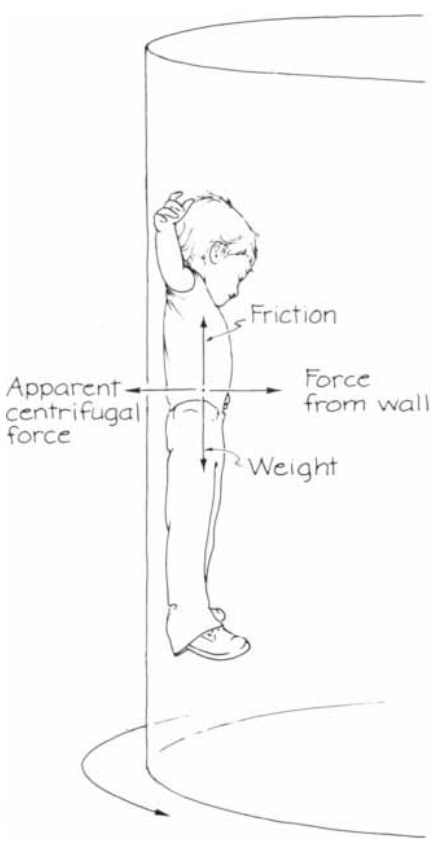
As for the second assumption, if the losses of energy were entirely negligible, the unpowered coaster would arrive at the loop with all the energy it got at the launch. The intervening hills and valleys would not matter. They do matter, of course, because they provide more opportunity for energy losses. Therefore the initial hill must be higher than the theory would indicate. On the Double Loop at Geauga Lake the initial hill is considerably higher than the theoretical value, so that the coaster is still traveling

at a good clip when it reaches the top of the loop.

The Corkscrew is a similar roller coaster except that the loops are helical. Once the coaster enters the loops it moves in a corkscrew fashion until it emerges again. At two points the passengers are fully upside down.

The physics of this ride is similar to that for the Double Loop. The major difference lies in the direction of the apparent centrifugal force. With the Double Loop the center of the motion in a loop is at a single point. The centrifugal force appears to be directed radially outward from that point. As the coaster travels around the loop, this force rotates in a vertical plane. With the Corkscrew the center of motion continuously moves vertically and horizontally as the coaster travels through the loops. Hence the direction of the apparent centrifugal force is not confined to a vertical plane. This added feature is one reason the Corkscrew has become so popular with coaster addicts.

Geauga Lake has two other rides that are similar to the standard roller coaster. The water slide starts high above the ground. Water pours down the interior of the slide to provide lubrication and even a small amount of propulsion. The principle is simple: the initial gravitational potential energy is steadily converted into kinetic energy, so that the slider's speed increases during the descent. The lubrication provided by the water diminishes the loss of energy to friction.



The role of friction in the Rotor

The other ride is the Gold Rush Log Flumes. Passengers board a small boat shaped like a hollow log. It is really a car like the ones on the Big Dipper. Water flowing through the flume pushes the boat along until it is engaged by a chain system that drags it up a tall hill. From the crest the boat descends rapidly down a slope of about 45 degrees. At the foot of the hill it speeds into a trough of water, which quickly slows the motion and satisfyingly drenches the passengers. They also seem to be thrown forward, but the experience is illusory; what happens is that they continue to move forward briefly at the former speed.

Most of the other rides at an amusement park are based on rotational mechanics. The mildest of them is the merry-go-round. Here the rate of rotation is just enough to give the passenger a moderate sensation of centrifugal force. He seems to be thrust outward. Actually his body leans outward because the horse moves away from him as it travels in a circle and ends up pulling him along.

The Ferris wheel is similar except that its plane of rotation is vertical. The apparent centrifugal force seems periodically to increase and decrease the passenger's weight. When he passes through the bottom of the circle of travel, the centrifugal force appears to push him downward into the seat as if he then weighed more. In reality the seat pushes strongly against him as it keeps him moving in a circle. This force must be strong because it opposes the passenger's weight. At the top of the circle the passenger has the sensation of being somewhat lighter because the apparent centrifugal force is then upward, seemingly pulling him out of his seat. Actually the sensation comes from the fact that the force from the seat is then smaller.

At midpoint of the descent an even stranger sensation is felt. The force from the seat matches the passenger's weight, and the centrifugal force is outward. Hence the passenger feels as though he is about to be thrown forward out of the compartment.

My favorite among the rotating rides is the Rotor, which is a vertical cylinder with a diameter of about 12 feet. The rider stands with his back against the wall as the cylinder begins to spin. When the maximum spin rate is reached, the floor drops away, but the rider remains stuck to the wall. A particularly agile person might be able to squirm enough to get himself into an angled position or even upside down.

Why does the rider stick to the wall? From his perspective a centrifugal force pins him there. The resulting friction between him and the wall prevents him from falling when the floor is removed. A high rate of spin is called for, so that the apparent centrifugal force generates enough friction.

From the perspective of an outside observer the story is different. The rider is constrained to move in a circle because of a force from the wall. This centripetal force is responsible for the friction. Still, the spin rate has to be high if the force from the wall is to generate enough friction to hold the rider in place.

The Rotor at Geauga Lake has a roughly textured wall to increase the friction. With a smoother wall the centripetal force would have to be stronger to keep the rider from slipping. (One would either have to increase the spin rate or build a cylinder with a larger diameter.) Each time I rode the Rotor I was impressed by the overwhelming sensation that a centrifugal force was pushing me against the wall. In reality the wall was pushing on my back.

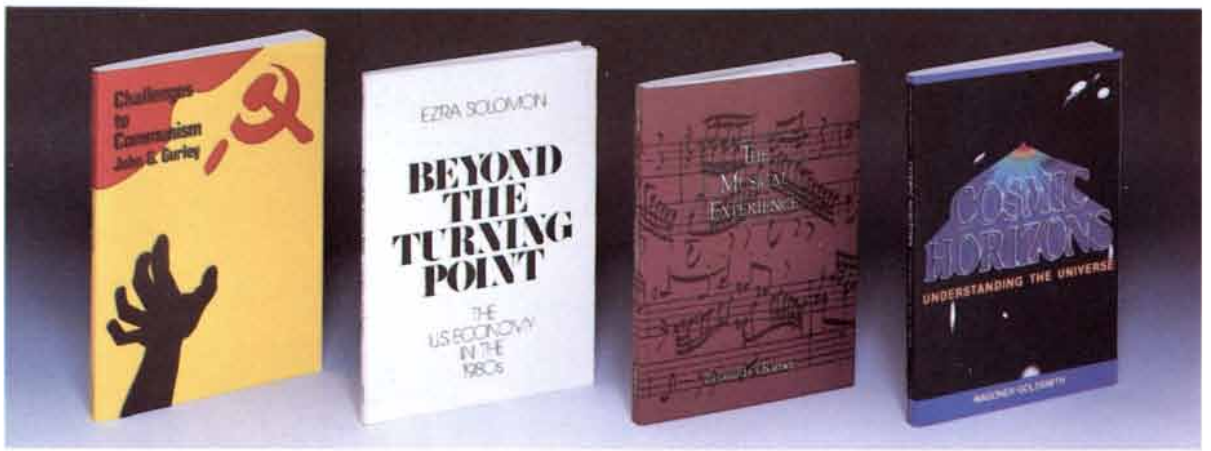
In order for the rider to stay in place his weight (a force vector downward) must not exceed the friction (a force vector upward). The amount of friction can at most be equal to the product of the friction coefficient (which depends on the roughness of the surfaces in contact) and the centripetal force from the wall. I estimated that the spin rate had to be about 30 revolutions per minute to hold me against the wall. Indeed, the apparatus did turn at about that rate.

Several other rides at Geauga Lake involve an apparent centrifugal force. The Muzek Express consists of a series of cars moving on a circular track that traverses several small hills. The diameter of the track is roughly 30 feet. The ride is fast, and so the centrifugal force on a passenger is quite strong. The hills provide extra thrills. Usually two people ride side by side in a car. Since they both feel an outward force, the passenger on the outside is squeezed against the wall of the car by the passenger on the inside. The forces are surprisingly large even if a passenger is small. I cannot avoid being pushed into the wall even when the inside passenger is my young daughter, who weighs less than half what I do.

The Enterprise is a rotating ride with cars individually suspended on radial arms extending from a central hub. As the cars begin to move in a horizontal circle the apparent centrifugal force makes the car rotate outward on the radial arm. Soon the car has rotated almost 90 degrees, and the passenger can see the ground directly below the window that originally was on the inside.

This rotation results from the way the mass of the car and the mass of the passenger are distributed with respect to the suspension axis of the car. A combined centrifugal force operates on the common center of mass of the passenger and

In pursuit of excellence



From communism to the cosmos, economic analysis to music appreciation, these extraordinary new books showcase the work of today's most innovative thinkers. Written by members of Stanford University's renowned faculty, these books, originally published for the exclusive Portable Stanford series, are now available to the public.

Provocative and often controversial, the Portable Stanford has repeatedly been honored for presenting the best of contemporary thought in a highly readable format, designed to be read in an evening or two. You will find incisive thinking, clearly communicated without technical jargon or lengthy footnotes, published for those who are curious about new ideas in fields outside their own.

CHALLENGES TO COMMUNISM

John G. Gurley

Is world communism now in the beginning stages of a long-term decline? This comprehensive study suggests that it is, and explains why. The author also carries forward the theme of his highly acclaimed *Challengers to Capitalism: Marx, Lenin, Stalin, and Mao*, that communism has weakened present-day capitalist countries. Demonstrating how capitalist and communist countries now confront one another in social and economic disarray, Gurley points to the emerging Third World as an increasingly important element in this precarious balance of power.

hardcover: 0-7167-1506-0 $20.00
paperbound: 0-7167-1507-4 $10.95

BEYOND THE TURNING POINT THE U.S. ECONOMY IN THE 1980s

Ezra Solomon

The distinguished economist, a former member of the President's Council of Economic Advisors, examines the economic issues of the '80s both historically and analytically. He traces the source of our problems and explores the outlook for the U.S. in the context of past events.

"Ezra Solomon has brought his high intellect, vast experience, and great insight to this readable and informative analysis of the prospects for our economy. Everyone can learn from reading this book, including those voting on economic policy in Washington."—George P. Shultz, former Secretary of the Treasury

paperbound: 0-7167-1391-8 $7.95

THE MUSICAL EXPERIENCE SOUND, MOVEMENT, ARRIVAL

Leonard G. Ratner

A lively, straightforward exposition of the ways musical elements combine to convey emotion, this is perhaps the ultimate book for those wishing to expand their musical understanding. Using illustrative material from familiar concert music, the author explores musical forms in terms of rhythm, melody, harmony, and texture. The book makes accessible to music lovers the fundamentals of musical style and form. Selected musical examples, recorded on soundsheets bound into the book and playable on any standard phonograph, guide listeners to a fuller appreciation of this appealing art.

hardcover: 0-7167-1475-2 $20.00
paperbound: 0-7167-1476-0 $10.95

COSMIC HORIZONS UNDERSTANDING THE UNIVERSE

Robert Wagoner and Donald Goldsmith

A mind-expanding exploration of the composition of the universe as astronomers now understand it, *Cosmic Horizons* sets in perspective the fundamental principles of modern cosmology. The authors discuss the "big bang" theory, the significance of elementary particles in the development of the universe, and recent advances in particle physics, all of which have led to a more accurate perception of the world around us. This book provides new insights into the sophisticated techniques that allow scientists to probe farther into space—and further back in time.

hardcover: 0-7167-1417-5 $18.95
paperbound: 0-7167-1418-3 $9.95

These books are available at fine bookstores.
To order directly from the publisher, please send a check for the total amount
(plus $1.50 for postage and handling; California, New York, and Utah residents add appropriate sales tax) to:
Order Department, W. H. Freeman and Company, 4419 West 1980 South, Salt Lake City, Utah 84104.

Beethoven was the classic performer of his time. Today, it's the Ford Electronic Premium Sound System. Designed, engineered and quality tested by Ford, specifically for Ford and Lincoln-Mercury automobiles. This highly sophisticated stereo system will faithfully reproduce the musical performance of the most demanding artist. From Beethoven to Bach. From Bach to Rock. And everything in between. The Ford Electronic Premium Sound System. The classic performer in a full line of high performance sound systems by Ford.

Available at your Ford and Lincoln-Mercury dealers today. Beethoven never heard it so good.

Ford Electrical and Electronics Division

the car. Initially this point lies below the suspension axis. Also acting through the point is the combined weight of the passenger and the car. These two forces compete in orienting the car. Initially gravity pulls the car into the normal orientation, but as the ride moves faster and the centrifugal force gets stronger the car is rotated increasingly out of the vertical.

This much of the ride was disturbing, but the next part almost did me in. Once the ride had reached its highest speed the large arm that held the central hub was turned to make the plane of the moving cars vertical. I was then moving in a vertical circle, being completely upside down at the top and greatly compressed by the forces acting on me at the bottom. I closed my eyes and began to count the prime numbers.

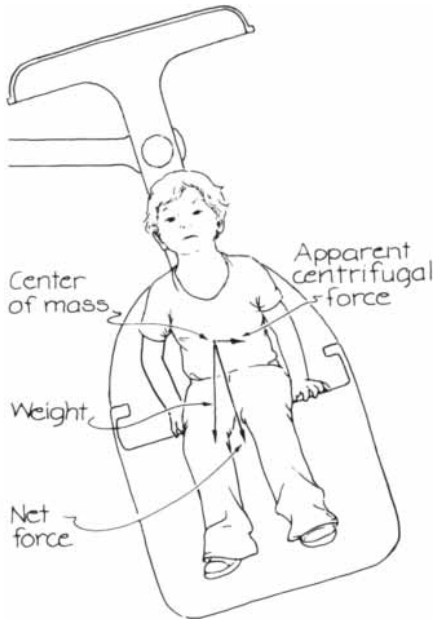
My next ride also held a surprise. It was a set of swings about 20 feet in diameter suspended from a central hub. When the hub began to turn, I moved in a circle below the rim of the hub. As the speed increased, the apparent centrifugal force moved me outward so that I traveled in a larger circle than before. The faster the hub turned, the larger the circle was.

From my perspective three forces affected me. I still had weight, which was directed downward. The chair and its suspension chains provided a second force directed toward the attachment of the chains to the overhead hub. The third force was the fictitious centrifugal force I felt throwing me outward. The angle between the chains and the vertical was set by the balancing of the three forces. When the speed of the ride increased, the angle also increased, so that the forces again balanced.

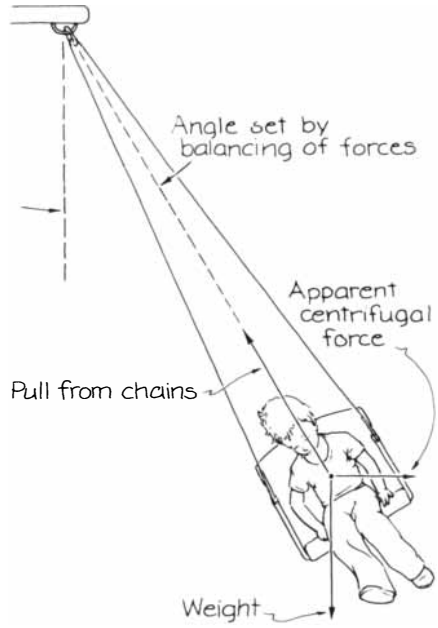
The surprise of the ride was that the hub soon tilted about 10 degrees or so out of the horizontal. Part of my travel around the apparatus was then downhill. My speed increased during the descent as potential energy was converted into kinetic energy. As a result I circled the apparatus in a large radius. In the uphill part of the circle I slowed as the hub was forced to hoist me, and so here I circled with a smaller radius.

I ended my busy day at Geauga Lake with three rides that delivered similar types of motion. The first was the Scrambler, which has long been popular at amusement parks. It consists of a central hub from which several radial arms extend. I call them the primary arms. At the end of each primary arm four secondary arms extend outward. Each one carries at its outer end a car for two or three passengers.

The ride consists of two circular motions. The primary arms rotate steadily about the center of the ride while each set of four secondary arms twirls below the pivot at the end of the primary arm.



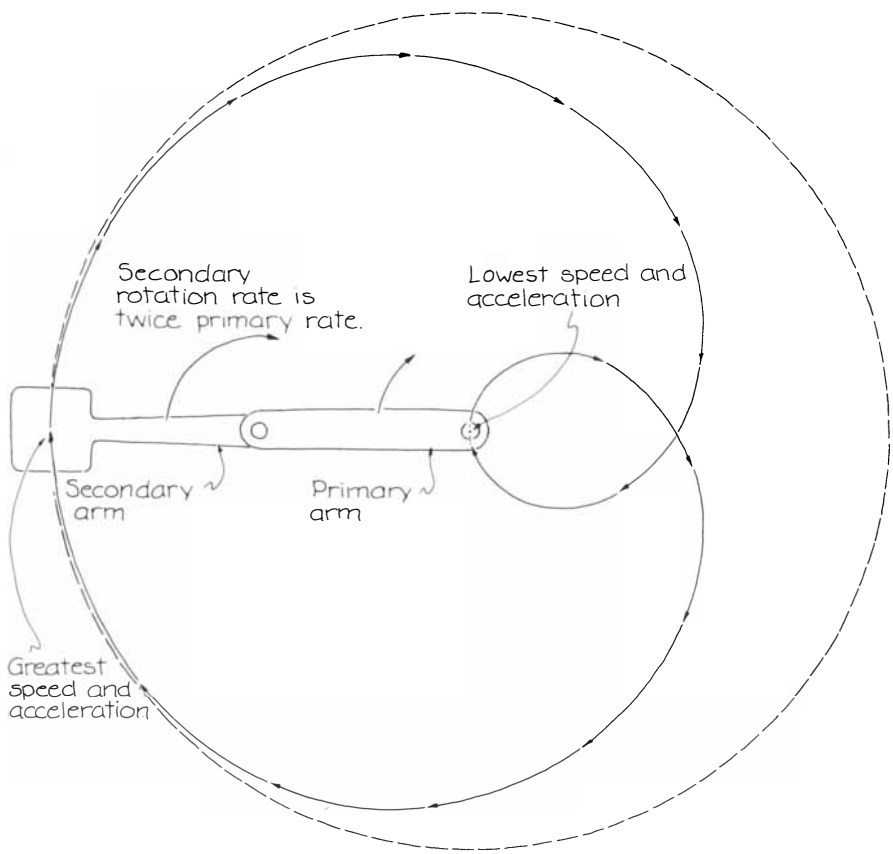
Forces in the Enterprise



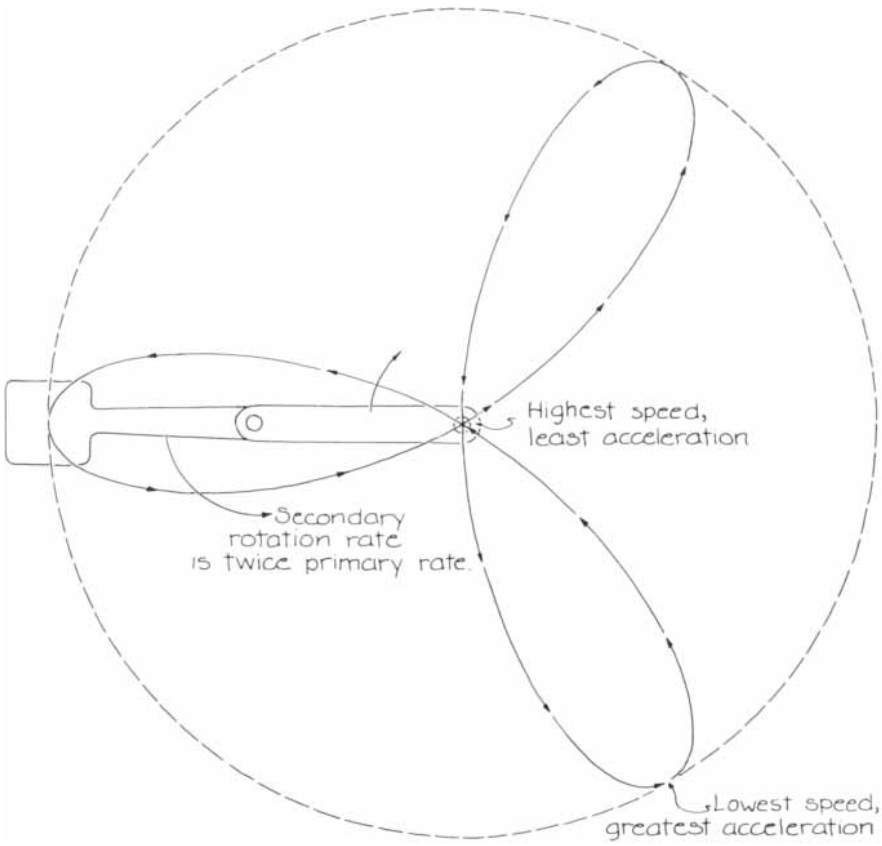
What happens with a rotating swing

From an overhead perspective the primary arms move clockwise, the secondary arms counterclockwise. (In a related ride called Calypso both motions are clockwise.)

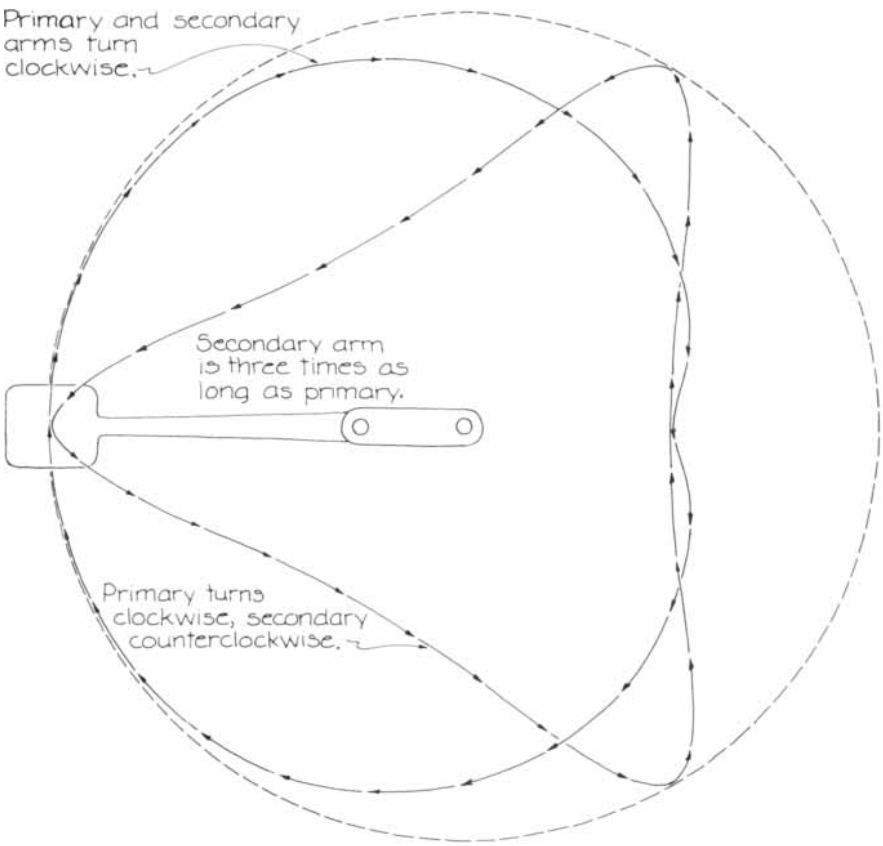
I set about studying the types of motion in rides such as the Scrambler and the Calypso. To model what happens to a rider I focused on a single primary arm (turning clockwise) and a single secondary arm (turning in either direction). As the primary arm makes a full revolution does the passenger loop or spiral? Where are the speed and the acceler-



The motions in a Calypso ride



The motions in a Scrambler ride



The motions in a Calypso or a Scrambler with arms of unequal length

ation greatest? How should the arms rotate to give an unforgettable ride? Should the arms be approximately the same length (as they are in the Scrambler and the Calypso)?

I found that if the arms are the same size and rotate at the same rate and in the same direction, the ride is bound to be rather boring, because the passenger merely goes in a large circle. The ride is not much better if the arms turn in opposite directions. In this arrangement the passenger would travel on a straight line over the center to the opposite side of the ride and then would return on the same line.

A better ride results when the primary and secondary arms rotate at different rates. Suppose the secondary arm turns twice as fast as the primary one. When the primary and secondary arms move in a clockwise direction, as they do in the Calypso, the passenger first spirals in toward the center of the ride and then out again, so that he travels through a loop on the side opposite to the starting point. After spiraling outward he passes through his initial location and begins the trip again.

His speed and acceleration are highest when he is farthest from the center, that is, when he passes through the initial point. They are lowest when he passes over the center of the ride. My calculations approximate the conditions of the Calypso but are off somewhat because to simplify matters I visualized arms of equal length. In order to accommodate all the primary and secondary arms on the Calypso the secondary arms are shorter than the ones in my calculations, so that the cars do not crash near the center of the ride.

If the primary and secondary arms turn in opposite directions, as they do in the Scrambler, a more interesting motion results. At first the passenger moves counterclockwise, but he quickly heads for the center of the ride and then outward again. When the arms are fully extended, he is directed back toward the center. When the primary arm has completed one revolution, the passenger has traveled through a pattern resembling three narrow petals. He is moving at the highest speed when he passes over the center of the ride. Surprisingly, the acceleration there is the lowest. The speed is the lowest and the acceleration the highest when the passenger is farthest from the center.

The low speed at that point results because the circular motion of the secondary arm is carrying the passenger counterclockwise while the motion of the primary arm is clockwise. The two motions oppose each other when the passenger is farthest from the center and augment each other as he is carried close to the center. The high acceleration at the far point develops because

the direction of the velocity out there is changing rapidly.

On my home computer I worked out the paths for other conditions. If the primary arm is much longer than the secondary arm, the passenger might spiral toward and then away from the center. In other cases he would move through a path consisting of a series of cusps or loops superposed on a large circle. Another interesting situation arises when the secondary arm is longer than the primary one. If the secondary arm turns slower than the primary one and in the same direction, the passenger will spiral gradually toward the center and then away from it. If the motions are in opposite directions, the ride will include an abrupt change in direction.

My last ride of the day was on the Tilt-A-Whirl. I sat in a compartment that was free to move around a small circular track, pivoting on a center point at my feet. Six of these compartments, running on a hilly track, moved around the center of the apparatus while they were also pivoting on their individual center points. The result was three types of motion. One was a basic counterclockwise circling about the center of the entire ride. The second was a smaller circling of the compartment in either direction. The third was the vertical motion over the hills.

The interesting part was that I could often control the small circling of my compartment by anticipating the hills and shifting my weight. When the compartment was turning in its small circle and beginning to descend from a hill in the larger motion, I threw my weight in the direction of the compartment's turn. I was transforming some of the potential energy of my body (from being up on the hill) into kinetic energy applied to the rotation of the compartment.

When I timed this exercise correctly, I set the compartment spinning rapidly. My experience was similar to that in the preceding two rides. If the spin direction was in the same direction as the large-scale circling of the ride, the speed and centrifugal force were quite large when I was farthest from the center of the ride. If the spin was in the opposite direction, the acceleration was high when I was far from the center but the speed was high closer to the center.

You might explore the amusement parks near you for other rides. One that I have heard described, but lack the courage to even look at, is Demon Drop. The victim—sorry, the passenger—is secured in a chair that is lifted 131 feet and then dropped in a virtually free fall to the ground. The huge kinetic energy of the ride is apparently dissipated when the apparatus curves into a horizontal section of track at the bottom of the fall. I have no intention whatever of verifying this assumption.

BIBLIOGRAPHY

Readers interested in further explanation of the subjects covered by the articles in this issue may find the following lists of publications helpful.

COMPUTER RECREATIONS

AUTOMATA STUDIES. Edited by Claude E. Shannon and John McCarthy. Princeton University Press, 1956.

MATHEMATICAL GAMES. Martin Gardner in *Scientific American,* Vol. 223, No. 4, pages 120–123, October, 1970, and Vol. 224, No. 2, pages 112–117, February, 1971.

WINNING WAYS FOR YOUR MATHEMATICAL PLAYS. Elwyn R. Berlekamp, John H. Conway and Richard K. Guy. Academic Press, 1982.

LOTUS 1-2-3 USER'S MANUAL. John Posner, Steven E. Miller, Ezra Gottheil and Jeff Hill. Lotus Development Corporation, 1983.

LABOR-INTENSIVE AGRICULTURE

HIRED HANDS: SEASONAL FARM WORKERS IN THE UNITED STATES. Stephen H. Sosnick. McNally & Loftin, 1978.

THE H-2 PROGRAM AND NONIMMIGRANTS. Hearing before the Subcommittee on Immigration and Refugee Policy, November 30, 1981 (J-97-85). U.S. Government Printing Office, 1981.

THE DEMAND FOR SEASONAL FARM LABOR IN CALIFORNIA. Philip L. Martin and Richard Mines. Working Paper 83–9, University of California at Davis, 1983.

SEASONAL FARM LABOR IN THE UNITED STATES. Edited by Robert Emerson. Iowa State University Press, 1983.

THE ENGINEERING OF MAGNETIC FUSION REACTORS

RECENT DEVELOPMENTS IN THE DESIGN OF CONCEPTUAL FUSION REACTORS. F. L. Ribe in *Nuclear Technology,* Vol. 34, No. 2, pages 179–208; July, 1977.

PROGRESS TOWARD A TOKAMAK FUSION REACTOR. Harold P. Furth in *Scientific American,* Vol. 241, No. 2, pages 50–61; August, 1979.

MAGNETIC FUSION REACTORS. Robert W. Conn in *Fusion,* edited by Edward Teller. Academic Press, 1981.

THE LARGE-SCALE STRUCTURE OF THE UNIVERSE

THE FIRST THREE MINUTES: A MODERN VIEW OF THE ORIGIN OF THE UNIVERSE. Steven Weinberg. Basic Books, Inc., 1977.

THE BIG BANG: THE CREATION AND EVOLUTION OF THE UNIVERSE. Joseph Silk. W. H. Freeman and Company, 1980.

THE GROWTH OF STRUCTURE IN THE UNIVERSE. J. R. Gott in *Physical Cosmology,* edited by Roger Balian, Jean Adouze and David N. Schramm. Elsevier-North Holland, Inc., 1980.

THE LARGE-SCALE STRUCTURE OF THE UNIVERSE. P. J. E. Peebles. Princeton University Press, 1980.

MODERN COSMOLOGY. Ya. B. Zel'dovich in *Highlights of Astronomy, Vol. 6,* edited by R. West. D. Reidel Publishing Co., 1983.

THE PROCESSING OF RNA

RIBONUCLEIC ACIDS FROM ANIMAL CELLS. James E. Darnell, Jr., in *Bacteriological Reviews,* Vol. 32, No. 3, pages 262–290; September, 1968.

THE DEFINITION OF A LARGE VIRAL TRANSCRIPTION UNIT LATE IN AD2 INFECTION OF HELA CELLS: MAPPING OF NASCENT RNA MOLECULES LABELED IN ISOLATED NUCLEI. Jeffrey Weber, Warren Jelinek and James E. Darnell, Jr., in *Cell,* Vol. 10, No. 4, pages 611–616; April, 1977.

SPLICED SEGMENTS AT THE 5′ TERMINUS OF ADENOVIRUS 2 LATE mRNA. Susan M. Berget, Claire Moore and Philip A. Sharp in *Proceedings of the National Academy of Sciences of the United States of America,* Vol. 74, No. 8, pages 3171–3175; August, 1977.

AN AMAZING SEQUENCE ARRANGEMENT AT THE 5′ ENDS OF ADENOVIRUS 2 MESSENGER RNA. Louise T. Chow, Richard E. Gelinas, Thomas R. Broker and Richard J. Roberts in *Cell,* Vol. 12, No. 1, pages 1–8; September, 1977.

THE INITIATION SITES FOR RNA TRANSCRIPTION IN AD2 DNA. Ronald M. Evans, Nigel Fraser, Edward Ziff, Jeffrey Weber and James E. Darnell in *Cell,* Vol. 12, No. 3, pages 733–739; November, 1977.

IMPLICATIONS OF RNA • RNA SPLICING IN EVOLUTION OF EUKARYOTIC CELLS. James E. Darnell, Jr., in *Science,* Vol. 202, No. 4374, pages 1257–1260; December 22, 1978.

VARIETY IN THE LEVEL OF GENE CONTROL IN EUKARYOTIC CELLS. James E. Darnell, Jr., in *Nature,* Vol. 297, No. 5865, pages 365–371; June 3, 1982.

THE DEAD SEA

SOME GEOCHEMICAL ASPECTS OF THE DEAD SEA AND THE QUESTION OF ITS AGE. Yaacov K. Bentor in *Geochimica et Cosmochimica Acta,* Vol. 25, No. 4, pages 239–260; 1961.

THE MICROBIOLOGY AND BIOGEOCHEMISTRY OF THE DEAD SEA. A. Nissenbaum in *Microbial Ecology,* Vol. 2, pages 139–151; 1975.

THE DEAD SEA: DEEPENING OF THE MIXOLIMNION SIGNIFIES THE OVERTURE TO OVERTURN OF THE WATER COLUMN. I. Steinhorn, G. Assaf, J. R. Gat, A. Nishry, A. Nissenbaum, M. Stiller, M. Beyth, D. Neev, R. Garber, G. M. Friedman and W. Weiss in *Science,* Vol. 206, No. 4414, pages 55–57; October 5, 1977.

SIX MILLENNIUMS OF BUFFALO KILLS

AN INTRODUCTION TO THE ECOLOGY OF EARLY PREHISTORIC COMMUNAL BISON HUNTING AMONG NORTHERN PLAINS INDIANS. George W. Arthur. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 40, 1975.

BISON PROCUREMENT AND UTILIZATION: A SYMPOSIUM. Edited by Leslie B. Davis and Michael Wilson. Memoir 14, Plains Anthropologist, 1978.

PREHISTORIC HUNTERS OF THE HIGH PLAINS. George C. Frison. Academic Press, 1978.

THE EXTINCTION OF THE AMMONITES

GEOMETRIC ANALYSIS OF SHELL COILING: COILING IN AMMONOIDS. David M. Raup in *Journal of Paleontology,* Vol. 41, No. 1, pages 43–65; January, 1967.

HYDROMECHANICAL DESIGN OF FOSSIL CEPHALOPODS. J. A. Chamberlain in *Ammonoidea: Evolution, Classification, Mode of Life, and Geological Usefulness of a Major Fossil Group,* edited by M. R. House and J. R. Senior. Academic Press, 1980.

CHAMBER REFILLING IN *NAUTILUS.* P. Ward and L. Greenwald in *Journal of the Marine Biological Association of the U.K.,* Vol. 62, pages 469–475; 1981.

SHELL SCULPTURE AS A DEFENSIVE ADAPTATION IN AMMONOIDS. P. Ward in *Paleobiology,* Vol. 7, No. 1, pages 96–100; 1981.

BILATERAL NEGOTIATIONS AND THE ARMS RACE

PROGRESS IN ARMS CONTROL? Introductions by Bruce M. Russett and Bruce G. Blair. W. H. Freeman and Company, 1979.

ARMS CONTROL AND DISARMAMENT AGREEMENTS. United States Arms Control and Disarmament Agency, 1982.

THE AMATEUR SCIENTIST

HARRY G. TRAVER: LEGENDS OF TERROR. Richard Munch. Amusement Park Books, Inc., Mentor, Ohio, 1982.

Red Adair and his Rolex stopped at nothing to blow out The Devil's Cigarette Lighter.

Red Adair puts out oil-well fires.

The most famous of them was nicknamed The Devil's Cigarette Lighter.

It was in the Sahara, at a place called Gassi Touil.

Every day, over 15 million cubic meters of gas roared 200 meters into the desert sky from this terrifying blowout.

Working under tons of falling water to combat the heat, Red and his team were able to maneuver 250 kilos of special explosive to within half a meter of the base of the flames. They set off the blast, and the fire was out in a split second.

In the slightly less heated atmosphere of the Rolex factory in Geneva, craftsmen create a watch designed to withstand the most appalling conditions.

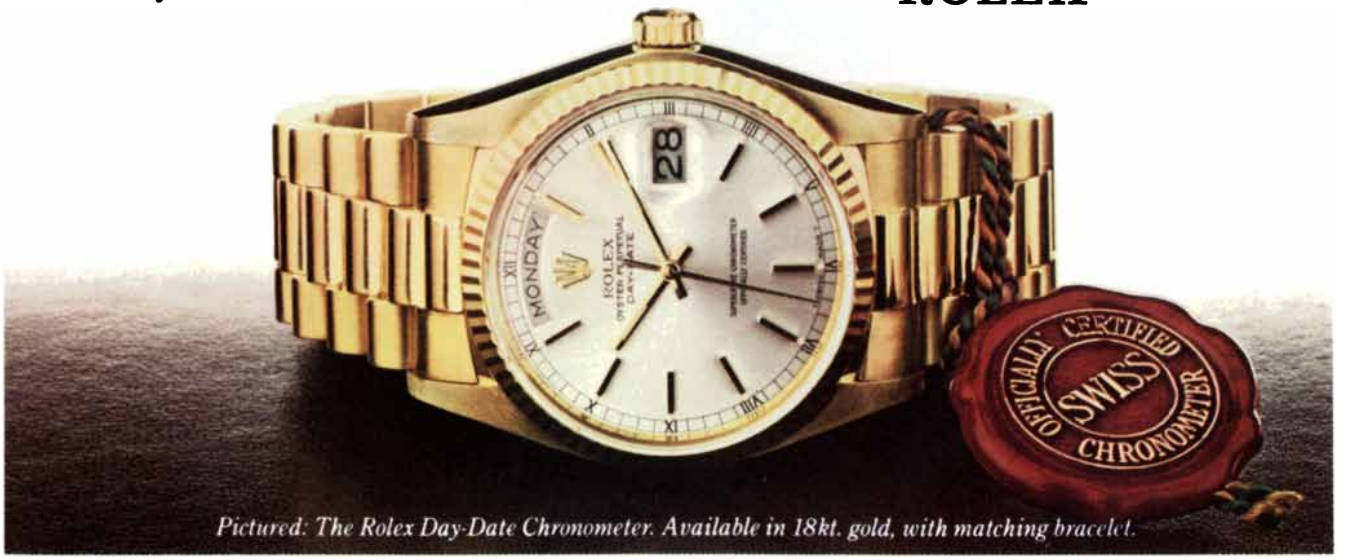
Every Rolex chronometer we make is officially tested night and day for two weeks. The Rolex movement must survive 15 days of extreme temperature changes, hanging unguarded by its rugged Oyster case.

But who could even guess at the sort of treatment a Rolex can expect to receive on the wrist of a man like Red Adair?

In 1977, Red and his team returned in triumph from the North Sea, after taming the Bravo blowout, a mixture of boiling oil and gas screaming out of the well-head at several hundred k.p.h.

The Daily Mail's reporter observed, "Solid gold Rolex watches were clamped to their wrists like a company badge." Some company. Some badge.

ROLEX



Pictured: The Rolex Day-Date Chronometer. Available in 18kt. gold, with matching bracelet.

Write for brochure. Rolex Watch, U.S.A., Inc., Dept. 416 , Rolex Building, 665 Fifth Avenue, New York, NY 10022.
World headquarters in Geneva. Other offices in Canada and major countries around the world.

Today's Chevrolet

Move into more. New Chevrolet Celebrity.

Four or five years ago, your smaller car seemed enough car. But now you're ready to move into more.

More room. More comfort. More power. And more than just a little more prestige.

For which we introduce our smooth, quiet, front-wheel-drive Chevrolet Celebrity.

Move into Celebrity comfort, Celebrity convenience. Comfort that begins with more passenger room than 98 out of 101 imports. More passenger room, in fact, than Chrysler LeBaron. Plus the convenience of more trunk space than Mercury Marquis.

More? Celebrity's standard electronically fuel-injected engine is so advanced it's automatically fine-tuned by computer. And gives you more standard cubic inches than any front-wheel-drive Datsun, Toyota, Honda, Mazda, Ford, Mercury or Dodge.*

*All comparisons based on latest available specifications at time of printing. Some Chevrolets are equipped

1984 Celebrity Sedan shown with available Eurosport Equipment Package, Aluminum wheels and Eagle GT tires.

GM

Let's get it together... buckle up.

All inside a shape so aerodynamic it cruises at 50 MPH on less than 12 horsepower.

More excitement. And front-wheel drive. Exemplified by our new Celebrity Eurosport shown here. All the virtues of Celebrity, all wrapped up in head-turning new European styling.

All mounted atop a Special F41 Sport Suspension. All at a price that will make Europe's best blush with envy.

And you with pride.

Isn't it time you moved into more car? Especially when all that much more doesn't cost all that much more. In fact, try to find any other front-wheel-drive car with Celebrity's passenger room at a lower sticker price.

You'll see what we mean by Chevrolet taking charge. By bringing you more of what you want today.

For less.

with engines produced by other GM divisions, subsidiaries, or affiliated companies worldwide. See your dealer for details.

DEWAR'S PROFILE:

MARK STORY

HOME: New York City.

AGE: 35

PROFESSION: Commercial film director, Pfeifer-Story Productions.

HOBBIES: Writing the ultimate self-help book for the non-gregarious, *How to Spend the Least Amount of Time with People You Don't Like.*

LAST BOOK READ: *Post Office*, Charles Bukowski.

LATEST ACCOMPLISHMENT: Directed *Fur*, a satirical short film, for *Saturday Night Live.*

WHY I DO WHAT I DO: "After eight years of taking orders in an advertising agency, the time had come. The directee would become the director. And I did."

PROFILE: Works well with people. Would prefer not to. "Closet recluse."

HIS SCOTCH: Dewar's® "White Label."® "After a long casting session and too many stage mothers, having a Dewar's and soda is the only honorable thing to do."