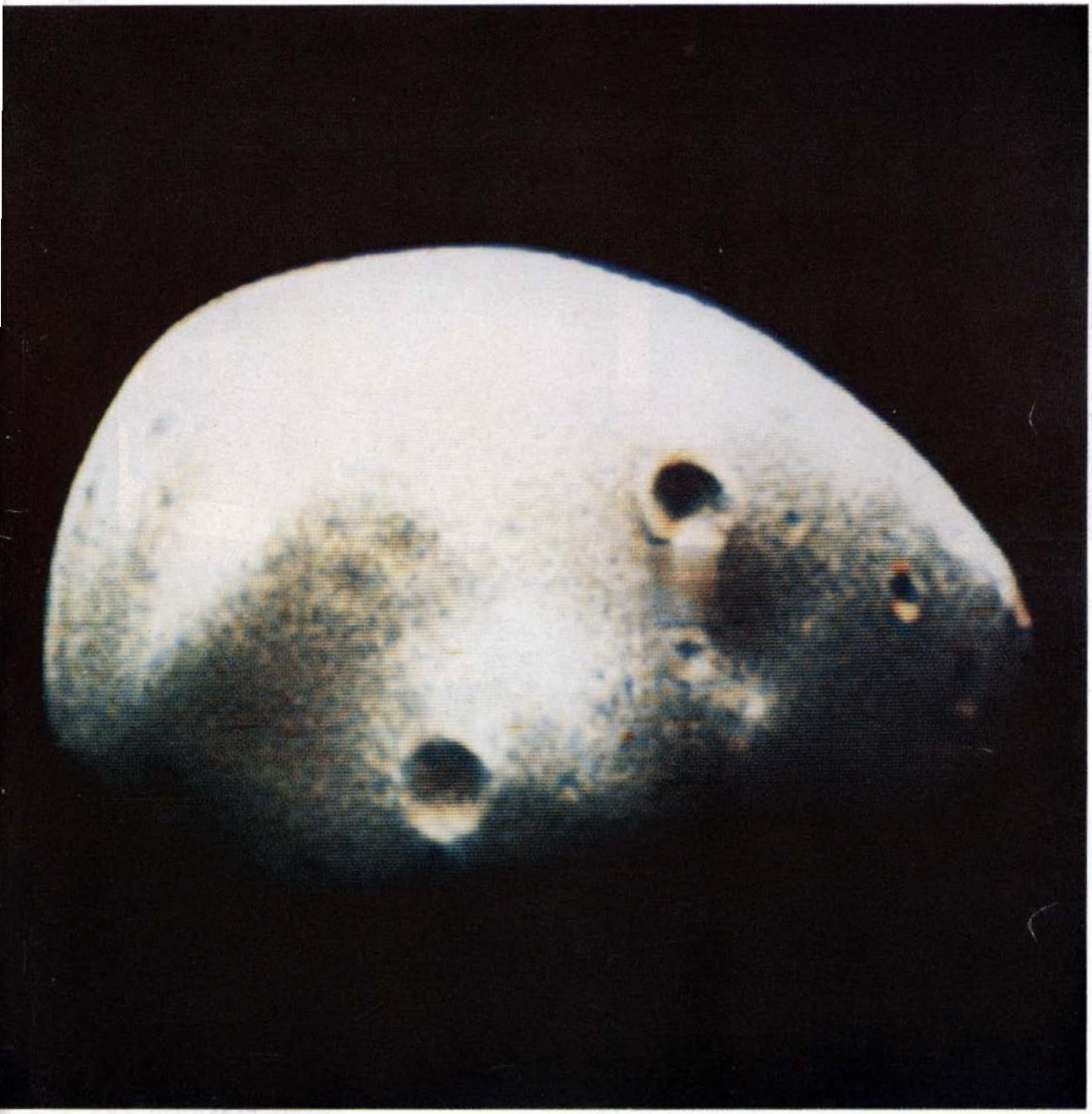
SCIENTIFIC AMERICAN



THE MOONS OF MARS

$1.50

February 1977

THE SX-70 AND ITS CLOSE-UP LENS HELP YOU APPRECIATE THE LITTLE THINGS IN LIFE.

Bees at work. Insured jewelry. Rare stamps. Test-tube precipitates.

SX-70 Land cameras can give you instant pictures of demanding close-up subjects like these.

Because we designed an optional close-up lens for the Deluxe SX-70, the SX-70 Model 2, and the new SX-70 Alpha series.

As you will see, that's a very impressive addition to the already impressive capabilities of the SX-70 family of photographic systems. What other camera can give you all this:

Single-lens reflex framing (the only *folding* SLR in the world) gives you an accurate preview of each picture.

Fully automatic functioning set in motion by a 12,000 RPM motor. Whether you're shooting with available light or with flash, you never have to worry about your light conditions, or shutter speeds, or keeping track of film development.

You even get automatic time exposures of up to 14 seconds.

Pictures whose brilliant Superclear colors last and last, thanks to stable, fade-resistant SX-70 Colorlock dyes.

Virtually grainless pictures that let you study the smallest details under a magnifying glass.

Sequential photos at 1.5-second intervals at a touch of the electric shutter button.

Pictures of subjects from 10.4 inches to infinity, without stopping to change lenses.

And *close-ups*? You can take one-half life-size pictures even *without* our close-up lens (which is quite a feat in itself). But to get even *closer,* just slip the close-up lens into its accessory holder, and you can take pictures as close as 5.5 inches from your subject. And come away with *full life-size images* in your hands.

So if you're about to buy an SX-70 (or if you already own one), buy the close-up lens for it. And then go out and photograph a little.

LIFE-SIZE IMAGES FROM THE POLAROID SX-70 LAND CAMERA.

Practical.

Practically perfect.

After bringing you a perfectly practical car, it should come as no surprise that we now bring you a car that's practically perfect.

The Volkswagen Rabbit.

In February of 1976, *Car and Driver* said of our car, "What we have now is a faster Rabbit that has benefited from step-by-step, under-the-skin attention to detail—which is damn encouraging because it shows that VW is sending the already-excellent Rabbit down the yearly refinement path that made the Beetle last almost four decades. Using that system, the Rabbit may be the world's first perfect car in just a few short years." Last year alone, we made 17 major changes and improvements toward making our '77 Rabbit even more perfect.

Since it was already big on room and performance, we added fuel-injection to help give it easier starts, yet allow it to use an economical grade of gas.

In a world that's far from perfect, isn't it nice to find something that's practically there.

Rabbit

One of the new generation Volkswagens.

Established 1845 **SCIENTIFIC AMERICAN** February 1977 Volume 236 Number 2

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $15 PER YEAR, U.S., ITS POSSESSIONS AND CANADA; $18 PER YEAR, ALL OTHER COUNTRIES.

executive health

the report that briefs you on what to watch

Volume X, Number 5 • Pickfair Bldg., Rancho Santa Fe, Calif. 92067 • Area 714:756-2600

Alton Ochsner, M.D.

ON THE ROLE OF VITAMINS C AND E IN MEDICINE

A world-famous surgeon tells you how and why he uses these two essential vitamins

PUBLISHER'S NOTE: *Dr. Ochsner is one of the outstanding international leaders in modern medical progress. Now Emeritus Professor of Surgery at Tulane University School of Medicine, he maintains an active practice at the famed Ochsner Clinic in New Orleans. As a member of our Editorial Board, we have asked him, out of his unique long personal experience with vitamins C and E, to tell you how and why he uses them.*

—Richard Stanton

The American public has become very health-conscious which is extremely desirable because most of us, when we arrive in this troubled world, are endowed with the most marvelously efficient mechanism ever devised, and much depends on us whether this mechanism will function properly and last without becoming prematurely obsolete.

No longer is longevity the principal consideration, and rightly so, because the desideratum is healthy and useful life as long as possible. Because of the health-consciousness of the public, people are avid for information concerning their health and factors which may improve it. It is inconsistent, however, that individuals concerned about remaining healthy and prolonging a useful life, adopt practices which are definitely known to accelerate aging, produce disabling illness, and shorten life. These are the use of tobacco, the abuse of alcohol, and excesses of all kinds.

Vitamin use has been a controversial subject for a number of years, and although vitamin deficiency is extremely undesirable, can be hazardous and even fatal, often vitamins are used when they are not needed. However, with advancing age it is probably desirable to use vitamin supplements because of de-

"HOW LONG WILL I LIVE?"

Before you get any older, isn't it time you find out how to take the best care you can of the only body you will ever have?

What keeps well people well? Medical men have long concentrated upon sick people and how to get them well . . . not upon well people and how to keep them well. Now many top research scientists are concentrating their efforts on *preventive medicine . . . how to keep well people well.*

May we suggest that you get the benefits of this new research for yourself? Do as so many thousands of executives do. Subscribe to Executive Health Report. The members of our *Editorial Board* are among the world's most distinguished authorities on *preventive medicine.* Their wise advice can help you not only live longer but enjoy those extra years! (Note their high qualifications as shown on opposite page.)

Executive Health Report is not sold on newsstands but only by private subscription at $18 a year in the U.S.A. and its possessions. $19 a year in Canada and Mexico. All other countries $24 by surface mail, $28 by air mail. Individual reports (back issues) $1.50 per copy.

Subscribe now under this unusual introductory offer:

(1) **Your choice of any three of the reports listed below ($1.50 each) FREE!**

(2) **Your money back at anytime during the entire year** if you do not find our reports live up to your expectations.

Never forget: *"Men's lives are chains of chances"* but as Euripides saw clearly so long ago: *"Chance fights ever on the side of the prudent."* Your only insurance against "tomorrow" is what you do today. You have but one life . . . doesn't it make sense to find out how to take the best care of it you can?

Please study the reports listed here and **circle your three choices:**

Sir Hans Krebs, M.D.: On the overuse and misuse of medication. Too many patients are being made ill by drugs due to their own or their physician's carelessness.

Alton Ochsner, M.D.: "On the Role of Vitamins C and E in Medicine." A world-famous surgeon tells you how and why he uses these two essential vitamins.

John K. Lattimer, M.D., Sc.D.: On That Treacherous Gland . . . Your Prostate.

On Fatigue, the Great Deceiver: Why most men never get their "second wind."

If You Sit At a Desk All Day, how to avoid a pot-belly and double-chin.

Never Take a Chance. Never Ignore Any Sign of a TIA (Transient Ischemic Attack) such as a sudden temporary weakness of an arm or leg.

The Anatomy of Courage. Some truths a man must learn to accept about life (and what he must do if he is to face up to them).

120/80 or what? High blood pressure: the hazard of your executive job.

The executive's dilemma: "Now I lay me down to sleep" (I hope!).

On "The Horizontal Exercise." New research findings about sex and how to keep your middle age young!

John Yudkin, M.D.: On "This Slimming Business" . . . The truth about the prevention and cure of overweight!

Linus Pauling, Ph.D.: What about Vitamin E? Eminent investigators now suspect it may be one of the key factors to help resist disease and slow the aging process.

Go easy gentlemen, too much social drinking damages your liver (even though you may feel well, eat well, and never get tight!)

Mark D. Altschule, M.D.: Is it true what they say about cholesterol? Do so many of our favorite foods, such as eggs, that contain cholesterol increase your risk of heart disease? Or are those TV ads for "substitute" foods that loudly proclaim: "No cholesterol, no animal fat" a lot of pseudo-scientific nonsense?

"The non-dieting diet." Walking is magic to keep or win back a strong, lean body (and that is just the first of its great health benefits.)

On how to live 90 to 100 healthy years! (The syndrome of longevity . . . its 7 great "constants").

On The Arthritis Mystery. Can what you eat—or don't eat—make you arthritis-prone or arthritis-resistant?

Alton Ochsner, M.D.: On "The Chair Disease" . . . Why blood clots in your veins are a little-realized occupational hazard of desk-bound executives.

Hans Selye, M.D.: On Stress Without Distress. Your mind can make or break you!

The B Vitamins . . . Part I. On B_{12} . . . When to suspect a deficiency of this remarkable vitamin in your diet.

Stephen R. Elek, M.D.: On "The Hurry-up Disease." Why it may be a key factor that triggers heart attacks as early as 40.

The B Vitamins . . . Part II. On Vitamin B_6 (Pyridoxine) "The Sleeping Giant of Nutrition."

Linus Pauling, Ph.D.: For the Best of Health, How Much Vitamin C Do You Need? People who take the optimum amount of vitamin C may well have, at each age, only one quarter as much illness and chance of dying as those who do not take extra vitamin C.

The B Vitamins, Part IV . . . On Folic Acid: The most commonly deficient B vitamin.

George C. Griffith, M.D.: On those irregular heart beats (arrhythmias). Some mean little or nothing, but others warn your heart is in trouble.

Ross Hume Hall, Ph.D.: Beware of those fabricated foods. There is still too much we do not know about all the chemical additives that are hidden away in the fine print on the labels of processed foods.

Roger J. Williams, Ph.D., D.Sc.: On your startling biochemical individuality. Some amazing facts about your body you need to know if you want to understand yourself (and other people) better.

On "The Unsuspected Illness"—Hypothyroidism. How it can subtly sap health in a variety of ways . . . and a simple test to uncover it.

On Estrogens . . . The Controversy Over "The Pill." Some women should never take it! Some women should never take it beyond a certain age! Why?

Please use the coupon below, under our money-back at any time guarantee.

EXECUTIVE HEALTH, Pickfair Bldg., Rancho Santa Fe, CA 92067

Gentlemen: Enclosed is my check for $_____ for a year's subscription to Executive Health to start with this month's issue. I have circled the three $1.50 reports I am to receive free. It is understood that I am to get my money back if at any time during the entire year I become dissatisfied with your reports. In addition, I would appreciate your sending me a complete list of your 70 other reports because among them may be some from which I might greatly benefit and would otherwise miss.

NAME (please print) _____

ADDRESS _____

STATE/COUNTRY _____ ZIP _____ SA-4

WHEN YOU BUILD A SPEAKER TO SOUND GREAT ON EVERY PART OF THE MUSIC, YOU CAN'T CUT CORNERS ON ANY PART OF THE SPEAKER.

A single HPM-100 weighs almost 60 pounds.

The fact it weighs more than a Large Advent speaker, Bose 901 or JBL L100 is not an accident.

Our speaker frames are made of heavy cast aluminum instead of the usual stamped metal, so you hear only the speakers vibrating and never their frames.

Our magnets are oversize to spare your ears needless distortion.

And our cabinet is made out of special compressed wood that's denser and heavier than ordinary wood. So the sound is forced out of the cabinet instead of being absorbed by it.

Of course, not everything that adds to the sound of an HPM-100 also adds to its weight.

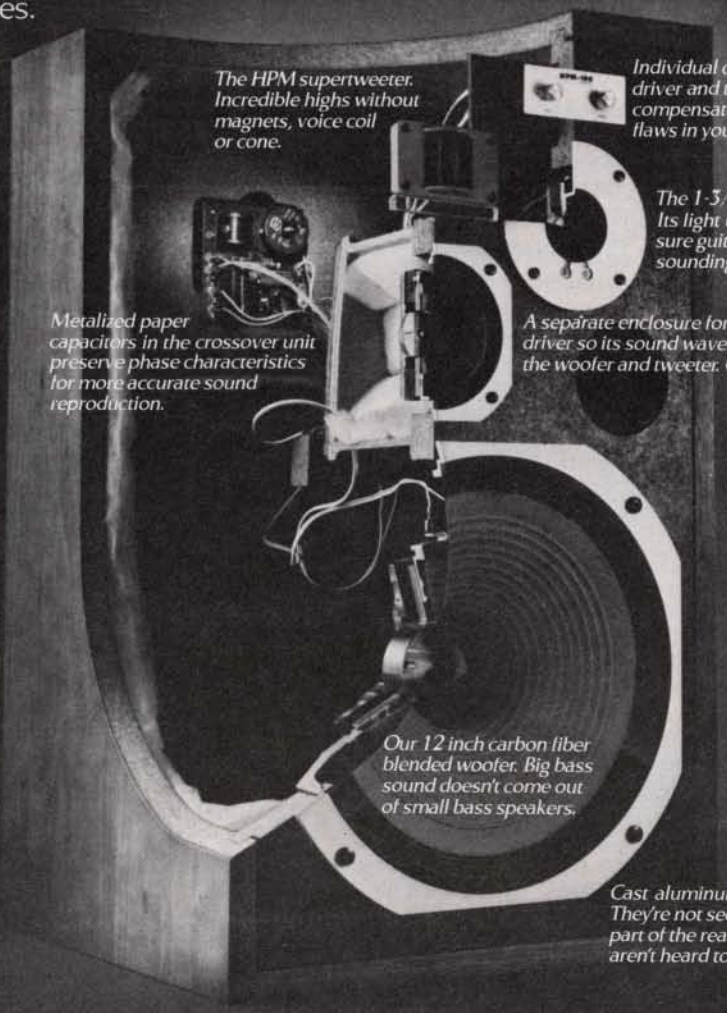
Our supertweeter uses nothing but a piece of High Polymer Molecular film to produce incredibly clear and crisp high frequencies.

Our midrange driver and tweeter have cones that are light enough to give sharp response, but rigid enough not to distort.

And our 12 inch woofer has a long throw voice coil and unique carbon fiber blend cone (instead of the typical cardboard cone) that work to produce the kind of realistic bass you not only hear, but feel.

Naturally, we could go on. About our 12-1/2 feet of damping material. Or about the aluminum screws that keep our speakers from falling out. They're ordinarily used to keep airplanes from falling apart.

But we figure at this point you'd rather hear our speakers in person than hear any more about them from us.



HPM-100™
The all-around great speaker.

PIONEER

THE COVER

The picture on the cover is a computer-generated color image of Deimos, the smaller of the two moons of Mars (see "Phobos and Deimos," by Joseph Veverka, page 30). A pair of images of Deimos obtained by the *Viking 1* orbiter, one at the wavelength of violet light and one at the wavelength of orange, were combined in a single image in search of color differences on the moon's surface. The image is shown here oriented so that the illumination is from top to bottom. This prevents the apparent relief of surface features from reversing so that depressions such as craters seem to be elevations. The test image showed that, at least down to a resolution fine enough to register any object 200 meters or more in diameter, the surface of Deimos is a uniform gray in color; slight tints of orange on the rims of some craters are artifacts of the imaging process.

THE ILLUSTRATIONS

Cover photograph courtesy of the Jet Propulsion Laboratory, California Institute of Technology

Page	Source
21	Andrew Christie
22–24	U.S. Navy
25	U.S. Air Force
26–29	Andrew Christie
31–32	Jet Propulsion Laboratory
33	Lorelle M. Raboni
34	Jet Propulsion Laboratory (*top*), Lorelle M. Raboni (*bottom*)
35–36	Lorelle M. Raboni
37	Jet Propulsion Laboratory
38	Department of Archaeology, University of Durham
40	Tom Prentiss
41	The Vindolanda Trust
42–43	Tom Prentiss
44–45	Department of Photography and Teaching Aids Laboratory, University of Newcastle upon Tyne
46	The Vindolanda Trust
56	Robert P. Sharp
59	Hughes Aircraft Company
60–62	Dan Todd
63	Communications Satellite Corporation
64–73	Dan Todd
75	Earl P. Benditt
76	Carol Donner
78–79	Earl P. Benditt (*left*), Carol Donner (*right*)
80–81	Carol Donner
82–84	Jerome Kuhl
87	Fritz Goro
90–97	Allen Beechel
100–101	Laszlo Kubinyi
102	Laszlo Kubinyi (*top*), Jerome Kuhl (*bottom*)
103	Jerome Kuhl
104	Laszlo Kubinyi (*top*), Jerome Kuhl (*bottom*)
105	Jerome Kuhl
106–107	John E. Heuser
108–111	Bunji Tagawa
112	Michael W. Klymdowsky, Michael J. Ross, Robert M. Stroud and Michael A. Raftery (*left*), Bunji Tagawa (*right*)
113–116	Bunji Tagawa
121–125	Ilil Arbel
129	*The Various and Ingenious Machines of Agostino Ramelli (1588).* © 1976, The Johns Hopkins University Press
130	*The Mycenaean World.* © 1976, Cambridge University Press
132	*Mechanical Design in Organisms.* © 1976, John Wiley & Sons

LETTERS

Sirs:

The article by Drell and von Hippel ["Limited Nuclear War," by Sidney D. Drell and Frank von Hippel; SCIENTIFIC AMERICAN, November, 1976] was an appropriate review of where we stand today on the general subject of strategic limited nuclear war. I regret that the word strategic was not in the title of the article, since there are other schools of thought that have based a successful deterrent to aggression on the selective limited use of *tactical* nuclear weapons having individual yields more than 1,000 times less than those discussed in the article by Drell and von Hippel.

Of concern to me in the article was the fact that after a comprehensive discussion of the subject I was left without any concrete suggestions as to what one might do. Somehow I sensed that a reader might assume that what was being suggested was a civil defense program to reduce the number of casualties rather than a way to keep the strategic threshold as high as possible.

Since we were successful in limiting massive ABM deployments, I would suggest that it might be appropriate to seek a treaty on banning any massive civil defense programs. If it is indeed true that the U.S.S.R. does not have an active civil defense program, and it is clear that we do not, then it should be relatively easy to ban something that does not exist.

H. M. AGNEW

Chairman
General Advisory Committee on Arms Control and Disarmament
Washington, D.C.

Sirs:

We regret that Dr. Agnew found our article left him "without any concrete suggestions as to what one might do." Our analysis showed that limited nuclear conflict involving militarily effective strikes against U.S. strategic forces would cause very large civilian casualties even if extensive civil defense protection is assumed to be available and fully utilized. It was our explicit conclusion that preparation for limited nuclear counterforce wars in all its aspects, including the development and deployment of a new force of missiles designed specifically as hard-silo killers and the inauguration of extensive new civil defense population-evacuation programs, would make no contribution toward diminishing the present "balance of terror" and would be harmful to the stability of the present strategic balance between the U.S. and the U.S.S.R. We therefore advocated that both nations "limit their traditional technological arms competition by restraining the testing and deployment of new weapons designed to destroy hardened ICBM [intercontinental ballistic missile] silos." One particularly straightforward and verifiable step for accomplishing this goal is to negotiate at the strategic-arms-limitation talks an equal annual missile-test-firing quota for each nation.

In his letter Dr. Agnew also raises the separate issue, not discussed in our article, of the possible deterrent value of the limited *use* of low-yield tactical battlefield nuclear weapons, particularly of the "mininukes" being developed at the Los Alamos Scientific Laboratory, of which he is the director. No matter how small its yield, a nuclear weapon is unmistakably nuclear. Once a war starts, information about what is happening will be ambiguous, and often wrong, and command and control of events will be incomplete, as we learned most recently in Vietnam. Once nuclear weapons are employed in war at all it will be very difficult, if not impossible, to verify the yields, sizes, numbers and types of the nuclear explosions set off. Once the nuclear threshold is crossed we face the grave danger of the eventual escalation from an initially limited nuclear war to an all-out nuclear holocaust.

In short, there is only one fact that is technically unambiguous, and that is whether or not nuclear weapons have been used at all. Therefore it is wisest for the U.S. to adopt as national policy

Scientific American, February, 1977; Vol. 236, No. 2. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and secretary; George S. Conn, treasurer; Arlene Wright, assistant treasurer.

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

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

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 35 cents.

Subscription correspondence should be addressed to Subscription Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. For change of address, notify us at least four weeks in advance. Send both old and new addresses and enclose an address imprint from a recent issue. (Date of last issue on your subscription is shown at upper right-hand corner of each month's mailing label.)

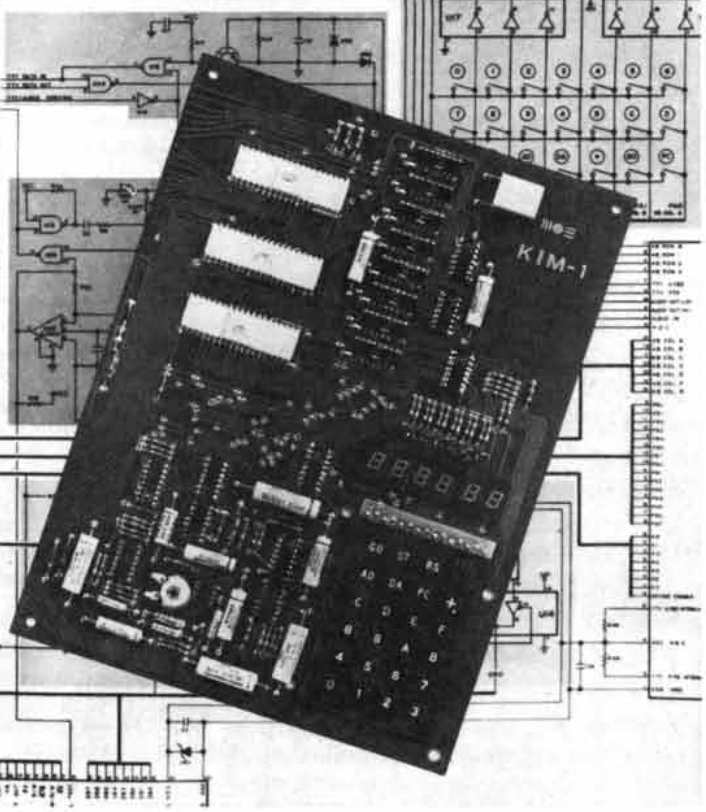
Name

New Address

Old Address

The Complete Personal MicroComputer!

KIM-1 Microprocessor by MOS Technology: A COMPLETE SYSTEM ON A SINGLE PRINTED CIRCUIT CARD



The KIM-1 (by MOS)—NOT A KIT. Fully Assembled Cost—$245!!

The age of the microprocessor is here and MOS Technology is leading the field with this unbelievable breakthrough. Now it is possible to have a complete system, fully assembled, tested, and warranted for only $245. The KIM-1 is conveniently designed on a single printed circuit card as pictured in this ad.

The KIM-1 System consists of a microprocessor, two ROMs (Read Only Memories) containing a monitor program, 1152 bytes of read/write memory, four I/O ports, two programmable interval timers, a six digit L.E.D. display, a keyboard, an audio cassette interface, and a TTY interface. All this for an unprecedented $245! KIM-1 is without a doubt the most complete system available in its price range.

Who Can Use The KIM-1 System?

- The Industrial/Commercial/Office User: The microprocessor, which replaces Random Logic, offers this classification of user a revolutionary alternative to an outside service bureau or an expensive in-house mini-computer system. For anyone working in this area or contemplating an automated system, the KIM-1 is an excellent, inexpensive learning device to introduce the numerous applications a microprocessor can offer the business community such as inventory control, payroll, accounting functions, research, laboratory instrument control, etc
- The Educational Marketplace: There are thousands of KIM-1 units in daily use by Computer Science classes as well as Math, Physics, Electrical Engineering, Chemistry, and Science Departments in Universities and Secondary Schools all over the world.
- The Hobbyist/Enthusiast: Certainly this growing group of professional and amateur "computer freaks" are finding hours of educational, experimental intrigue and fascination with the amazing KIM-1 "all-in-one" system. With new applications and peripheral equipment breakthroughs being discovered almost daily, the hobbyist/enthusiast can build a system of his own that will provide an exciting new "adult toy" that can perform all kinds of useful and fun functions at home, such as tax computation, keeping your personal financial records in order, designing and playing sophisticated games, running your ham radio station, and helping you to invent! You can even let it regulate your energy usage.

KIM-1 Includes:

• **Hardware:** KIM-1 module with 6502 μP Array • 6530 Array (2) • 1K Byte RAM • 15 I/O pins. • **Software:** Monitor Programs (Stored in 2048 ROM Bytes) • 500 Pages of Full Documentation: KIM-1 User Manual • System Schematic • 6500 Hardware Manual • 6500 Programming Manual • 6500 Programmer's Reference Card • 90 Day Manufacturer's Warranty—Seven Day Service!

Options and Peripheral Equipment Also Available:

• Fully Assembled Power Supply Source—$50 • KIM-2 (4K Word Memory)—$179 • KIM-3 (8K Word Memory)—$289 • Teletype Unit #CT-1024—$300 • KIM-4 "Mother Board"—$119 • KIM Resident Assembler/Editor Language Program—$150 • KIMATH—$50

Gentlemen: Please ship me _____ KIM-1 Systems at a cost of $245 per System plus $5.00 for shipping and insurance. If not satisfied I may return it for a prompt refund if returned within 2 weeks.

☐ Check or M.O. Enclosed (Ill. residents add 5% sales tax)
☐ Purchase Order From Well-Rated D&B Firm Enclosed
☐ Charge My Credit Checked Below:
☐ American Express ☐ Diners Club ☐ BankAmericard
☐ Master Charge ☐ Carte Blanche

Credit Card #_____

Master Charge Bank #_ _ _ _ Exp. Date_____

Name_____

Address_____

City_____ State_____ Zip_____

Signature_____ SCA-2/77

Send Coupon To:

Contemporary Marketing, Inc.

790 Maple Lane, Bensenville, Ill. 60106

312-595-0461

the highest possible nuclear threshold. This implies a gap between nuclear and non-nuclear warfare that is as clear and as wide as possible.

SIDNEY D. DRELL

Stanford University
Stanford, Calif.

FRANK VON HIPPEL

Princeton University
Princeton, N.J.

Sirs:

In "Science and the Citizen" for October, under the heading "Constant Constants," a rather confused account is given of the discoveries surrounding the BL Lacertae object AO 0235+164. It appears that you have relied heavily on the views of the radio astronomers who have made some of the observations. However, as a principal investigator in one of the two groups of optical observers who were the first to establish the existence of the two absorption-line red shifts in the object, I should like to say something about my view of the situation. The argument that is made by Morton S. Roberts and his associates and is repeated in a rather garbled way in *Scientific American* has no validity unless it is assumed that the object is at the distance equal to or greater than that given by the larger of the two absorption-line red shifts, that is, it must be supposed that these red shifts are of cosmological origin. From our investigation of this object we were not able to decide whether or not this is the case. Since AO 0235+164 has two absorption-line red shifts and so far no emission-line red shift, it must be assumed that, if the object is at a cosmological distance, the two absorption-line red shifts are due to at least one galaxy or cloud and possibly two. This is a most improbable situation, and although one cannot do statistics involving one object, I do not believe it is the case. The alternative proposal is that both absorption-line red shifts arise in gas that has been ejected from the highly active compact nonthermal object. This is an explanation that some of us prefer. It also has its difficulties, but it does allow of the possibility that AO 0235+164 is not at a cosmological distance, as well as the possibility that it is. Thus all the publicity that has been generated about the "constant constants" is based on rather flimsy evidence, and on only one of what I believe are two or three possible interpretations of the observations.

MARGARET BURBIDGE

Revelle College
University of California
San Diego

As a dramatic introduction to membership in the BOOK-OF-THE-MONTH CLUB®

in a short trial membership you can obtain WILL and ARIEL DURANT'S

MONUMENTAL ELEVEN-VOLUME HISTORY

The Story of Civilization

for only $24.75 [Publisher's list price: $24.45]

The Suggested Trial: You simply agree to buy four Club choices within a year at substantial savings on most books you choose

EVER SINCE THE FIRST VOLUME of this remarkable magnum opus appeared forty-one years ago, it has been hailed as a literary achievement as well as an epic history of civilization. As such it certainly deserves a place in every library, especially in homes where there are young people of school age. Each volume, including the recently published *Age of Napoleon*, has been given not only extraordinary critical acclaim but wide general readership throughout the world.

"Our century has produced no more successful attempt to narrate the whole common story of mankind"—CLIFTON FADIMAN

I. Our Oriental Heritage. Ancient Egypt and the Near East. The Far East, early to modern times.

II. The Life of Greece. Explores all facets of Greek life from prehistoric times to the Roman conquest.

III. Caesar and Christ. The rise of Rome and Christianity and the collapse of classic civilization.

IV. The Age of Faith. Christian, Islamic and Judaic civilizations, 325 to 1300, including the Crusades.

V. The Renaissance. Italy's golden age, 1304 to 1576. A turbulent world of intrigue and great art.

VI. The Reformation. Europe's religious conflicts, from two centuries before Luther to Calvin.

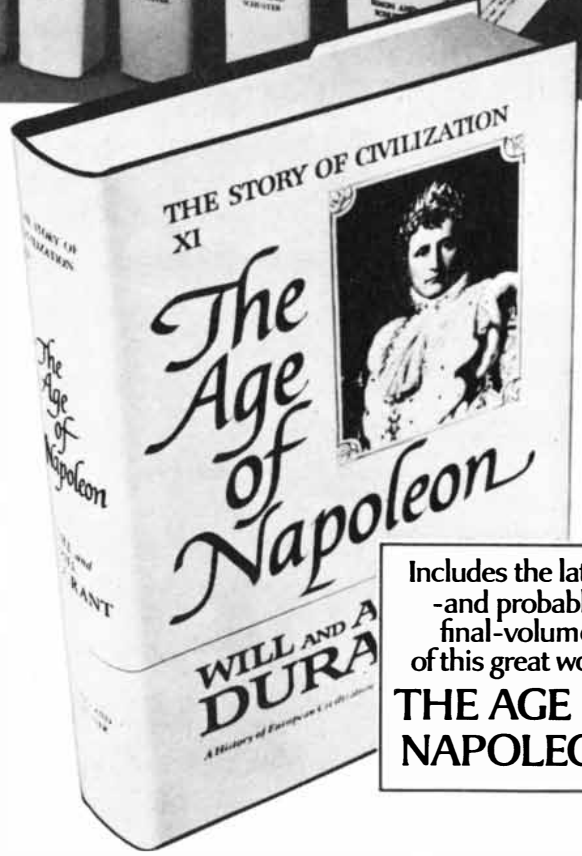
VII. The Age of Reason Begins. Europe, 1558 to 1646. The age of Shakespeare, Rembrandt, Galileo.

VIII. The Age of Louis XIV. The brilliant era of the "Sun King," Milton, Cromwell, Peter the Great.

IX. The Age of Voltaire. Europe from 1715 to 1756. The world of Frederick the Great, Wesley, Bach.

X. Rousseau and Revolution. Europe from the Seven Years' War to the storming of the Bastille.

XI. The Age of Napoleon. France's domination of European history, from the fevers of the French Revolution to the time of Napoleon's historic defeat at Waterloo. A history of European civilization from 1789 to 1815.



Includes the latest -and probably final-volume of this great work:

THE AGE OF NAPOLEON

BOOK-OF-THE-MONTH CLUB, INC., Camp Hill, Pennsylvania 17012

The legend continues...

Mercedes-Benz presents a

Announcing an important new design from Mercedes-Benz. Sleek. Lean. With nimble handling. Ample space for five adults. Dozens of ingenious safety provisions. And fuel-injected power plants. The new Mercedes-Benz: Engineered like no other car in the world.

The new Mercedes-Benz required a full eight years to perfect. That may seem an almost leisurely pace.

However, when you come to understand the importance of this new Mercedes-Benz design, and the significance of its many engineering innovations, you'll see that it couldn't have been produced any faster.

New suspension

The design concept of the new Mercedes-Benz represents an exquisite balance among the needs for occupant protection, refined handling characteristics, and driver comfort. Maximizing each of these qualities required particular engineering finesse.

Perhaps the major achievement is the new front suspension. It is a simplified and strengthened front-end construction, buttressed with special gas-pressurized shock absorbers. It helps the new Mercedes-Benz deliver precise steering with instant response, virtually no lean in braking or cornering—and straight-line control on even the roughest roads. What's more, the lubricated-for-life ball joints are completely maintenance free.

There are dual-circuit power disc brakes on all four wheels—just as there have been on all Mercedes-Benz automobiles since 1968.

The look of the future

This new design is a fresh look for Mercedes-Benz. Closer to the road.

Three distinctive models. Each one is fuel injected. One of them will meet your precise driving requirements.

240 D

- Engine Type—Diesel, 4-cylinder, fuel injection, overhead camshaft, 5 main bearings
- Displacement—146.7 cu. in.
- Fuel/Fuel System—Diesel #2, mechanical fuel injection
- Manual Transmission—4-speed, fully synchronized
- Curb Weight—3210 lbs.
- Overall Height—56.6"
- Overall Length—190.9"
- Turning Circle—37'
- Trunk Capacity—17.7 cu. ft.
- Passengers—5
- Wheelbase—110"

300 D

- Engine Type—Diesel, 5-cylinder, fuel injection, overhead camshaft, 6 main bearings
- Displacement—183.4 cu. in.
- Fuel/Fuel System—Diesel #2, mechanical fuel injection
- Automatic Transmission—4-speed, torque converter
- Curb Weight—3515 lbs.
- Overall Height—56.6"
- Overall Length—190.9"
- Turning Circle—37'
- Trunk Capacity—17.7 cu. ft.
- Passengers—5
- Wheelbase—110"

280 E

- Engine Type—6-cylinder, continuous fuel injection, double overhead camshafts, 7 main bearings
- Displacement—167.6 cu. in.
- Breakerless, transistorized ignition system
- Automatic Transmission—4-speed, torque converter
- Curb Weight—3530 lbs.
- Overall Height—56.6"
- Overall Length—190.9"
- Turning Circle—37'
- Trunk Capacity—17.7 cu. ft.
- Passengers—5
- Wheelbase—110"

singular new achievement.

Slightly wider. Clean-limbed. The new effect is subtle but undeniable.

Inside, there's new luxuriousness, with ample front and rear legroom and headroom. And the trunk offers 17.7 cubic feet of usable space.

A perceptive observer may notice that all the frame members supporting the roof seem more slender than in previous Mercedes-Benz models. Actually, these crucial safety members have been strongly reinforced. And their slim shape contributes to driver visibility. Another visibility aid: a total of 27.3 square feet of tinted glass.

The passenger compartment is a steel shell surrounded by lateral-impact-resistant elements, with crushable safety zones in front and rear.

The front safety zones are now creased for even more precisely defined deformation should an accident occur.

The rear crush path has been lengthened by moving the gas tank forward to a protected position above the rear axle.

And in front, the steering mechanism is positioned well behind the front wheels to protect it in a collision.

The aesthetics of safety

Study the dashboard's well-thought-through details and take pleasure in them. The sense of stark elegance. The intelligent arrangement of switches and controls. The impressively sized steering wheel with a built-in safety chest pad. Anatomically designed seats. Impact-resistant handles on all doors.

Fore and aft, a new type of energy-absorbing bumper flows smoothly into the car's silhouette.

The new Mercedes-Benz is, quite possibly, a masterpiece. A cursory look will indicate that. But only when you take the wheel will you recognize the significant difference between this and all other cars. Arrange a drive with your authorized Mercedes-Benz Dealer. Then you'll agree: the legend continues.

Mercedes-Benz

Engineered like no other car in the world.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1927: "The first isolation and crystallization of an enzyme has been achieved by Dr. James B. Sumner, assistant professor of biological chemistry at the Cornell Medical College. The enzyme is known as urease. Chemists have been attempting to purify enzymes for nearly a century, but up to the time of Dr. Sumner's work no enzyme had ever been prepared in pure condition, and the chemical nature of enzymes was entirely unknown. Indeed, a prominent worker in this field, Dr. Richard Willstätter of Germany, recently declared that the enzymes belonged to no known group of chemical substances. An enzyme is a catalyst of a special sort. It is extremely unstable and of a colloidal nature. These are the chief reasons why the isolation of an enzyme has been considered an almost impossible task."

"'Helium solidified under a pressure of 150 atmospheres at the temperature of its boiling point, and under 28 atmospheres at 1.5 degrees absolute. Solid helium forms transparent mass.' Thus did Professor W. H. Keesom of the University of Leiden recently announce to the scientific world that he had at last succeeded in freezing the gas helium. 'In one experiment,' said Professor Keesom, 'part of the substance was liquid and part solid.'"

"The well-designed audio-frequency amplifier and loud speaker of a radio receiving set may now be used to reproduce phonograph music with great volume and perfect fidelity of tonal quality. The device that makes this possible is the 'gradeon.' It consists of a special electrical pick-up, a volume control and a plug. To make use of this electrical phonograph arrangement the present soundbox is removed from the tone arm and replaced by the electrical pick-up; the volume-control box is placed in a corner of the phonograph, and the plug, on the end of a long flexible cord, is inserted in the radio set in place of the detector tube. It is said that the reproduction is superior to that of the ordinary phonograph."

"The work of Dr. Edwin P. Hubble with the great 100-inch reflecting telescope of the Mount Wilson Observatory has shown that our 'Milky Way,' or galaxy, is not alone in space. Scattered around the sky are millions of other galaxies. In some of the closest spiral nebulae Dr. Hubble has made photographs that actually show the individual stars, and from the study of these stars he has determined the approximate distances of the galaxies. But the galaxies that are farther removed have also had their approximate distances determined, because they all are of nearly the same brightness. The fainter they appear, the farther away they are, on the average. According to Dr. Hubble, 'the nebulae are so distant that in observing them we are witnessing events which actually occurred in past geological ages. The nearest of them all, the Magellanic Clouds, present the appearance they had back in the Great Ice Age. The spiral in Andromeda is a Pliocene object. The border of the observable region takes us back to the late Paleozoic.'"

SCIENTIFIC AMERICAN

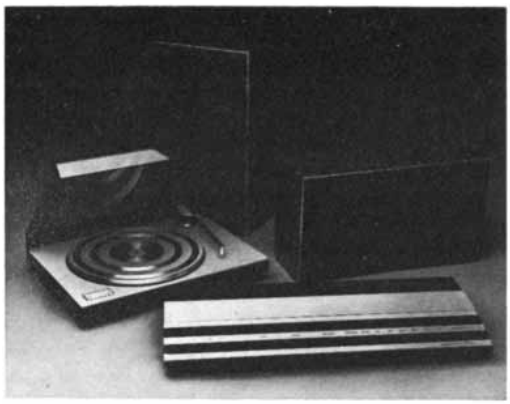
FEBRUARY, 1877: "The articulating telephone of Mr. Graham Bell consists of two parts, a transmitting instrument and a receiver, and one cannot but be struck by the extreme simplicity of both instruments. The transmitting instrument consists of a horizontal electro-magnet attached to a pillar about three inches above a horizontal mahogany stand. In front of the poles of this magnet—or more correctly speaking magneto-electric inductor—is fixed to the stand in the vertical plane a circular brass ring, over which is stretched a membrane, carrying at its center a small oblong piece of soft iron that plays in front of the inductor magnet whenever the membrane is in a state of vibration. The ends of the coil surrounding the magnet terminate in two binding screws by which the instrument is put in circuit with the receiver. That instrument consists of a vertical bar electro-magnet enclosed in a tube of soft iron, by which its magnet field is condensed and its attractive power within that area is increased. Over this is fixed, attached by a screw at a point near its circumference, a thin sheet-iron armature of the thickness of a sheet of cartridge paper, and this when under the influence of the transmitted currents acts partly as a vibrator and partly as a resonator."

"Dr. Schliemann's excavations at Mycenae are yielding results that are of immense value. The most interesting part of the explorer's work is just now in progress, as he has at last reached human remains in a preserved state. When the news spread that the explorer had found a tolerably well-preserved body, people flocked to Mycenae by the thousands from all parts of Greece to view it. The corpse, however, threatened disintegration at any moment, and Dr. Schliemann, in despair of keeping it, sent for a portrait painter to prepare a picture of it. Luckily it lasted two days, and before that period had elapsed a smart druggist from a town in the vicinity suggested soaking the remains in spirit in which gum sandarac had been dissolved. This was done, and Dr. Schliemann now thinks that the body can be removed to Athens unimpaired."

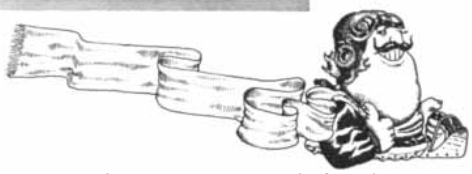
"Photography has proved an invaluable aid in the study of solar physics. With its help astronomers now obtain pictures of sun spots accurate in all their detail. At the observatory of the Roman College, Father Secchi has photographed the sun daily. By comparing these pictures the periodicity of the spots has been determined, and from data thus obtained astronomers have reached the belief that the sun not only acts as a center of attraction and a luminous source but also exercises a potent effect on magnetic phenomena."

"In London two skating rinks with artificial ice floors are now in successful operation. The floor of each rink is arranged in the form of a shallow basin, on which are laid a series of flat or oval pipes. The basin is filled with water so as to cover the pipes. The pipes contain glycerine and water, which is made to circulate through the pipes by steam power; the liquid within the pipes is refrigerated by evaporated sulphurous acid gas, contained within a tank, through which one end or portion of the rink basin pipes pass. The sulphurous acid gas is condensed into liquid form by compression pumps as fast as it evaporates in the refrigerating tank, and it is then allowed to evaporate again. Thus a continual evaporation goes on within the tank, producing a temperature of from 30° to 40° F. below the freezing point. The glycerine and water is hence so greatly reduced in temperature that the water in the rink basin congeals."

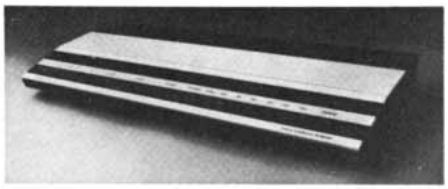
"A good many honest but misguided people have expressed the belief that *Scientific American* has been too severe in its remarks about spiritualistic frauds, illusions and the like. We are pleased therefore to find our diagnosis sustained by so excellent a medical authority as the London *Lancet*. Particularly blamable, the *Lancet* thinks, is the president of the Psychological Society and other patrons and readers of psychology. They ought to know better than to give their countenance and support to a pursuit in which weaker heads are in danger of being turned. Efforts to determine whether or not there is a force outside the material world are beginning to tell on the mental strength of some who have been lured into the toils of a kind of psychology that is no longer a science, because it has cast adrift the principles of nature and elects to run riot in vain imaginings and idle conceits."



The Bang & Olufsen Beosystem 1900. It's so simple, most people don't get it.

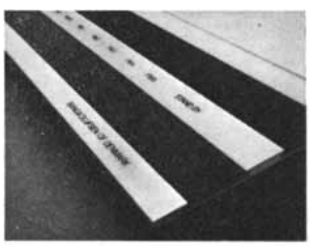


An alternative to the airplane cockpit school of audio design. It's not knobs and dials that make superb sound, it's superb engineering. In the Beosystem 1900, there is almost none of the former, and a great deal of the latter.

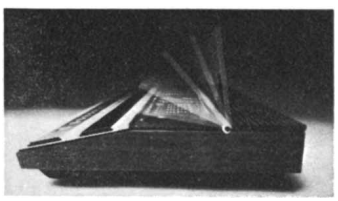


A few cases in point:

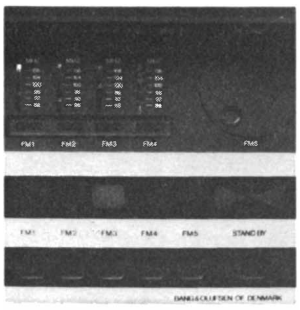
Your finger, the component. With the Beomaster® 1900, you become part of the system. All major controls are electronically activated by a light touch of your finger on the front control panel. The instant you touch it, an illuminated indicator appears for each function, you always know the operational status of the 1900, even in the dark.



For details, look inside. Secondary controls, for bass, treble, and FM tuning, are out of sight, literally—concealed behind an aluminum door that opens and closes in a manner reminiscent of the Starship "Enterprise."



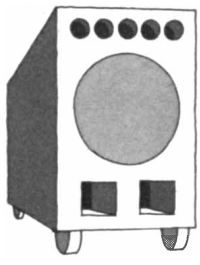
Thanks for the memory. The Beomaster 1900 also allows you one unforgettable convenience. You may pre-set the volume level and pre-tune up to five FM stations. Then, at the instant you want it, you have the station you want, at the level you want. Why clutter your memory when the system has one?



The turntable, taken to its logical conclusion. The Beogram® 1900 turntable's very low mass tone arm and MMC 4000 cartridge work magnificently with each other, because they are *made* to work with each other, by engineers who talk to each other, listen to each other, and design for each other. If that strikes you as overwhelmingly logical, you'd be surprised how other turntables are put together.

A scratched record is forever. (How to protect your investment.) No matter how little you've spent on your record collection, chances are some of it is irreplaceable, which makes it priceless. It makes sense to protect it—the way our MMC 4000 cartridge does with an effective tip mass of only 0.4 milligrams. (A tiny square of this page, this big □ weighs 1.0 milligram.) This results in a touch so delicate that it's almost impossible to scratch your records while playing them. It also reduces wear considerably enabling your records to continue working well past normal retirement age.

We don't recommend this, but with the MMC 4000 cartridge, it won't hurt



It's not size that counts. It's performance. Can a speaker small enough to fit on an eight-inch shelf (or unobtrusive enough to hang on a wall) impress your audiophile friends? Yes, if they keep their eyes closed ...and their ears open.

The missing link: Our 100% solution. Phase distortion—a principal villain in speaker performance—was identified in 1973 by Bang & Olufsen engineers. The first practical solution to the problem was presented in London in 1975 to the international organization, the Audio Engineering Society, by Bang & Olufsen engineers.

Today that solution is an integral part of our Beovox® Phase-Link® Loudspeakers (Pat. Pend.).

If a child can operate it, will an adult buy it? Because *usability* is at the heart of the Beosystem 1900's design, it is true that a child can operate it. But only a very sophisticated adult can truly appreciate it. Welcome. Write to us at: Bang & Olufsen of America, 515 Busse Road, Dept. 131 Elk Grove Village, Illinois 60007, we'll be happy to send you our brochure and dealer list.

Bang & Olufsen

THE AUTHORS

KOSTA TSIPIS ("Cruise Missiles") is a physicist at the Massachusetts Institute of Technology who now devotes all his time to questions of defense policy and arms control. A native of Greece, he came to the U.S. in 1954 to attend Rutgers University as a Fulbright Scholar. After receiving a B.S. in electrical engineering and an M.S. in atomic physics at Rutgers he went to Columbia University, where in 1966 he obtained his Ph.D. in high-energy particle physics. That year he joined the faculty at M.I.T. He became a U.S. citizen a year later. He writes: "I developed an increasing interest in the problem of science in public affairs and particularly in arms control. Eventually I decided that the problems of arms limitation are too serious and important to be doing only with my left hand, and so now I spend all my time doing research, lecturing and writing on the technical aspects of arms limitation. In 1973 I joined the Stockholm International Peace Research Institute as a researcher for two years, and at the same time I accepted the post of research fellow at the Center for International Studies at M.I.T."

JOSEPH VEVERKA ("Phobos and Deimos") is assistant professor of astronomy at Cornell University. He obtained his undergraduate education in physics at Queen's University in Canada. After completing his Ph.D. degree in astronomy at Harvard University in 1970, he joined the Laboratory for Planetary Studies at Cornell. He is particularly interested in the history and evolution of planetary satellites and in their direct exploration by spacecraft. In 1971 and 1972 he was a member of the *Mariner 9* television team that carried out the first detailed examination of the Martian satellites. He is currently a member of the Viking Orbiter imaging team.

ROBIN BIRLEY ("A Frontier Post in Roman Britain") is director of the Vindolanda Trust. He received an M.A. in modern history at the University of Oxford. After military service with the Royal Marine Commandos he was an instructor in schools for 10 years (including six years at Gordonstoun, where he taught history to Prince Charles). Thereafter he taught in colleges for three years. He has excavated on the northern frontier of England for many years, notably at Housesteads on Hadrian's Wall and at the fortress of Carpow in southern Scotland. He has a major work on Vindolanda now in press for the New Aspects of Antiquity series of the publishers Thames and Hudson. Birley is a Fellow of the Society of Antiquaries of London.

BURTON I. EDELSON ("Global Satellite Communications") is director of the COMSAT Laboratories of the Communications Satellite Corporation in Clarksburg, Md. There he is involved with research and development in spacecraft, microwave systems, signal processing and transmission technology. He was graduated from the U.S. Naval Academy in 1947 and earned his M.S. and Ph.D. degrees at Yale University. He first became interested in space technology while he was serving as a naval officer developing equipment for navigation and for communication between ships at sea via satellites in orbit around the earth. As a Navy project manager he progressed from the development of shipboard equipment to the designing of the satellites themselves. In 1967 he left the Navy and joined COMSAT to work on various commercial applications of space technology.

EARL P. BENDITT ("The Origin of Atherosclerosis") is professor of pathology and chairman of the department of pathology at the University of Washington School of Medicine. He received his M.D. degree from the Harvard Medical School in 1941. After completing his internship at the Philadelphia General Hospital he went to the University of Chicago Clinics. He remained there from 1944 through 1957, when he went to the University of Washington. He writes: "My scientific interests are broadly in the study of disease and specifically in the study of human disease. For many years my students and I have been interested in how cells and tissues respond to injury. When we started, neither methods nor certain fundamental biological concepts were available to study human disease in the way I wanted to and felt was necessary. Because of that we devised experiments with animals designed to be models of the disease in human beings. It has been a great delight to me to observe, to encourage others and to participate in developments that have led to our being able to study fundamental aspects of diseases in human beings. I am fascinated by the interaction of human beings with their environment and by the environment's role in the production of disease."

RICHARD N. ZARE ("Laser Separation of Isotopes") is Higgins Professor of Natural Science at Columbia University. Born in Cleveland in 1939, he received his B.A. degree from Harvard University in 1961 and his Ph.D. (in chemical physics) from the same institution in 1964. After working at the Massachusetts Institute of Technology and the University of Colorado, he became professor of chemistry at Columbia in 1969 and was named Higgins Professor in 1975.

ROBERT M. KRAUSS and SAM GLUCKSBERG ("Social and Nonsocial Speech") are respectively professors of psychology at Columbia University and Princeton University. Krauss received both his bachelor's and doctor's degrees from New York University. He then taught at Princeton, Harvard and Rutgers before joining the faculty of Columbia in 1970. He has done research in interpersonal bargaining and theoretical work in social psychology. Currently he is studying the nonverbal and verbal behavior involved in acts of self-presentation, research that includes the investigation of nonverbal accompaniments to attempts to deceive others. He is also interested in the nonverbal clues people employ to regulate the flow of conversation. Glucksberg also received his Ph.D. from New York University and has been at Princeton since 1963. He is the coauthor, with Joseph H. Danks of Kent State University, of *Experimental Psycholinguistics,* a general introduction to the psychology of language. His research interests have included problem solving and creativity, the memory of adults and children, the relation between language and thinking, and the strategies and mechanisms used by people in understanding both spoken and written discourse. Currently he is engaged in studying the ways in which words and sentences are represented in the memory of adults. Glucksberg's other activities include working on an introductory psychology textbook, consulting with the Bureau of Consumer Protection of the Federal Trade Commission on questions concerning the use of language in advertising, and trying to master Beethoven's *Waldstein* Sonata.

HENRY A. LESTER ("The Response to Acetylcholine") is associate professor of biology at the California Institute of Technology. He reports: "I grew up in Teaneck, N.J., and attended Harvard University, where I was interested in particle physics and in student theater. As a graduate student at Rockefeller University in New York I received a Ph.D. in biophysics, worked in the laboratory of H. K. Hartline, Floyd Ratliff and F. A. Dodge, and spent lots of time in New York's little theaters. I then worked for two years at the Pasteur Institute. Since 1973 I have been at Cal Tech, which is a wonderfully exciting place for neurobiologists. I now spend my free time backpacking, sailing and collecting Hogarth prints."

GM

MARK OF EXCELLENCE

How good can a car make you look?

Very, very good when that car is Chevrolet's world class luxury compact, Concours.

There's an international flavor to Concours. It's luxurious, of course, in the manner of fine touring cars. Its size allows it to feel at home on autobahns or freeways.

The Concours interior is finely detailed and handsomely finished as you would expect in a world class car. Outside, Concours reflects a restraint that is characteristic of international good taste. That

Concours is also sensible in size and price only emphasizes the world's new attitude toward automotive value.

Finally, there is quality. Quality backed by engineering that's been refined and tested. Quality in keeping with your taste in clothes, in homes and in the company you choose. Concours quality.

When we build a luxury compact, we build one you'll want to tell the world about.

Chevrolet

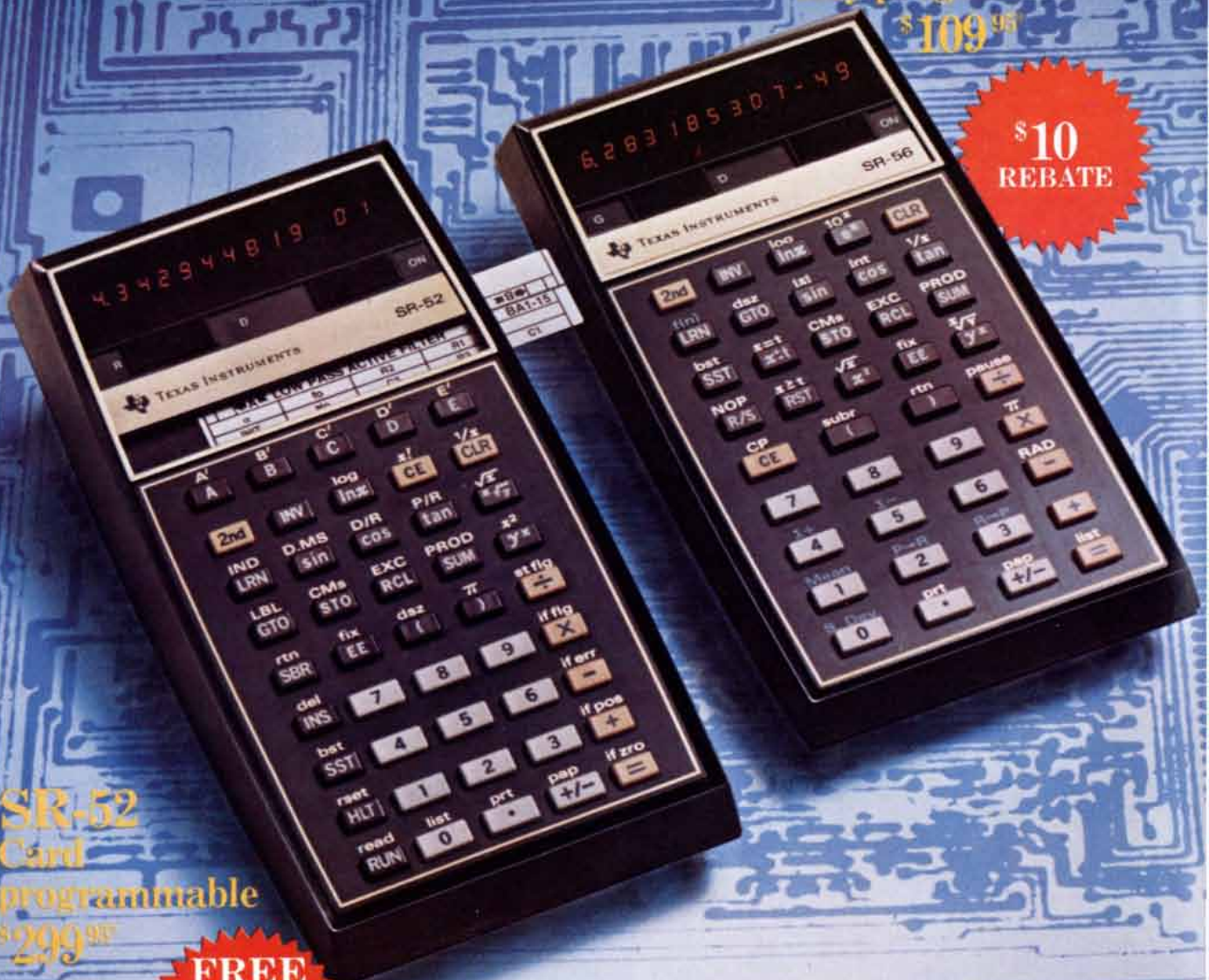
CONCOURS.

A world class luxury compact from Chevrolet.

Texas Instruments has just made buying a programmable calculator a better deal than ever.

SR-56
Super slide rule
Key programmable
$109.95

$10 REBATE



SR-52
Card programmable
~~$299.95~~

FREE
~~$59.90~~
WORTH OF SOFTWARE

FREE...$59.90 worth of software libraries when you buy an SR-52. $10 rebate when you buy an SR-56.

Thousands of professionals like you have discovered the decision enhancing power of personal programmable calculators. Perhaps you've considered it, too. Take advantage of these limited-time offers and buy one now.

SR-52

The card programmable calculator with computer-like power. 224 program steps and 22 data memories let you solve complex problems. Fast. With less chance of error. You can load complete programs from small magnetic cards in just two seconds. Process and record data or perform complicated calculations automatically. Select a program from the SR-52 Basic Library, which includes 22 prerecorded program cards. There's also a wide variety of optional prerecorded libraries – or you can record your own programs.

Programming is easy with TI's exclusive AOS (Algebraic Operating System). You enter expressions – both numbers and functions – from left-to-right, just as you would write them out on paper.

The SR-52 becomes a printing calculator when mounted on the Texas Instruments PC-100 printer. This quiet, high-speed printer provides hard copy printouts of your data. Anything from intermediate results to answers, to listing an entire program at the push of a key.

Membership in TI's Professional Program Exchange (PPX-52) is also available to you. As a member, hundreds of user-submitted programs will be available to immediately help you in your professional field.

Buy an SR-52 anytime between January 20, 1977 and March 31, 1977 and Texas Instruments will send you two software libraries – a $59.90 value – free.† Choose from Mathematics, Statistics, Finance, or Electrical Engineering. See details in coupon below.

SR-56

A powerful, super slide rule calculator that's key programmable, too. 74 preprogrammed functions and operations easily handle tough scientific problems. 100 programming steps plus 10 memories allow you to obtain results once requiring the assistance of a computer. Yet no programmable is easier to master. There's no special entry sequence to learn with TI's unique AOS (Algebraic Operating System). AOS allows easy left-to-right entry of expressions, both numbers and functions. Build your own programs and use them again and again. Or select one from the SR-56 Applications Library. 56 different programs in mathematics, statistics, finance, electrical engineering, and more are contained in the 192-page Library. Select a program, follow the listing, and you can begin immediately to solve your own problems.

TI's PC-100 printer will turn your SR-56 into a quiet, high-speed printing calculator. Hard copy printout provides intermediate results, answers, or will print an entire program listing at the push of a key. In addition, a single program allows you to print the calculator's entire data memory content.

And, if you buy an SR-56 anytime between January 1, 1977 and March 31, 1977, Texas Instruments will send you a $10 rebate.† See details in coupon below.

*U. S. suggested retail price, may vary elsewhere.

†Offers void where prohibited by law. Good in continental United States only.

TEXAS INSTRUMENTS
INCORPORATED

SR-52 FREE Software offer.

M

Indicate choice of 2 software libraries below and (1) return this completed coupon along with (2) your completed SR-52 serialized customer information card (packed in box) and (3) a dated copy of proof of your purchase, verifying purchase between Jan. 20 and March 31, 1977, to:

SR-52 Free Software Offer
Texas Instruments Incorporated
P. O. Box 1210
Richardson, Texas 75080

Name _____
Address _____
City _____ State _____ Zip _____
SR-52 Serial No. _____ (from back of calculator)
☐ Math ☐ Statistics ☐ Finance ☐ EE

Texas Instruments reserves the right to substitute software libraries of equal value, based upon availability. Please allow 30 days for delivery.

SA1A

SR-56 $10 Rebate.

M

Texas Instruments will rebate $10.00 of your original SR-56 purchase price when you (1) return this completed coupon, (2) along with your completed SR-56 customer information card (packed in box), and (3) a dated copy of proof of your purchase, verifying purchase between Jan. 1 and March 31, 1977, to:

SR-56 $10 Rebate
Texas Instruments Incorporated
P. O. Box 1210
Richardson, Texas 75080

Name _____
Address _____
City _____ State _____ Zip _____
SR-56 Serial No. _____ (from back of calculator)
Please allow 30 days for rebate.

SA1A

65573

Established 1845 SCIENTIFIC AMERICAN February 1977 Volume 236 Number 2

Cruise Missiles

This new category of inexpensive, highly accurate weapons presents a difficult but not insuperable problem to arms-control negotiators: how to distinguish reliably between strategic and tactical versions

by Kosta Tsipis

The partial success achieved by negotiators for the U.S. and the U.S.S.R. in the ongoing effort to limit the deployment of strategic nuclear weapons rests on the mutual recognition that each side has at its disposal the "national technical means" (primarily reconnaissance satellites) to distinguish reliably between strategic, or intercontinental-range, weapons and all the other weapons in the other side's arsenal. The long-range cruise missile, a new type of weapon currently under development in the U.S., may prove to be an exception to that rule. The problem is that there appears to be no observable distinction between long-range cruise missiles (that is, those capable of strategic missions) and short-range cruise missiles (those suitable only for tactical missions). In other words, there is no obvious, unambiguous correlation between the physical appearance of a given cruise missile and its intended target.

According to reports in the daily press, the heralded advent of the long-range cruise missile has already created a major obstacle to the successful conclusion of the second round of strategic-arms-limitation talks (SALT II) between the U.S. and the U.S.S.R. The immediate issue is whether or not cruise missiles should be included in the total of 2,400 strategic delivery vehicles that the 1974 Vladivostok understanding between President Ford and Secretary Brezhnev had set as an upper limit for both parties. The basic properties of cruise missiles that have led to the present disagreement threaten to similarly impede future strategic-arms-limitation negotiations.

The arms-control dilemma presented by the cruise missile is compounded by the fact that although cruise missiles appear to be operationally inferior to existing strategic weapons in either a deterrent role or a counterforce role, they have the potential of becoming extremely cost-effective tactical weapons. For example, short-range cruise missiles could eventually replace the manned fighter-bomber in many of its missions, thereby substantially reducing the number of costly facilities such as aircraft carriers and foreign bases that such aircraft require.

Accordingly the U.S. has opposed the inclusion of cruise missiles in the numerical quota for strategic delivery vehicles, because—given the visual indistinguishability of the different types of cruise missile—such a provision would prevent the deployment of tactical cruise missiles as well as strategic ones. The U.S.S.R., on the other hand, insists on including all cruise missiles potentially capable of long-range missions in the quota for strategic weapons, precisely because there would be no way to determine whether a given cruise missile deployed by the U.S. is a tactical weapon or a strategic one. Thus the impasse at SALT II continues.

But what is a cruise missile? How does it work? What can it do, and why is it not possible to tell one that has a range of 5,000 kilometers from one that can fly only a tenth of that distance?

I shall attempt to answer those questions here by describing the various types of cruise missile now under development or planned, by examining the strategic and tactical capabilities of the different versions and by discussing their potential military usefulness and their implications for arms-control efforts. I shall also address the difficult problem of relating the intended mission of a cruise missile to its observable characteristics by offering a suggestion for a possible technical basis on which the problem might be solved.

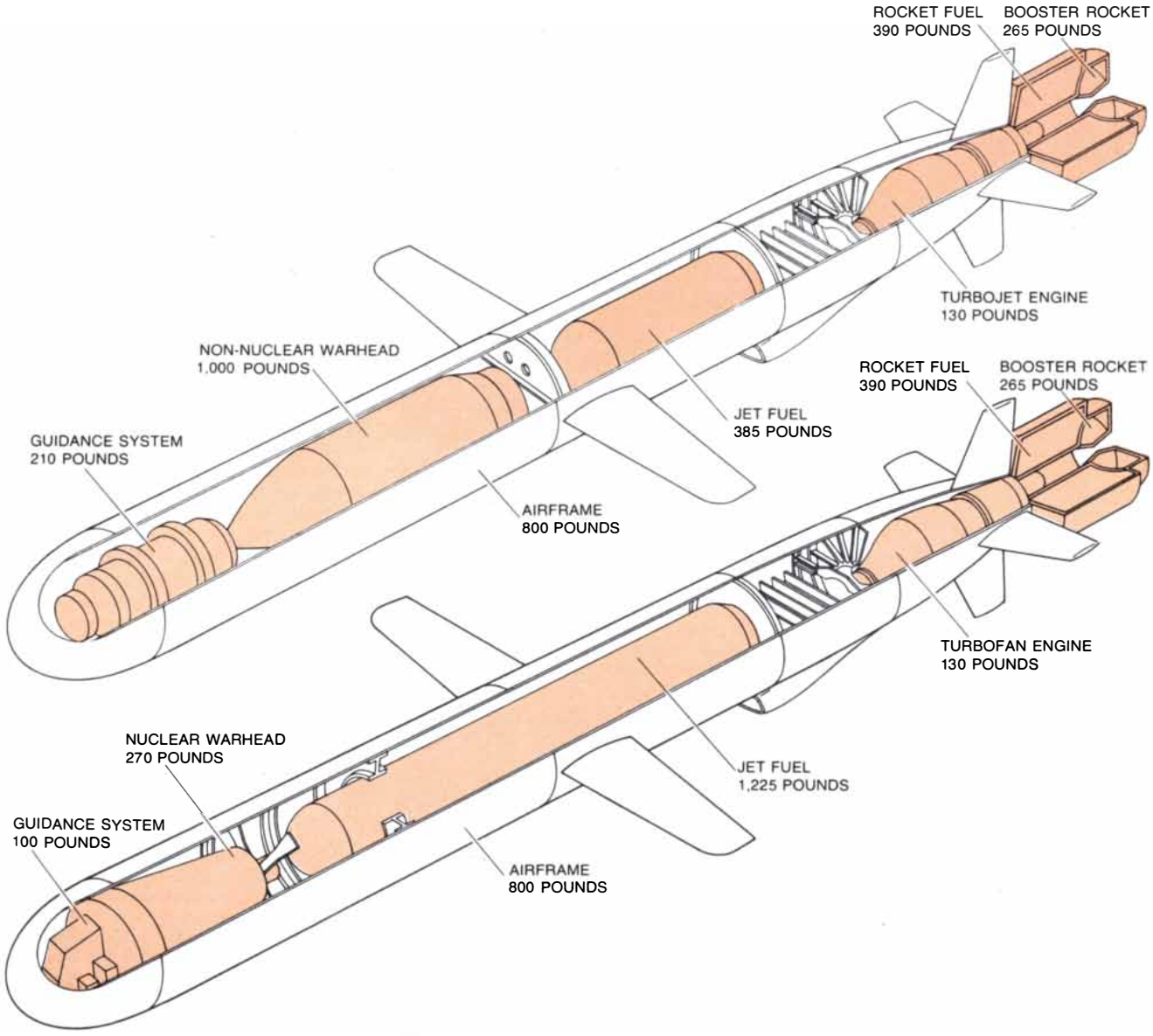
A cruise missile can be defined as a dispensable, pilotless, self-guided, continuously powered, air-breathing warhead-delivery vehicle that flies just like an airplane, supported by aerodynamic surfaces. Unlike a ballistic missile, which is powered and hence usually guided for only a brief initial part of its flight, after which it follows a free-fall trajectory governed only by the local gravitational field, a cruise missile requires continuous guidance, since both the velocity and the direction of its flight can be unpredictably altered by local weather conditions or changes in the performance of the propulsion system. A ballistic missile is guided for the first five of the 20 minutes or so it takes to travel 5,000 kilometers; a cruise missile, which usually flies at subsonic speed, would require close to six hours of continuously guided flight to cover the same distance. Hence guidance errors that accumulate with time would be almost 100 times larger for a cruise missile than for a ballistic missile with a comparable range. The cumulative deviation from a preassigned track over a trajectory of thousands of kilometers would be very large in the case of the cruise missile, and therefore its accurate arrival on target could be achieved only with continuous guidance that is corrected from time to time by fresh location information. To obtain the necessary location information accurately a long-range cruise missile employs a device that can correlate information obtained by an on-board sensor about the terrain it is flying over with some kind of map stored in the memory of an on-board computer.

Cruise missiles have served as warhead-delivery systems in the past, beginning with the German V-1 "buzz bomb" of World War II and continuing with such weapons as the U.S. Matador, Regulus and Snark missiles and the Russian

Shaddock missile, which is still deployed aboard some Russian submarines and surface warships. None of these earlier versions were capable of obtaining location information to correct their guidance system during flight, and as a result they were not very accurate. Furthermore, they were powered by inefficient jet engines that in general did not allow ranges in excess of a few hundred kilometers.

The main difference between the older versions of the cruise missile and those now under development in the U.S. is that recent advances in technology have made available two important new components: (1) microelectronic devices that can update the location information of a cruise missile while it is in flight and therefore improve its accuracy by three orders of magnitude and (2) small, efficient jet engines that for every hour of flight consume only about a pound of fuel for every pound of thrust they generate. Both of these technological advances affect primarily the performance of strategic cruise missiles, since at tactical ranges the flight time is measured in minutes and therefore even a moderately accurate guidance system needs no mid-flight correction. Moreover, a tactical missile can be fitted with a homing device, such as radar, that detects the target and guides the missile onto it.

A long-range cruise missile employs an inertial-guidance system, consisting essentially of three or more accelerometers mounted on gyroscope-stabilized platforms, to guide it along a preassigned course. A practical inertial-guidance system suitable for a cruise missile could allow the missile to drift about a kilometer or so off course for every hour of flight. The effects of weather and the imperfections of the jet engine that powers the missile increase the drift. After several hours of flight the missile could be 10 or more kilometers away from its intended impact point. If, however, the missile could from time to time "recognize" where it is and compare its actual position with where it should be according to its preassigned trajectory, then the on-board computer could instruct the automatic pilot to make the appropriate maneuvers to bring the missile back to the correct trajectory. Furthermore, the known difference between the actual position and the intended position is used by the computer to calibrate and reset the inertial-guidance system, a process that compensates for and reduces the



SEA-LAUNCHED CRUISE MISSILE (SLCM), currently under development for the U.S. Navy by the Convair Division of the General Dynamics Corporation, is shown in these cutaway diagrams in both its tactical, or short-range, version (*top*) and its strategic, or long-range, version (*bottom*). Without the booster rocket, needed to launch either weapon from a submarine or a surface vessel, both missiles are 53 centimeters in diameter and 6.24 meters long. Weights of various components are indicated. Externally two versions appear identical.

missile's drift by a factor of two or three.

There are several ways in which a cruise missile can determine its actual location while it is in flight. I shall briefly describe three such systems; they are called the terrain-contour-matching technique (Tercom in current military terminology), the area-correlation technique and the global-positioning-satellite technique.

The terrain-matching technique, first patented in 1958, relies for its operating principle on the simple fact that the altitude of the ground above sea level varies as a function of location. If one were to make a rectangular map of an area two kilometers wide and 10 kilometers long, divide the map into squares perhaps 100 meters on a side and record in each square the average elevation of the ground in it, one would obtain a digital map consisting of 2,000 numbers, each number corresponding to the elevation of a point of known coordinates on the ground. A set of such maps, which can be made much larger and can have squares with smaller sides if required, is stored in the memory of the computer aboard the missile.

The missile is also provided with a downlooking radar altimeter capable of resolving objects on the ground smaller than the map squares from a height of several kilometers. As the missile approaches the region for which the computer memory has a map, the altimeter starts providing a stream of ground-elevation data. The computer, by comparing these data with the elevation data it has in its memory, can determine the actual location of the missile with an accuracy comparable to the size of the map cell. It then instructs the autopilot to take any corrective steps necessary to return the missile to its intended trajectory. As many as 20 such maps can be stored in the memory of the computer to enable the missile to update its location information and correct its trajectory frequently during its overland flight.

FIRST UNDERWATER LAUNCH of the Navy's new SLCM took place on February 13, 1976, at the Naval Undersea Center off San Clemente Island in California. The missile was ejected from a submerged torpedo tube and was propelled to the surface of the water by means of its booster rocket. Once out of the water it automatically jettisoned its protective covers and extended its tail fins as it climbed to an altitude of more than 300 meters, still under booster power; at that stage the wings and the jet-engine inlet scoop were deployed, the spent booster rocket was jettisoned, and the engineless test missile then glided over the range for two miles. (In the operational model the jet engine would take over for the aerodynamic portion of the flight.) The SLCM, which has been designated Tomahawk, is designed to be launched not only from torpedo tubes of a submarine but also from a surface ship, an airplane or the ground.

The area-correlation method, which is still in the research stage, is based on a similar mapping principle. Instead of ground altitude above sea level, however, it measures the microwave reflectivity of the ground as a function of location. Instead of a radar altimeter the missile has a detector that can sense the differences in the microwave reflectivity of the terrain it is flying over. Advanced area-correlation schemes envision missiles with on-board systems that incorporate terrain maps made at one part of the electromagnetic spectrum and detectors that operate at a different wavelength. For example, such a system might be able to match signals from a microwave radiometer or an infrared detector with data from a map made in the visible part of the spectrum. This approach is possible because features such as lakes, rivers, roads, railroads and other man-made structures offer sharp "contrast edges" over a large portion of the spectrum. The area-correlation technique can be applied to determine the location of the missile over all kinds of terrain, whereas the terrain-matching technique works well only over rough, hilly ground. Neither system works over water.

The third way to locate the position of a cruise missile is the global-positioning-satellite system, which is also under development in the U.S. The projected system will consist of 24 satellites in polar orbits positioned in such a manner that any place on the earth's surface will have at least four of the satellites in sight at all times. Every few thousandths of a second the satellites will broadcast exactly synchronous coded signals that can be received by passive equipment on the cruise missile. By determining the difference in the arrival times of four such signals the missile's computer can calculate the distance of the missile from each satellite. In addition the satellites will broadcast information describing their orbits around the earth. With this information and the four different arrival times of the signals the missile's computer can determine the true position of the missile to within 10 meters in three dimensions without any other external data. From that information it can in turn deduce its velocity at any instant.

Of the three techniques I have described only the satellite system promises to be inexpensive enough to be practical for short-range cruise missiles. Because of their brief flight time such missiles do not require position-updating information. Instead they need to recognize and home on their target. For mobile targets radar homing is preferred where it is possible, but for fixed targets beyond the line of sight the global-positioning-satellite system can be used to maneuver the missile onto the known location of the target.

Advances in the technology of small jet engines have been equally important in the development of both tactical and strategic cruise missiles. Small turbofan engines weighing less than 130 pounds and yet capable of generating as much as 600 pounds of thrust are now available. Engines of this type consume less fuel than turbojets of equivalent size; they are more complex systems, however, and hence they cost much more. Accordingly turbofan engines are considered suitable for cruise missiles with a range of more than 500 kilometers that carry expensive payloads such as nuclear warheads, whereas turbojets are cost-effective for cruise missiles with a range of less than 500 kilometers that carry conventional high-explosive warheads.

The difference in the efficiency of the two types of jet engine is related in part to the difference in the temperature of the exhaust gases produced by the engines. Although the turbine-inlet temperature for small engines of both types is limited to about 1,850 degrees Fahrenheit, a turbojet engine exhausts its gases at 1,450 degrees, whereas a turbofan engine, because of turbulent mixing at the outlet, exhausts them at 600 degrees. Obviously the latter engine makes more efficient use of the heat energy of its fuel. The difference between the exhaust temperatures of the two types of engine gives them different infrared "signatures." As a result it should in principle be possible to determine from a distance whether a given missile is powered by a turbofan engine or a turbojet engine.

The rate of progress in microelectronics has been spectacular, but the development of small jet engines is laborious. It takes many years to develop a new engine or to improve the efficiency of an existing one by a few percent. It is therefore reasonable to expect that the power plants for cruise missiles will not change substantially in the next decade or so. Small improvements in efficiency, and hence in range for a fixed volume of fuel, can be expected as new composite materials are adopted for turbine blades, but basically the fuel-consumption rate and the thrust of the small engines are not subject to a technological breakthrough. One can conclude that the aerodynamic performance of cruise missiles will not change greatly in the near future.

The technological advances I have described have been applied in the development of several types of U.S. cruise missile. Of these I shall discuss only two: the Harpoon antishipping missile, which is now entering production and is strictly a tactical cruise missile, and the sea-launched cruise missile (SLCM), which is still under development and which has both a strategic version and a tactical one. These two major types of missile have been chosen because in combination they illustrate the special advantages and disadvantages of cruise missiles.

The Harpoon missile is quite small, measuring 34 centimeters in diameter and 3.84 meters in length. Its total volume is only .3 cubic meter. Without its booster rocket it weighs 1,144 pounds. It can be launched against a ship from a submarine, a surface vessel or an airplane. A ground-based version is also possible. The Harpoon is powered by a turbojet engine that has a thrust of 660 pounds and a fuel-consumption rate of about 1.5 pounds of fuel per pound of thrust per hour of flight. That gives the Harpoon a maximum range of about 100 kilometers at a speed of Mach .85 (85 percent of the speed of sound). Since the engine is expected to work only for a short time it has many cast parts instead of machined ones. Hence it can operate satisfactorily for only a short period but costs substantially less than a turbofan engine of the same size designed to operate for many hours.

The guidance system of the Harpoon missile consists of a radar altimeter that keeps it flying a few meters above the surface of the sea, a mid-course guidance unit that keeps it on a steady course and a sophisticated active radar scanner that can detect a target as small as a patrol boat in all weather conditions at about half its maximum range and a target as large as a destroyer at much greater distances. The missile can distinguish between two targets if they are well separated and will head for the larger one. It carries a 500-pound warhead that penetrates the deck of the target ship and explodes inside by means of a deceleration fuse. In 32 launches from a variety of sea and air platforms the Harpoon has found its target 29 times at operational ranges.

Both the tactical and the strategic versions of the sea-launched cruise missile are 53 centimeters in diameter and 6.24 meters long and have a volume of 1.37 cubic meters without their booster rocket. Without the protective capsule in which they are carried and launched they both weigh about 3,200 pounds. Both versions can be launched from the torpedo tubes of a submarine or from a surface ship, an airplane or a ground platform. The exact ranges of the two versions are classified, but the aerodynamic properties of the missile indicate that the strategic version is capable of a range of 2,000 kilometers at low altitude and perhaps 50 percent more if the first 1,500 kilometers are flown at higher altitude and the rest at treetop level. The strategic version is powered by a turbofan engine with a thrust of 600 pounds and an average fuel-consumption rate at sea level of about a pound of fuel per pound of thrust per hour of flight. At sea level the missile has a cruising speed of Mach .7 and a maximum speed of Mach .85. A much lower fuel-consumption rate is possible at higher altitudes with a

lower net thrust. Since the missile cannot fly at speeds lower than Mach .44, a booster rocket is used that ignites on launching and propels the missile for 12 seconds. At a height of 400 meters (assuming an ascent angle of 55 degrees) and a speed of Mach .55 the turbofan engine takes over. The booster is not necessary for missiles launched from aircraft.

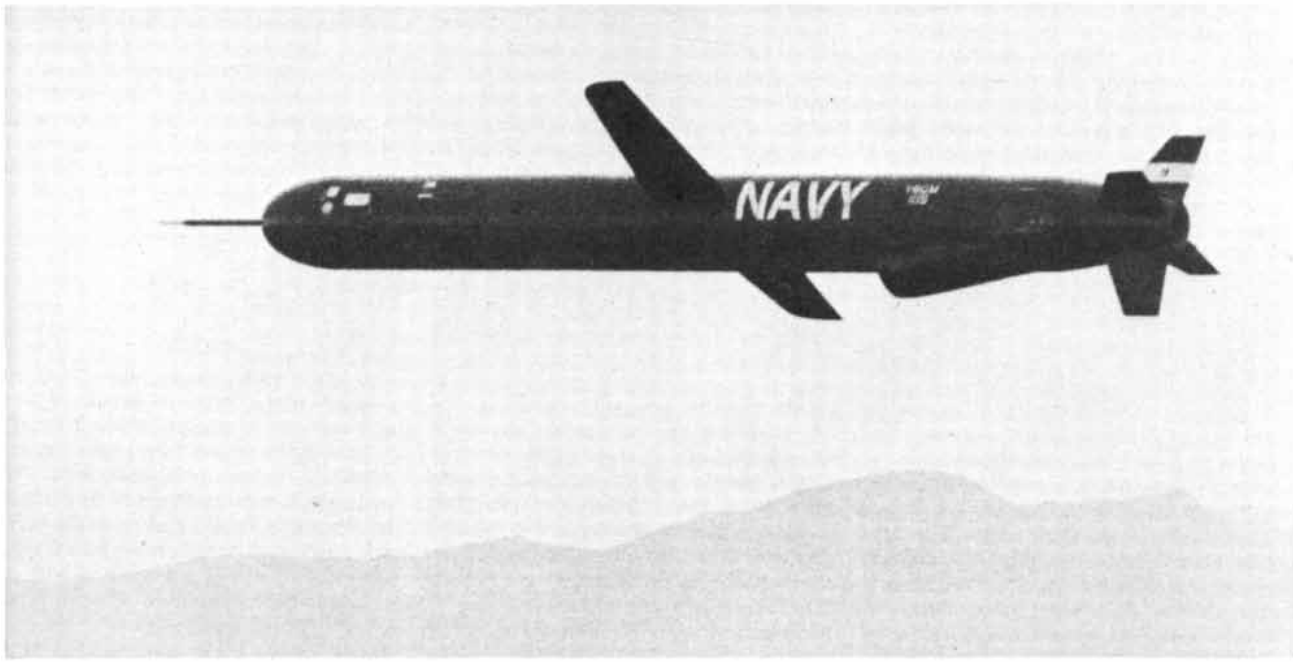
The guidance package of the strategic sea-launched cruise missile consists of an inertial-guidance system with an intrinsic drift of about 900 meters per hour of flight, augmented by a terrain-matching system. The radar altimeter of the terrain-matching system enables the missile to fly as low as 20 meters over water, 50 meters over moderately hilly terrain and 100 meters over mountains. This capability makes the missile difficult to detect with ground-based radar. The gyroscopes of the inertial-guidance platform require 25 minutes to align after the missile has been loaded into the torpedo tube of a submarine, a task that in turn requires five minutes. Therefore the strategic SLCM can be launched from a submarine in salvos of two or four (depending on the number of torpedo tubes) at best only once every 30 minutes. The ignition of the booster rocket under water generates a large amount of acoustical energy that can be detected at great distances. In addition the booster creates copious bubbles that are visible on the surface of the water for more than five minutes after the launch, and the exhaust plume of the booster is visible over an area 80 kilometers in radius as the missile climbs to 400 meters. Accordingly the position of the submarine can be determined by a variety of means after it has launched one or more of its missiles under water.

The terrain-matching system of the strategic sea-launched cruise missile is provided with a dozen or more maps, on which the terrain is digitized at intervals of less than 100 meters and the elevations are recorded with an accuracy of better than three meters. Since the missile is expected to fly initially over water, where the updating of location information is impossible, the first land map is made wide enough (perhaps as wide as 10 kilometers) for the missile not to miss the intended landfall. The radar altimeter starts taking readings before the missile is expected to fly over a given map area and stops taking them at an equal distance after it has left that area. The computer uses a simple minimum-absolute-deviance algorithm to match the readings of the altimeter with the points on the map. There is such large redundancy in the altimeter data that synchronization errors or even attempts to jam the altimeter from the ground will not degrade the performance of the system.

The accuracy with which this missile can be guided to its target is at best equal to the size of a map square; in practice it is probably about half that good. Since map squares can be made quite small, say 10 meters on a side, it is possible in principle to have comparable missile accuracy. A number of factors contribute to the degradation of this level of accuracy, however, and so it is expected that the strategic sea-launched cruise missile will have an accuracy of some 100 meters. The biggest errors are expected to come from human errors in mapping, from the injudicious choice of terrain to map and from the absence of suitable terrain for terrain-matching guidance near some targets.

The tactical version of the sea-launched cruise missile is powered by a turbojet engine that gives it a range of about 500 kilometers. It is guided by a system very similar to the one in the Harpoon missile, consisting of a mid-course guidance unit that keeps the missile flying in a straight line but does not adjust for its being blown off course by the wind. In addition the missile has a radar scanner with a comparatively short range, probably no more than 50 kilometers, which is designed to guide it onto the target. The mid-course guidance unit has a drift of about .2 radian per hour of flight. Hence errors as large as 40 kilometers will result at the end of a 500-kilometer flight. Therefore once the missile is in flight it needs some external source of information on the exact position of its intended target.

The line of sight over water does not extend beyond 50 kilometers, so that the necessary information cannot be provided by the launching platform; it has to be obtained by another vehicle, a spotter aircraft or a helicopter, which must be suitably equipped to identify the target and communicate the information to the launching platform or to the cruise missile itself. If the launching platform is a submarine, the tactical version of the sea-launched cruise missile becomes even more troublesome: not only will its launch reveal the position of the submarine but also problems of target acquisition and "friend/foe" identification become extremely complex. The range of the submarine's sonar



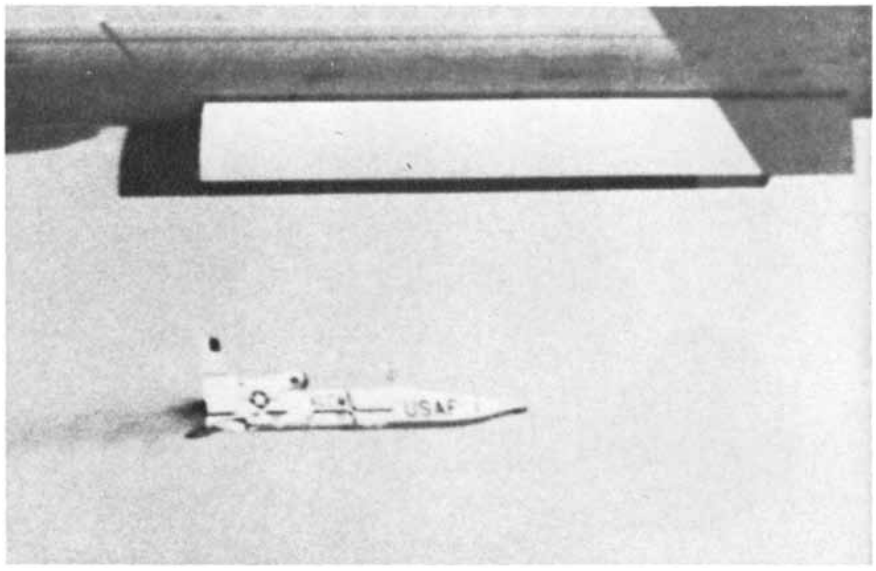
OVERLAND FLIGHT of a Tomahawk SLCM was photographed in the course of a recent test of its maneuverability at the White Sands Missile Range in New Mexico. This model is equipped with a turbofan engine and a terrain-contour-matching guidance system.

is considerably shorter than 500 kilometers, and while the vessel is submerged it cannot communicate either with the cruise missile or with an observation platform such as an aircraft. The mismatch of the cruise missile's range to the submarine's target-acquisition range makes the tactical version of the sea-launched cruise missile a weapon of dubious value.

Cruise-missile technology offers such flexibility in range, basing and types of warhead that an almost unlimited variety of alternative designs is possible. Here I have chosen to speculate on the military characteristics and arms-control implications of three possible types of missile because of the particularly challenging policy questions they raise. The first type is a very accurate long-range strategic cruise missile with a conventional high-explosive warhead; the second, which is already under development, is an airborne strategic cruise missile with a nuclear warhead; the third is a short-range land-based or ship-based tactical missile with a conventional warhead.

There is little doubt that guidance techniques either in existence or under development can endow a strategic cruise missile with pinpoint accuracy at the end of a 5,000-kilometer flight. This high degree of accuracy makes it feasible to use conventional warheads instead of nuclear ones against certain strategic targets such as large radar installations, industrial plants, petroleum refineries and so forth. It has been proposed that the U.S. develop a cruise missile that could carry a large conventional high-explosive warhead over intercontinental distances with an accuracy of better than 10 meters. This weapon would have to be about two cubic meters in volume (somewhat larger than the current sea-launched cruise missile), and it would have to be carried by either a surface ship or an aircraft of the cargo type; alternatively it could be land-based. If it were built in sufficiently large numbers, its proponents argue, it could provide the option of a non-nuclear response to some hypothetical coercive actions of an opponent such as the U.S.S.R. Thus it could raise the threshold of nuclear retaliation by enabling the U.S. to destroy specific targets with minimal collateral damage and without the onerous political burdens of a nuclear attack.

The second type of cruise missile that is under serious consideration in the U.S. is the air-launched cruise missile (ALCM). The current version of the air-launched missile is expected to have about half the range of the strategic sea-launched one. It is designed to be carried by either the B-52 intercontinental bomber or the new supersonic B-1 bomber. Armed with such missiles, the bombers would not have to penetrate the terminal air defenses of an opponent; they could merely penetrate to a given point and launch the long-range missiles toward their targets. Proponents of the air-launched cruise missile point out that since such a "standoff" carrier plane would not have to penetrate the air defenses of an opponent, the plane would not have to have supersonic speed, an elaborate system of electronic countermeasures or the capability of flying very low and very fast in order to avoid detection and evade attack; in other words, it would not have to be a combat aircraft at all. As a matter of fact, it is argued, a commercial wide-bodied jet transport such as the Boeing 747 or the McDonnell Douglas DC-10 could serve to carry as many as 100 cruise missiles. Commercial planes of this type have a longer range without refueling than either the B-52 or the B-1 does. If they were armed with air-launched cruise missiles, they would be able to replace the B-52 bomber in the U.S. arsenal at considerably less cost than the proposed B-1 could.

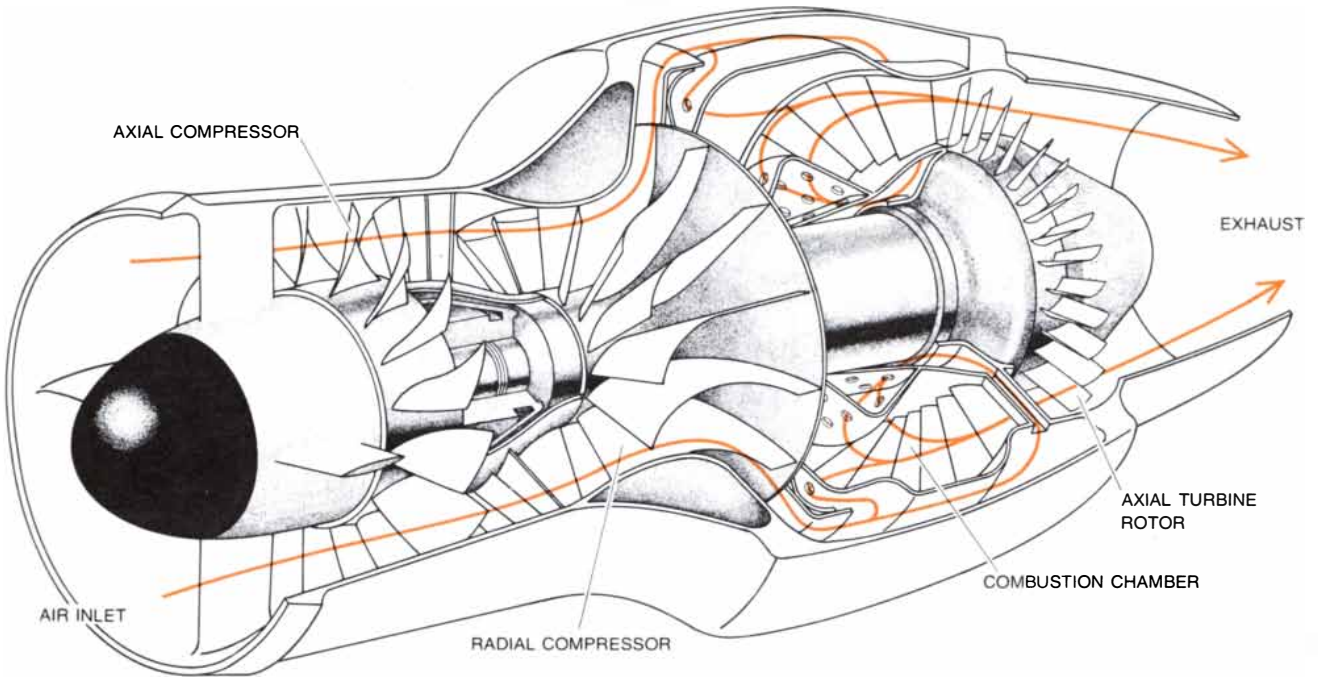


FIRST POWERED FLIGHT of the Air Force's new air-launched cruise missile (ALCM) took place on March 5, 1976, at the White Sands Missile Range. The missile, which is being developed by the Boeing Aerospace Company, was launched from the weapons bay of a B-52 bomber at an altitude of 10,000 feet. The powered portion of the flight lasted approximately 11 minutes. In this photograph the air scoop for the turbofan engine has popped up, the engine has started, the elevons (back wings) are fully extended and the vertical tail fin is unfolding; in a moment the larger forward wings will open. The ALCM can be launched either from the internal rotary weapons rack of the B-52 or from external pylons mounted under the wings.

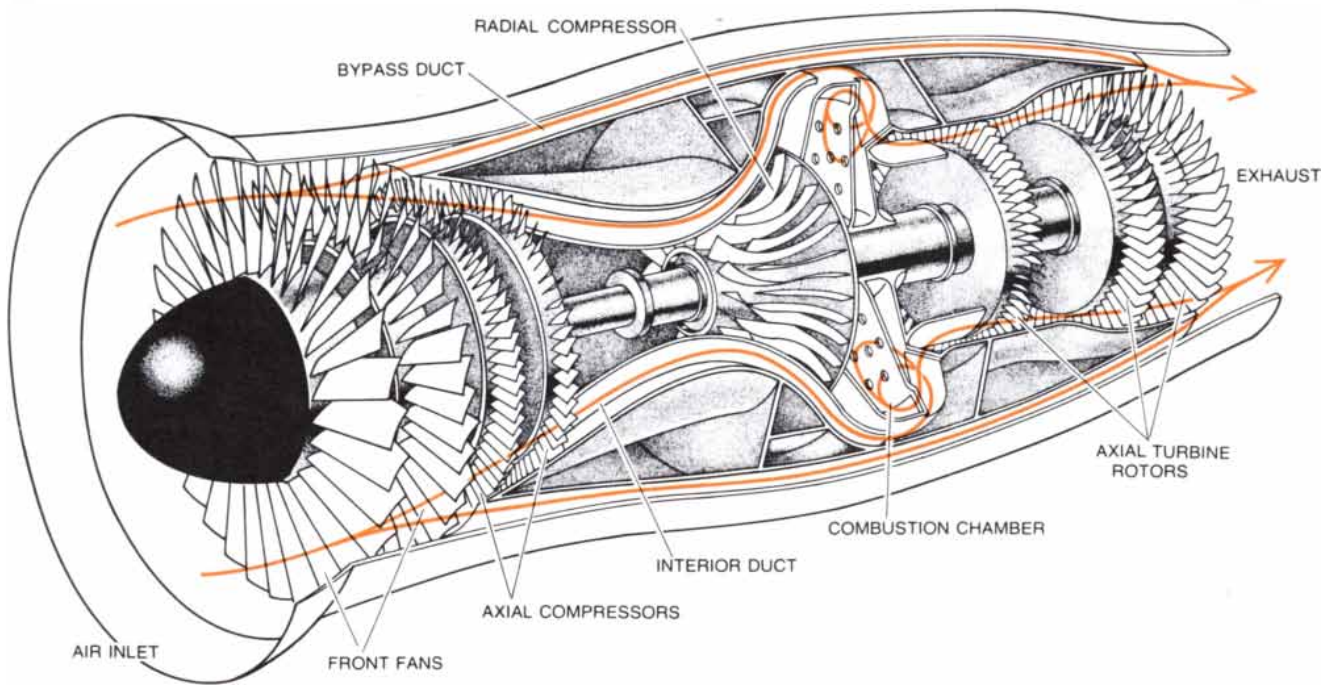
The third possible incarnation of the cruise-missile concept would be a tactical missile with a maximum range of 500 kilometers and a high-explosive warhead of between 400 and 500 pounds. This missile, its advocates say, could be guided exactly to its target either with the aid of the global-positioning-satellite system or by one of the pattern-recognition techniques; it could even be provided with the means to send back by way of a relaying aircraft or satellite a television outline of the terrain it flies over as it approaches its target so that it could be guided remotely by a human operator.

Such a small missile (less than half a cubic meter in volume) could be equipped with an inexpensive turbojet engine and could be programmed to avoid air defenses, fly at a constant altitude and operate in all weather conditions. It could, its proponents maintain, replace the manned fighter-bomber in many of its missions. If it were built in large quantities, it could cost as little as $50,000 per missile. Manned tactical aircraft, in contrast, currently cost more than $10 million and require a large aircraft-carrier task force to be carried within range of their targets. A typical task force can deploy only 36 attack aircraft, each capable of delivering about a ton of bombs per sortie to the target with less accuracy than that possible with cruise missiles. The entire multibillion-dollar task force could be replaced by a naval force capable of launching 180 tactical cruise missiles per day and consisting of a variety of ships less vulnerable and much less expensive than aircraft carriers. Ultimately, the advocates of this version of the cruise missile point out, such a missile could replace all the tactical nuclear weapons stationed by the U.S. in Europe.

In combination with short-range precision-guided missiles on the ground and remotely piloted vehicles carrying out the observation mission of manned aircraft, the tactical cruise missile armed with a chemical-explosive warhead may completely displace manned fighter-bombers and their long and costly logistical "tail" from the U.S. arsenal.



SMALL TURBOJET ENGINE was developed by Teledyne, Inc., for use in the Navy's Harpoon tactical antishipping cruise missile. The expendable engine, which is designed to operate for less than 15 minutes, incorporates mostly inexpensive cast parts and is said to cost about $15,000. Air enters the inlet and passes through an axial compressor and a radial compressor before entering the annular combustion chamber, where it is mixed with fuel and the mixture is ignited. The hot gases then pass through a turbine rotor before being exhausted. The turbine rotor drives the compressors by means of a shaft running down the axis of the engine. Thrust is produced only by the exiting stream of hot combustion products. Engine weighs less than 100 pounds, and yet it is capable of generating a thrust of 660 pounds.



SMALL TURBOFAN ENGINE developed by the Williams Research Corporation for the Air Force's ALCM has also been selected for installation in the strategic version of the Navy's SLCM. A turbofan engine is inherently more efficient than a turbojet engine of comparable size; it is also more complex and contains mostly machined parts and hence costs considerably more. In the turbofan engine the turbines drive not only the compressors for the gas-generator flow path but also a fan system that forces compressed air to flow through an annular bypass duct. As a result the turbofan generates thrust through two separate streams: the fan flow and the gas-generator flow. The ratio of the two flows is termed the engine's bypass ratio. The particular design shown in this diagram is described as a twin-spool turbofan with a low bypass ratio and a mixed exhaust. The low-pressure spool consists of a two-stage axial fan system followed by two axial compressor rotors in the gas-generator flow path, all driven by two axial turbines. The high-pressure spool consists of a single centrifugal compressor driven by an axial turbine. The engine weighs less than 130 pounds and generates more than 600 pounds of thrust.

Such a development would constitute a profound change in the entire military posture of the U.S., since it implies the abandonment of high-cost, low-attrition manned aircraft and their replacement with low-cost, dispensable cruise missiles. This prospect raises a host of technical, military and arms-control questions that have so far remained largely unexamined.

Because of the small size, great accuracy and low cost of cruise missiles, it would seem that they would be inherently superior to ballistic missiles as delivery vehicles for ranges greater than 10 kilometers and less than 5,000 kilometers. The long flight times of strategic cruise missiles and the subsonic speed with which they approach their target, however, make them quite vulnerable to hostile countermeasures. A ballistic missile, in the absence of an anti-ballistic-missile system, cannot be prevented from reaching its target once it is launched. Whereas the outcome of a strategic attack with ballistic missiles is comparatively certain and controlled, the outcome of a cruise-missile attack is uncertain, since it depends largely on the air-defense capabilities of the attacked country. As a result, although the accuracy and range of cruise missiles would suggest that they could serve successfully in a deterrent role, their relatively low speed makes them less suitable than ballistic missiles for that particular strategic mission. In order to be sure that cruise missiles would penetrate to their targets one would have to launch many of them against each target to saturate the air defenses. That would require the deployment of many thousands of cruise missiles, in clear violation of the numerical quota for strategic delivery vehicles established by the Vladivostok agreement.

No matter how many cruise missiles are deployed in a country, however, it would be impossible to verify their number by nonintrusive inspection, since they do not require identifiable launch facilities, such as silos, submarine launch tubes or airfields. Thus it is technically impossible to subject cruise missiles to the kind of numerical limits achieved in SALT II for ballistic missiles. The entire problem of limiting cruise missiles is further complicated by the fact that even during the testing of the weapon it would be possible to deduce from satellite data only the maximum range compatible with the visible characteristics of the missile, not its actual range. Therefore it is not possible at present to tell whether a given sea-launched cruise missile, say, is intended for a strategic mission or a tactical one.

All these considerations may lead one to conclude that the U.S. would have no choice but either to abandon any further efforts at controlling the proliferation of nuclear arms and go ahead with the deployment of cruise missiles or, in order to safeguard the achievements of SALT and the opportunity for further strategic-arms limitation, to forgo the deployment of cruise missiles altogether. Such a conclusion, however, seems unwarranted. A careful examination of the tactical and strategic missions that current and future cruise missiles could perform, and of the required launching platforms in each case, reveals that those applications of this delivery vehicle that make military sense are not incompatible with arms-limitation goals in general and the numerical reduction of strategic delivery vehicles in particular. Furthermore, it appears that the specific cruise missiles that threaten the SALT negotiations are either unnecessary for the security of the U.S. or are hasty and unexamined applications of the new technologies that do not make military sense.

Consider the strategic sea-launched cruise missile now in the advanced-development stage. This system cannot perform any new missions or outperform in any of the existing strategic missions the U.S. "triad" of land-based intercontinental ballistic missiles (ICBM's), submarine-launched ballistic missiles (SLBM's) and intercontinental bombers. Furthermore, launching a cruise missile of this type from ballistic-missile submarines would increase the submarines' vulnerability, first because they would have to abandon their present secure stations and approach the territorial waters of the U.S.S.R. and second because launching a cruise missile would reveal the position of the submarine for hundreds of kilometers. It would be foolhardy to lessen the invulnerability of our securest deterrent weapons system so that it could launch at most four cruise missiles of uncertain fate every 30 minutes, since the same submarine can stay in safe waters and launch 16 Poseidon or Trident I missiles with 10 warheads each in less than five minutes, making much less underwater noise.

The deployment of a limited number of long-range cruise missiles on "hunter-killer" submarines may appear militarily cost-effective, since it would force an opponent to treat every U.S. nuclear submarine as a strategic nuclear delivery system, thereby increasing the opponent's antisubmarine-warfare requirements. Such a policy is not, however, without serious drawbacks. First, to impose a strategic role on hunter-killer submarines would seriously complicate their command-and-control procedures and thereby impair their operational capabilities. Second, and perhaps more significant, the deployment of strategic nuclear missiles on tactical hunter-killer submarines could reduce the security of the U.S. deterrent fleet of Polaris/Poseidon submarines not only by forcing a rapid growth of Russian antisubmarine-warfare capabilities but also by eliminating the distinction between tactical and strategic submarines and thereby removing the current tacit inhibition against attacks on strategic submarines. In short, the deployment of the strategic sea-launched cruise missile seems on balance to be both unnecessary and unwise.

The hypothetical long-range strategic cruise missile with a chemical-explosive warhead suffers from a different set of fundamental disadvantages. This missile could in principle enlarge the spectrum of strategic options available to the U.S., since it would make possible the precise destruction of selected industrial or military targets without the use of nuclear explosives. Actually, however, such targets in the U.S.S.R. would probably be defended by active or passive air defenses a subsonic cruise missile could not penetrate easily; such terminal defenses would add to the vulnerability of these weapons and therefore make the outcome of an attack with them quite uncertain. Weapons with uncertain results cannot have a deterrent effect against even the mildest provocation, since they are not capable of the assured destruction of their intended targets. Just as the existence of an effective anti-ballistic-missile system could have denied the deterrent role of ballistic missiles, so could a future sophisticated air-defense system deny such a role to cruise missiles, particularly those with chemical-explosive warheads.

Finally, a long-range cruise missile with a chemical-explosive warhead would completely confuse the distinction between strategic weapons, which are now assumed to be nuclear, and tactical weapons, which are usually nonnuclear. Such a development would make strategic-arms-limitation negotiations particularly complex by coupling them to efforts to reduce tactical armaments and by blurring the distinction between nuclear and chemical explosives.

The long-range air-launched cruise missile could in principle have a practical military role. The version of this weapon now under development is burdened with artificial limitations on size and fuel that severely curtail its range to about half that of the sea-launched cruise missile, making it unsuitable as a standoff weapon. A future version capable of longer ranges and carried by large transport planes could, however, replace the B-52 bomber in the 1990's and obviate the deployment of the costly B-1 bomber. The deployment of such a cruise missile would create difficult arms-control problems, since again it would not be possible to ascertain the number of missiles deployed. A possible solution is to agree on the number of deployed carrier aircraft that could transport them and count each aircraft against an agreed number of existing

ballistic missiles outfitted with multiple independently targetable reentry vehicles (MIRV's). As a matter of fact, if all land-based MIRVed ballistic missiles were replaced by an equivalent number of transport planes carrying air-launched cruise missiles, the end result could be a more stable strategic balance between the U.S. and the U.S.S.R., for two reasons. First, the long flight time of cruise missiles and their vulnerability to point defenses preclude their use as first-strike weapons; second, their basing, if properly designed, could make them considerably less vulnerable to a surprise attack than land-based ballistic missiles are now.

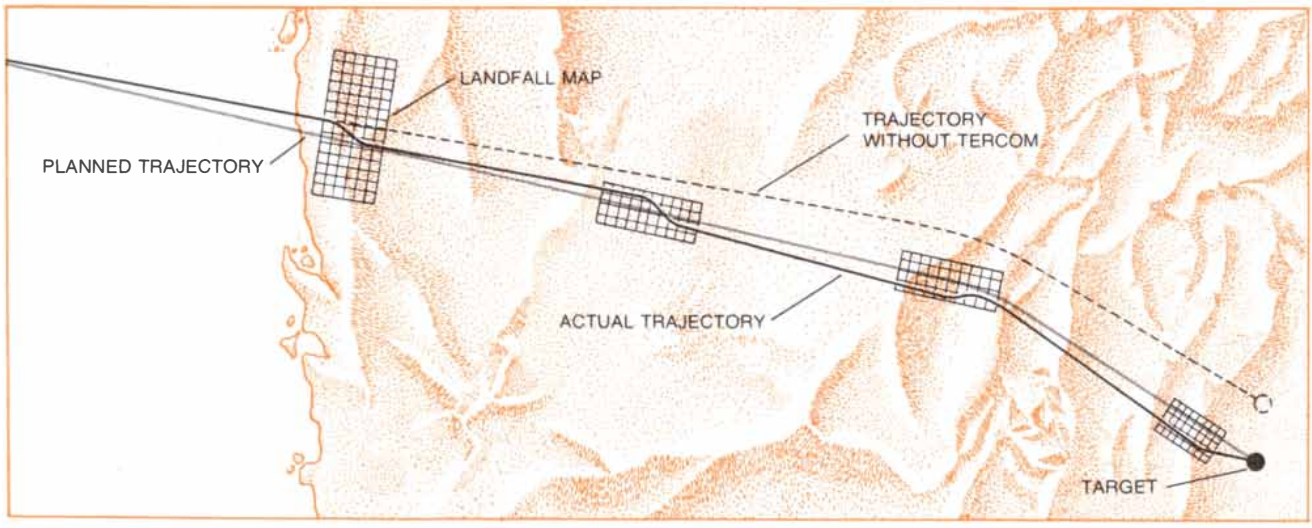
In spite of the stabilizing effect that such a proposal implies the deployment of the long-range air-launched cruise missile raises some serious verification questions. For example, if cruise missiles were deployed on jumbo jets such as the 747 or the DC-10, how could one determine without intrusive inspection which of these planes is a civilian transport and which carries strategic cruise missiles with nuclear warheads? Moreover, once the development and testing of such missiles is allowed how could another nation ascertain the number of missiles ultimately manufactured in the U.S. or their intended mode of deployment? The U.S.S.R., for example, could fear that in addition to whatever agreed number of air-launched cruise missiles was allowed, the U.S. could secretly deploy large numbers of booster-assisted cruise missiles based on ships or on land in allied countries within easy reach of the Russian interior. Thus it does not seem possible to deploy long-range cruise missiles without upsetting future strategic-arms-limitation efforts.

There are additional disadvantages to such a deployment, even if a formula for the verification of the number of platforms for air-launched cruise missiles and the basing of such missiles could be successfully negotiated. If past experience can be taken as a guide for future behavior, it is almost certain that a U.S. deployment of strategic cruise missiles would induce a Russian counterdeployment. Worse, U.S. development of such a weapons system would serve to validate the cruise-missile concept for other nations desiring a cheap, accurate delivery vehicle and might well convince them to develop a similar missile capable of reaching the U.S. Then it would be necessary for this country to erect a costly air-defense system not only against Russian cruise missiles but also against the cruise missiles of other countries. Such a system has been considered unnecessary until now because of the absence of a credible threat from the U.S.S.R. or any other country. It should not be forgotten that the deployment of an anti-ballistic-missile system in this country was justified on similar grounds: as a defense against Chinese ballistic missiles rather than Russian ones.

Tactical cruise missiles, unlike their strategic counterparts, offer considerable military advantages without creating such serious arms-control problems. As the Harpoon missile has demonstrated, it is possible to develop a small cruise missile powered by an inexpensive turbojet engine that has both the range and the accuracy needed for practical battlefield situations. On the other hand, the tactical sea-launched cruise missile is mismatched to the operational conditions of a naval encounter and appears to be grossly inaccurate; moreover, its conspicuous launching jeopardizes the safety of the launching submarine by revealing its position. The tactical SLCM is the perfect example of the misapplication of cruise-missile technology: it creates serious arms-control problems, since it is externally indistinguishable from the strategic SLCM, without incorporating any substantive military advantages.

The proposed tactical cruise missile with a chemical-explosive warhead is perhaps the most sensible current application of the new technological advances that have made cruise missiles feasible. With a volume of half a cubic meter and a turbojet engine, it can be identified by satellite as an unambiguously tactical missile. Although such identification may not be possible with current systems except over water, the technology exists to support the development of a reconnaissance satellite that could be programmed to detect, track and identify infrared signatures in the atmosphere and thereby distinguish a strategic cruise missile from a tactical one during testing.

The operation of such a monitoring system could be impeded by cloud cover, and therefore it could not verify with absolute certainty another country's faithful adherence to a treaty forbidding the development of long-range cruise missiles. Since no country would have any reason to take advantage of cloud cover to hide the development of a short-range cruise missile, however, it would be possible to develop and deploy those tactical weapons that seem capable of replacing the manned fighter-bomber, without fear of their being mistaken for long-range missiles by the



TERRAIN-CONTOUR MATCHING, abbreviated Tercom, is one of the terminal-guidance techniques currently being developed in conjunction with the U.S. cruise-missile program. The system relies on a set of digital maps stored in the memory of the missile's on-board computer; the maps consist of rectangular arrays of numbered squares representing the variation of ground elevation above sea level as a function of location. As the missile approaches an area for which the computer memory has a map, the on-board radar altimeter starts providing a stream of ground-elevation data. The computer, by comparing these data with the information it has in its memory, can accurately determine the actual trajectory of the missile and instruct the autopilot to return the missile to its planned trajectory. Four such

U.S.S.R. and therefore without threatening the efforts to limit strategic nuclear weapons.

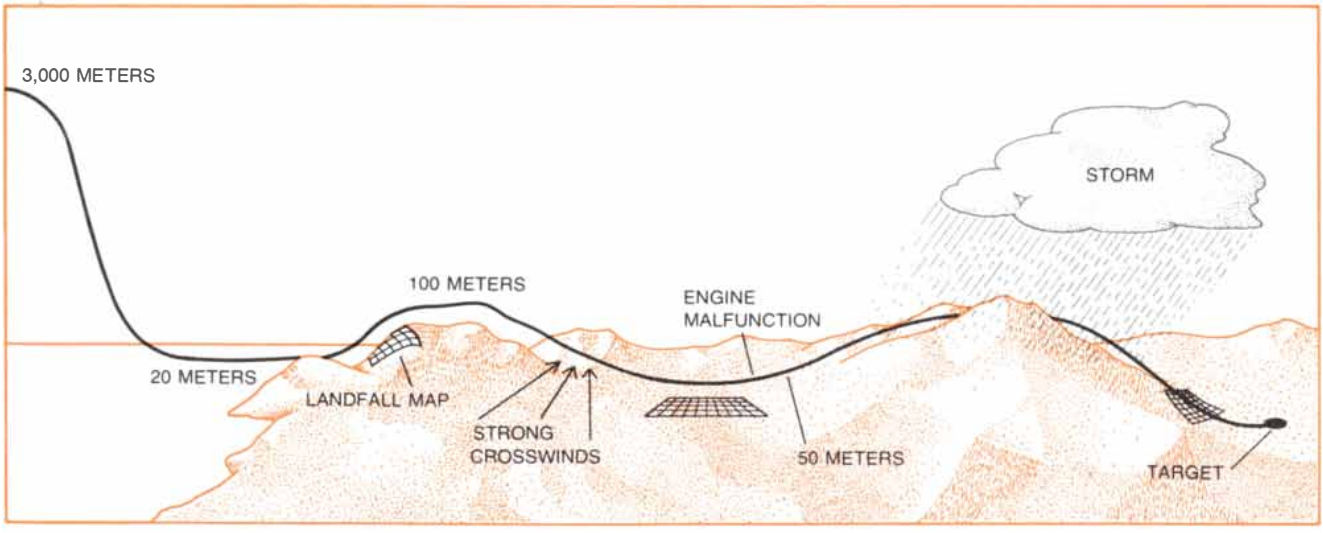
Two central conclusions can be drawn from the foregoing analysis of the technology and the performance characteristics of existing and contemplated cruise missiles. The first is that with one possible exception the development and deployment of strategic cruise missiles at this time is counterproductive for three reasons: they are unnecessary, their deployment would nullify the existing strategic-arms-limitation agreements and obstruct similar future efforts, and their deployment on nuclear submarines would increase the vulnerability and probably reduce the operational efficiency of that important deterrent force. The one possible exception is a future version of an air-launched cruise missile that could be deployed on transport planes in place of long-range bombers. The price of such a system, however, must be measured not only in dollars but also in terms of lost arms-control opportunities, the creation of new threats against this country and the abandonment of any numerical ceilings for strategic weapons.

The second conclusion is that negotiable criteria for differentiating between tactical and strategic versions of cruise missiles can and should be devised and incorporated into the design of future cruise missiles. The limiting criteria must be based on observable physical variables such as the volume of a cruise missile or the type of engine it is equipped with rather than on unverifiable variables such as the missile's range or the type of warhead it carries. For example, it is possible to differentiate between tactical and strategic cruise missiles by defining as tactical any missile that (1) has a volume of less than half a cubic meter, (2) is powered by a turbojet engine and (3) has a thrust of less than 600 pounds. A strategic missile, on the other hand, would be one that has a volume exceeding half a cubic meter and a turbofan engine.

The physical characteristics outlined above can be detected from orbiting reconnaissance satellites, and they do not impose (for the U.S. at least) any practical restrictions on the design of a cruise missile, since in each case the values of the relevant physical variables would be chosen within the proposed limiting criteria for economic and technical reasons. Reconnaissance satellites can provide the U.S. with information that something may be taking place in the U.S.S.R., but they cannot ensure that something is not taking place. Therefore although the U.S. can rely on such monitoring systems for early intelligence about cruise-missile developments in the U.S.S.R., the systems do not offer the unambiguous verification capability the U.S. Senate would need in order to ratify a treaty with the U.S.S.R. banning the development of strategic cruise missiles. What such monitoring systems do allow the U.S. to do is to exercise unilateral restraint in the development and deployment of long-range cruise missiles while inviting the U.S.S.R. to agree to a similar restraint. The U.S. can be certain that monitoring systems with the capabilities outlined here can detect the development of long-range cruise missiles at an early stage and so enable this country to abandon the unilateral restraint in plenty of time, if it chooses to do so.

The position of unilateral restraint is feasible for two reasons. First, no urgent response is necessary in case the U.S.S.R. is found to be developing long-range cruise missiles, because according to official accounts the U.S. is at least 10 years ahead in the technologies relevant to cruise-missile development. Second, the stability of the strategic balance between the two countries, in view of the many thousands of deliverable nuclear warheads available to both, cannot be upset unless one of the two deploys many thousands of long-range cruise missiles armed with nuclear warheads. Such a deployment, however, would take several years to complete and would be detected at a very early stage by the other side's monitoring satellites. A policy of unilateral restraint in the development and deployment of long-range cruise missiles by the U.S. not only is safe and desirable on economic grounds but also would allow for the orderly development of an effective tactical cruise missile.

Such a policy would of course impose stringent demands on the reconnaissance capabilities of both sides. It is essential for the success of present and future strategic-arms-limitation efforts to look ahead and define what reconnaissance capabilities will be necessary in order to bring these new weapons under control. The new technology that has made cruise missiles possible can also be applied to the development of monitoring systems with the resolution necessary to ensure compliance with the terms of agreements based on the criteria I have outlined. What has been lacking so far is political leadership with the will and the wisdom to exploit technology for the control of nuclear weapons rather than for their proliferation.



corrective maneuvers are shown in the vertical overhead view at the left. A perspective view of the missile's terminal flight path is depicted at the right. For the sake of fuel economy the early portion of the missile's flight would probably be at a high altitude. In the low-altitude penetration phase of the flight the missile would be able to fly as low as 20 meters over water, 50 meters over moderately hilly terrain and 100 meters over mountains, making the missile difficult to detect by ground-based radar. Unpredictable changes in local weather conditions and in the missile's airspeed due to a malfunction in the propulsion system are among the factors that can cause the missile to deviate from its planned trajectory. A terminal accuracy on the order of 100 meters is considered feasible for the Tercom system.

Phobos and Deimos

These tiny moons of the planet Mars have been viewed from close up by the Mariner and Viking spacecraft. They provide the first glimpse of the nature of the smaller bodies of the solar system

by Joseph Veverka

The pictures sent back from Mars by *Mariner 7* in 1969, by *Mariner 9* in 1971-1972 and by the two Viking spacecraft beginning last summer have revolutionized our knowledge of the planet and have enriched our understanding of the solar system in general. Among the most revealing of the pictures were those that showed not Mars itself but its two lumpy moons Phobos and Deimos. These tiny bodies have had a special charm ever since Johannes Kepler invented them, nearly three centuries before anyone knew they existed. Kepler firmly believed the universe was an intricate puzzle that included certain symmetries contrived by the Creator to compel man to exercise his ingenuity in order to understand them. Regarding the moons of Mars, Kepler reasoned as follows. The earth has one moon; Jupiter has four. (The other nine Jovian satellites were of course still unknown.) How many moons should the planet between the earth and Jupiter have? The doubling series 1, 2, 4... evidently appealed to Kepler's keen sense of mathematical regularity, and so he assigned Mars two moons. It is doubtful that in the absence of any observational evidence anyone really believed him, but the notion became well enough known to be echoed by both Swift and Voltaire in the century that followed.

Late in the 18th century Sir William Herschel found two new moons of Saturn with his 48-inch reflecting telescope, but he could not detect any satellites around Mars. Heinrich Ludwig d'Arrest, who helped to discover Neptune in 1846, also failed in the search for Martian moons. Not until 1877 did Asaph Hall, working at the U.S. Naval Observatory in Washington, succeed in observing two faint moving specks of light in the vicinity of the red planet. He named them Phobos (fear) and Deimos (terror), after the two sons of Ares (Mars in the Roman pantheon) who according to Greek myth drive the war god's chariot.

Why did Hall succeed where others had failed? In part it was because he was observing during a very favorable opposition, when the distance between the earth and Mars is at a minimum. In part it was because the Naval Observatory's 26-inch refractor was one of the best telescopes in the world at the time. Most of the credit must nonetheless go to Hall's skill and perseverance as an observer. Phobos and Deimos are notoriously difficult objects to detect from the earth. They are not only faint but also never very far away from Mars; it takes great skill to pick them out of the flood of scattered light that surrounds any telescopic image of the planet.

It was soon established that Phobos and Deimos move in almost perfectly circular orbits in a plane that virtually coincides with that of Mars's equator. The motion of both satellites is direct, that is, they revolve around Mars in the direction of its rotation, which would be counterclockwise in the view of an imaginary observer stationed above the planet's north pole.

The orbit of Phobos, the innermost moon, lies just outside the Roche limit of Mars: the critical distance inside which tidal disruption would keep any swarm of interplanetary debris from accreting into a single body. The orbit of Deimos lies just outside what is known as the stationary orbit position: the point where a satellite's period of revolution exactly equals the planet's period of rotation, so that from the surface of the planet the satellite appears to hang motionless in the sky.

The orbital period of Phobos, 7.7 hours, is much shorter than the rotation period of Mars, which is an earth-like 24.6 hours. Thus Phobos, unlike the earth's moon, would be seen by an observer on the surface of the planet to rise in the west, move quickly across the sky and set in the east. The same observer would see Deimos creep across the sky from east to west, taking some 60 hours to move from one horizon to the other. Neither passage would be particularly dramatic. Deimos would be about as bright as Venus is in the earth's sky. Phobos, being the nearer and larger satellite, would be several magnitudes brighter but would still be much less of a spectacle than the thinnest crescent of the earth's moon. Moreover, since the orbits of Phobos and Deimos are in the plane of the Martian equator and are so close to the surface of the planet, neither satellite could be seen from the poles. The observer would have to be closer to the equator than a latitude of 82 degrees to see Deimos and closer than 69 degrees to see Phobos.

Observations over the past few decades indicate that the orbital velocity of Phobos is slowly increasing. The phenomenon, termed secular acceleration, was first noted in 1945 by A. B. Sharpless of the Naval Observatory. Until recently the reality of the acceleration was a subject of controversy. Now, however, Phobos observations made during the *Mariner 9* mission of 1971–1972 have been thoroughly analyzed by Thomas C. Duxbury and G. H. Born of the Jet Propulsion Laboratory of the California Institute of Technology. They indicate that Phobos is indeed accelerating at a rate of about .001 degree per year per year. V. A. Shor of the Institute for Theoretical Astronomy in Leningrad, reexamining a series of telescopic observations, has independently arrived at a similar figure. The acceleration appears to be attributable to tidal drag. This may seem paradoxical, since drag would be expected to slow something down rather than speed it up. The drag would indeed cause Phobos to lose energy, but that would bring the satellite closer to Mars. Then the satellite would move faster on its smaller orbit. Assuming that the secular acceleration continues at its present rate, Phobos should crash onto the Martian surface in about 100 million years.

Phobos and Deimos are so small that it has not been possible to directly measure their size with telescopes on the earth. Early estimates of their diameter were informed guesses based on their observed brightness. The first photometric observations of the two moons were made by Oliver C. Wendell and Edward C. Pickering at the Harvard College Observatory between 1877 and 1882. The observations were crude, but they did show that Phobos was brighter

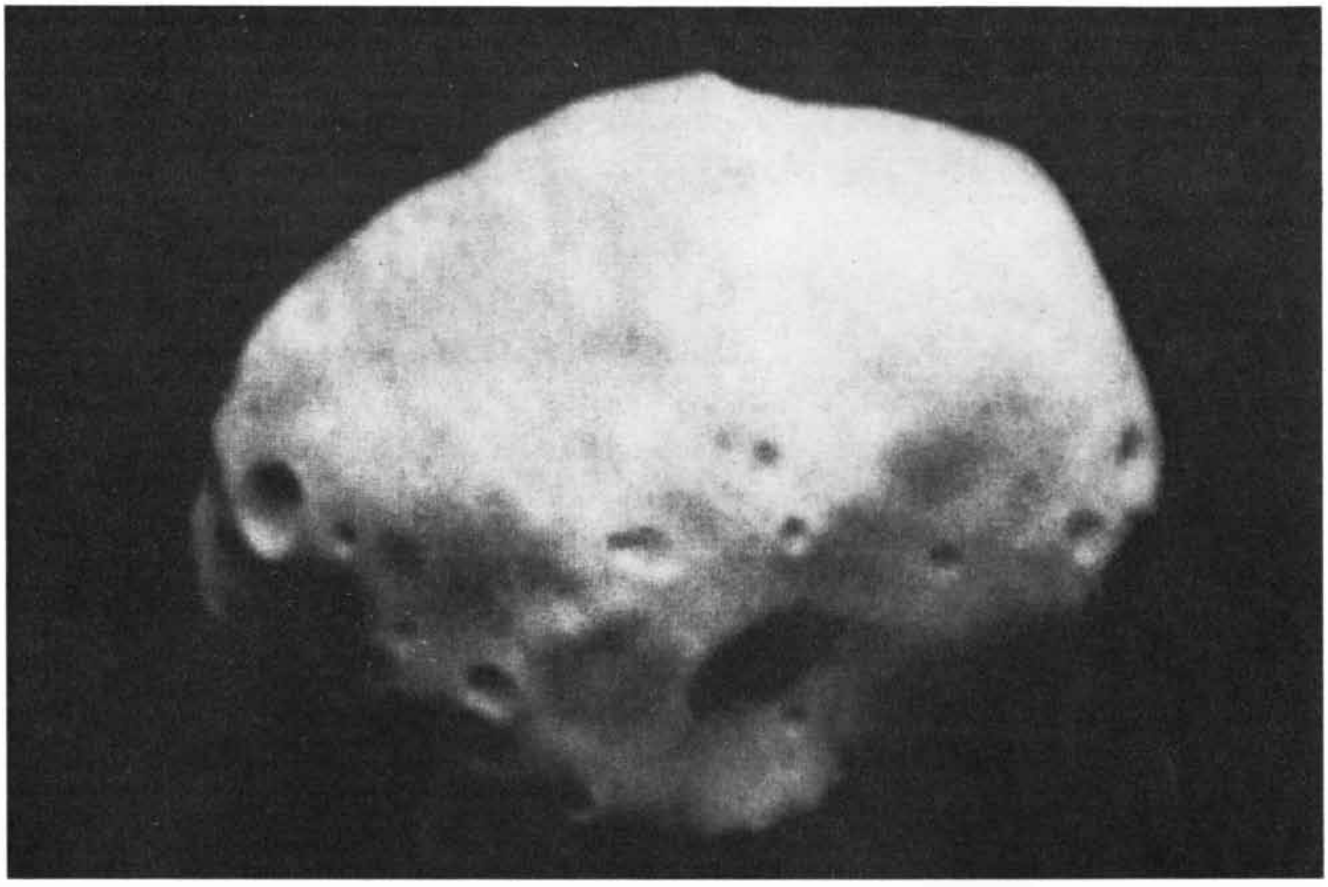


IMAGE OF PHOBOS, the larger of the two moons of Mars, is one of 27 obtained by *Mariner 9* as it orbited Mars in 1971–1972. Prominent in this view is the crater named for Asaph Hall, discoverer of the moons; it is six kilometers in diameter. The image is oriented so that the illumination is from top to bottom; otherwise the apparent relief of craters and other surface features would tend to reverse.

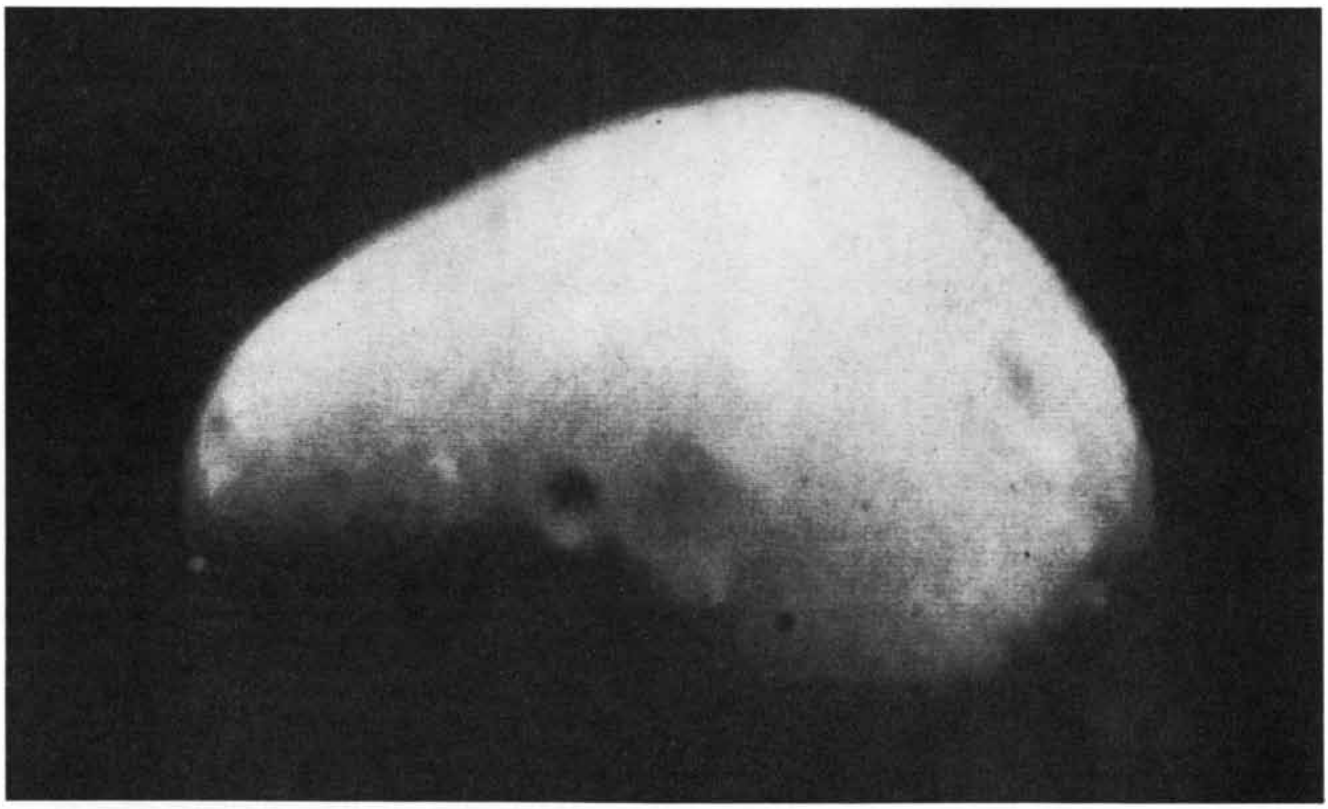
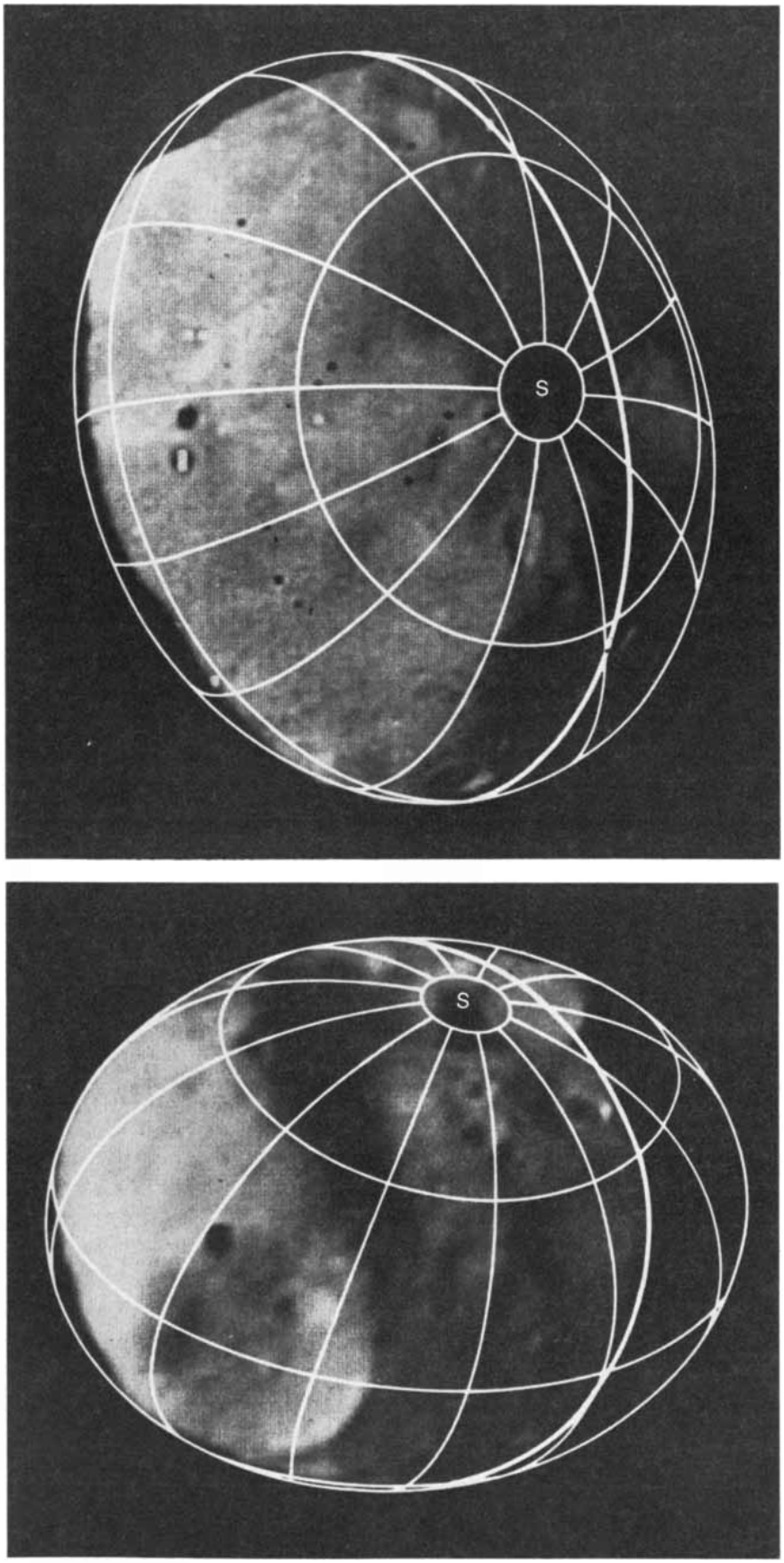


IMAGE OF DEIMOS, the smaller and more distant of the moons, is one of nine obtained by *Mariner 9*. The distinct circular crater near the center is named Swift; it is one kilometer in diameter. The subdued crater just to the right, two kilometers in diameter, is Voltaire.



SYSTEM OF COORDINATES for Phobos is imposed on images of the satellite in two orientations obtained 22 days apart by *Mariner 9*. The geometry of the coordinates is based on a triaxial ellipsoidal model of the satellite developed by Thomas C. Duxbury of the Jet Propulsion Laboratory of the California Institute of Technology. As the separate superpositions indicate, after allowance is made for some missing chunks of the moon the model gives a good fit.

than Deimos. Perhaps more significant was Pickering's conclusion that the two moons were not the same color as Mars: where the planet was reddish, they were grayish. This suggested that the surface of the satellites could not be composed of the same stuff that composed the surface of Mars.

The first modern photometric observations of Phobos and Deimos were not made until G. P. Kuiper undertook the task during a favorable opposition in 1956. Kuiper found Phobos to be some three times brighter than Deimos. Assuming that the two bodies were spherical and that their surfaces reflected roughly the same 11 percent of sunlight that the surface of the earth's moon does, he calculated that Phobos was 12 kilometers in diameter and Deimos six kilometers.

The first direct measurement of the size of Phobos came 13 years later. In 1969 the high-resolution camera aboard *Mariner 7* captured the silhouette of Phobos outlined against the disk of the planet. The image was scarcely seven picture elements wide, but it showed that Phobos was irregular in shape and much larger than Kuiper had estimated. Working with *Mariner 7* data, B. A. Smith of New Mexico State University calculated that Phobos was some 17 kilometers long and 23 kilometers wide. The fact that the size was greater than Kuiper had calculated on the basis of a surface material with the reflectivity of the earth's moon indicated that the material was actually only half as reflective as the earth's moon.

Detailed reconnaissance of both Martian satellites began on November 14, 1971, when *Mariner 9* went into orbit around Mars. In its observing lifetime *Mariner 9* obtained 27 views of Phobos and nine views of Deimos. On the average the resolution was good enough to show any feature more than 200 meters in diameter. The imagery of Phobos was sufficiently complete to make it possible to map most of the satellite's surface and to determine its shape with considerable precision. As the glimpse from *Mariner 7* had indicated, Phobos is irregular. Analyses of *Mariner 9* data by Duxbury, however, show that it is a triaxial ellipsoid if one allows for a few missing chunks. Its principal diameters are 27, 21 and 19 kilometers.

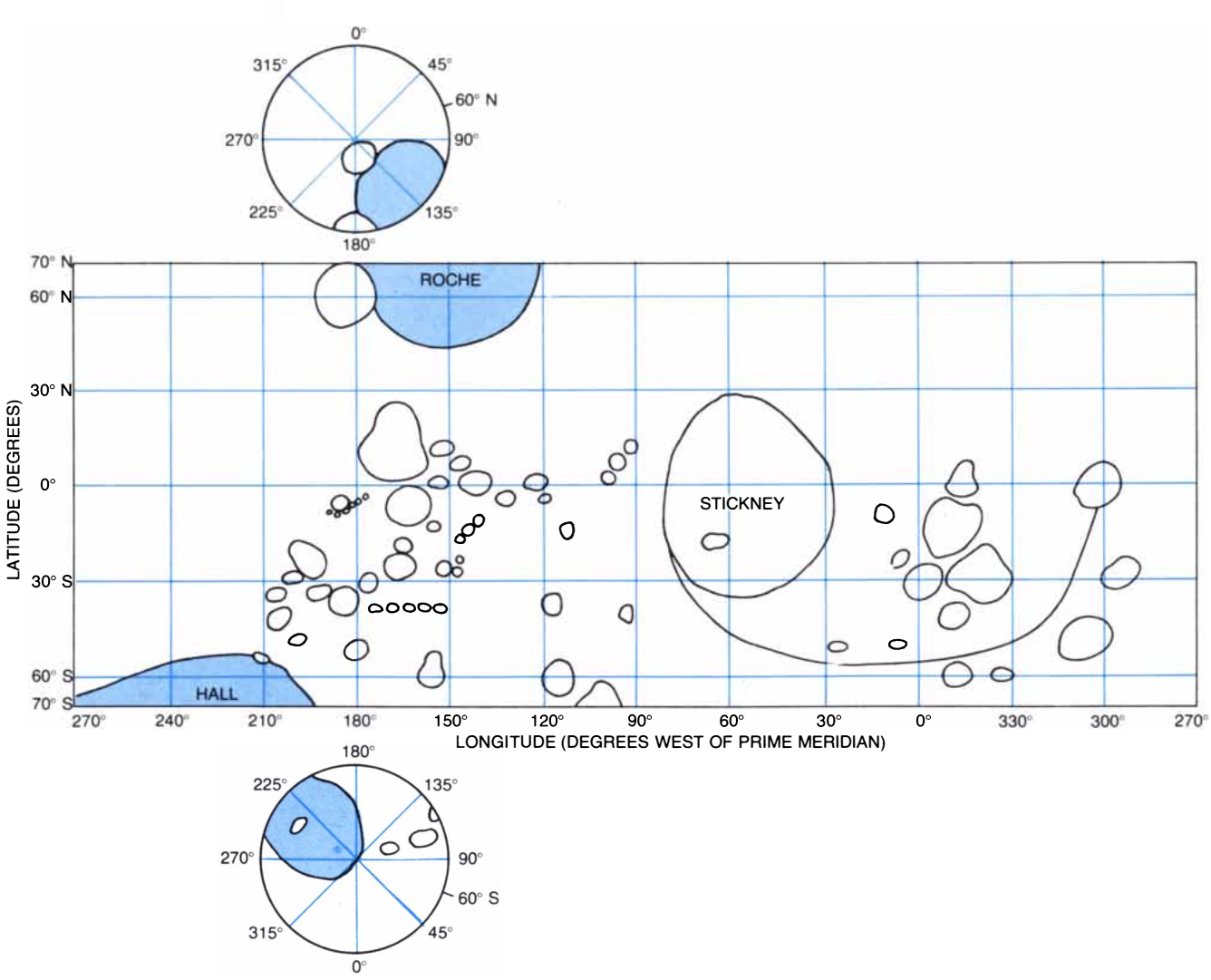
The *Mariner 9* coverage of Deimos was less complete because only the side of the satellite facing Mars could be photographed. Nevertheless, analyses of the limited imagery suggest that Deimos too is roughly ellipsoidal, with principal diameters of 15, 12 and 11 kilometers. There are slight irregularities in the ellipsoid, as there are in that of Phobos, but the peculiar fact remains that the two moons of Mars are almost identical in shape.

By tracking individual surface fea-

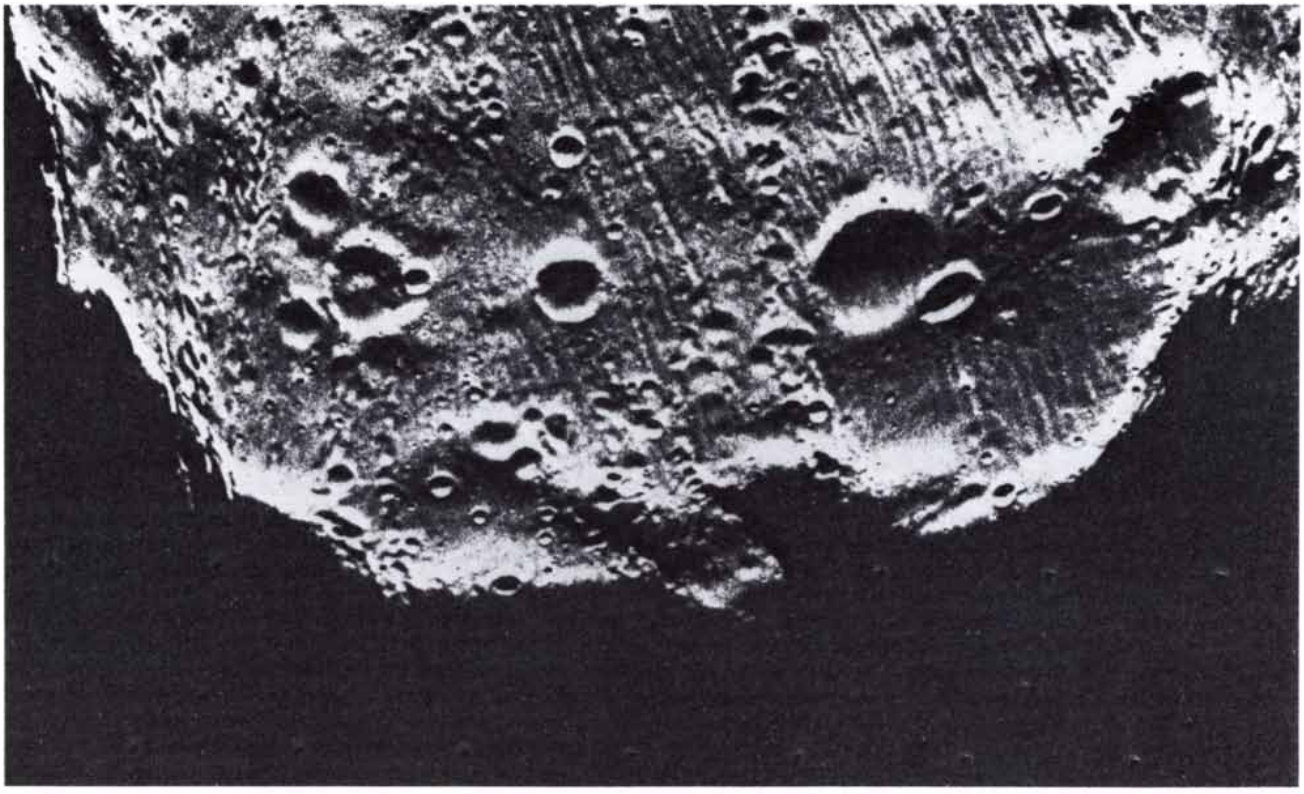
tures on each satellite analysts of the *Mariner 9* imagery were able to determine that both Phobos and Deimos rotate synchronously with their revolution around Mars. That is, one side of each satellite always faces the planet, as one side of the earth's moon always faces the earth. If a small, irregular body is set spinning rapidly in the vicinity of a larger body, tidal friction eventually brakes the rotation rate of the smaller body until that rate is synchronous with the rotation rate of the larger body. The time required to achieve the synchronous rotation is related to, among other things, the distance between the two bodies: the closer a satellite is to a planet, the shorter the spin-down time is. In addition, the more irregular the satellite's shape and the more eccentric its orbit, the shorter the spin-down time. For Deimos a rotation rate synchronous with that of Mars should have been achieved within a million to 100 million years. For Phobos, much closer to Mars, it should have been achieved within 10,000 to a million years. Such calculations put a lower limit on the length of time that has elapsed since the satellites were last set spinning. That spin may have been imparted by the violent impact of a large piece of interplanetary debris.

Before the *Mariner 9* imagery existed the probable appearance of the surface of small bodies such as Phobos and Deimos was a subject of debate. For an object to escape from the earth's moon it must have a velocity of 2,380 meters per second, but for one to escape from Phobos it needs a velocity of only about 15 meters per second. This low escape velocity means that when a piece of interplanetary debris hits Phobos, most of the collision products are blasted out into space. One question was therefore whether or not recognizable craters would be formed on bodies this small. Would the collisions leave mere pockmarks or would they make craters with raised rims, like those on larger bodies such as the earth's moon?

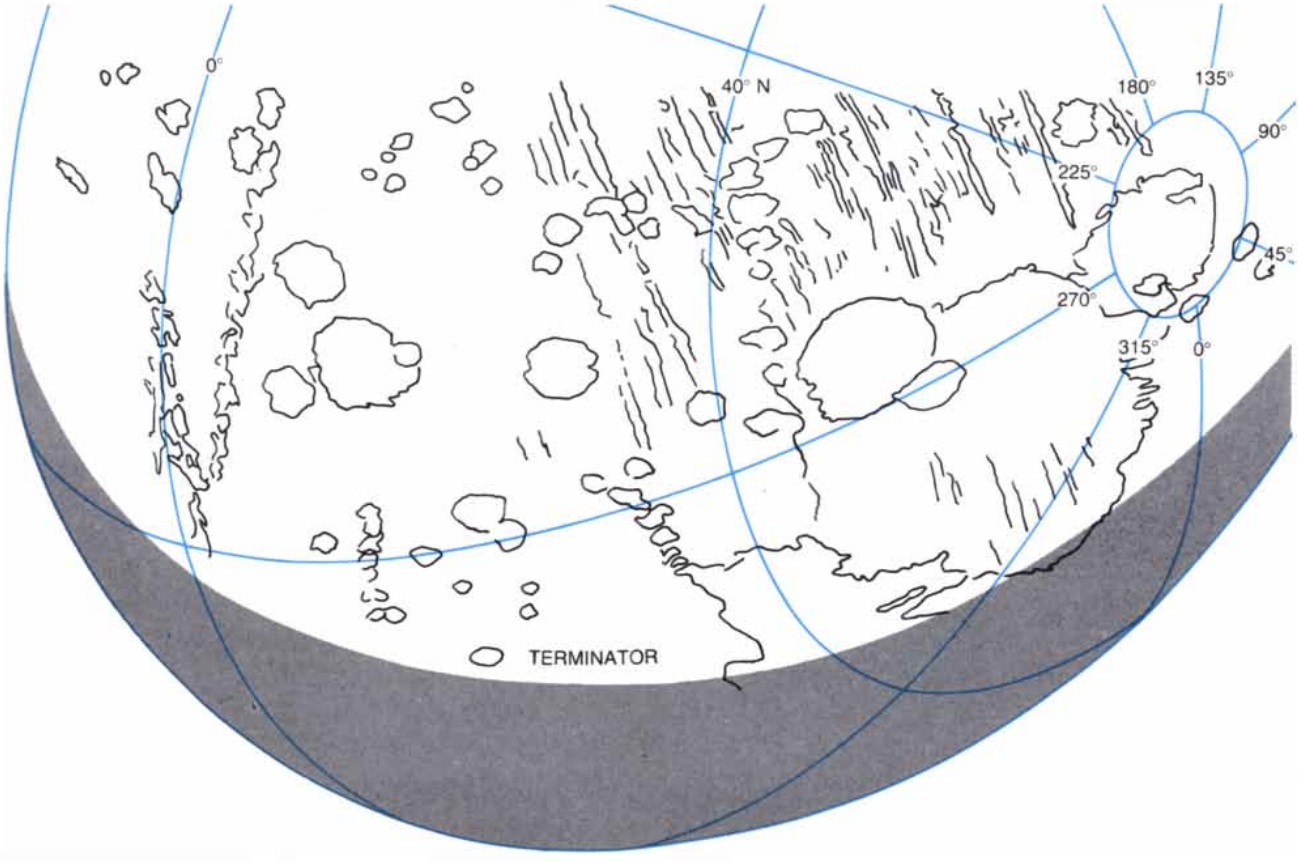
The *Mariner 9* imagery answered the question: both Phobos and Deimos showed a profusion of rimmed craters that were easily recognizable down to the limit of image resolution. Moreover, the craters on Phobos have all possible shapes, from one elongated crater shaped like a keyhole to others that are perfectly circular. There is also a wide range in the freshness of the craters, from what appear to be young craters with a conspicuously raised rim to eroded depressions that are so shallow they are barely visible. Notably absent are features prominent on the surface of the earth's moon, such as blankets of ejecta and craters with a central peak. Given the negligible gravity of Phobos, their absence is understandable. The two largest craters on the satellite are named Hall and Stickney, the first after the discoverer of the moons of Mars and the second after his wife, born Angeline Stickney, who is said to have encouraged him in his long search. They are respectively six and 10 kilometers in di-



SURFACE FEATURES of Phobos between 70 degrees north and 70 degrees south latitude appear in the central part of this map, a projection prepared by Duxbury on the basis of *Mariner 9* imagery. The largest crater on Phobos, Stickney, appears to the right of center; it has a maximum diameter of 10 kilometers. The next-largest crater, Hall, lies mainly in the south-polar region of the satellite (*color*); only its northern edge appears in the central projection. Most of the third-largest crater, Roche, lies in the north-polar region (*color*).



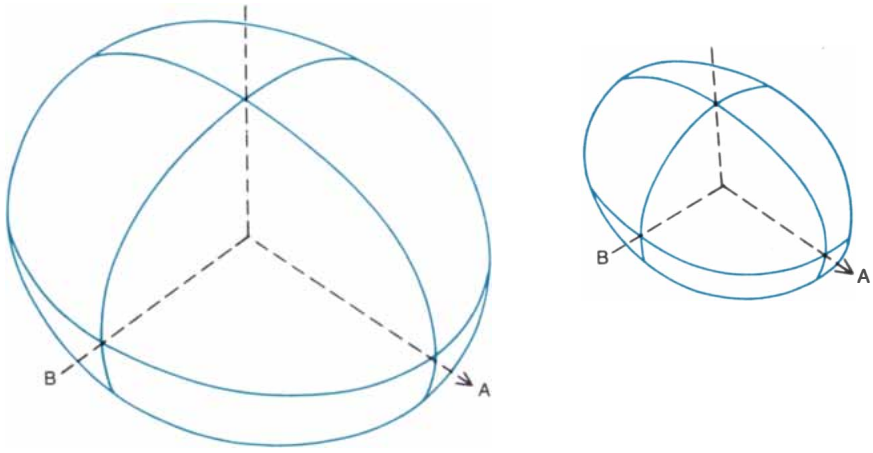
CLOSE-UP OF PHOBOS shows a portion of the satellite's surface extending from the north-polar region (*right*) to a little below the equator (*left*) and covering 70 degrees of longitude at its widest. The total area is nine by 18 kilometers. The image was obtained by the *Viking 2* orbiter in September, 1976, when less than 900 kilometers away. A series of prominent parallel grooves is evident at this resolution, which makes visible objects 40 meters or more in diameter. The cause of these curiously regular markings is uncertain at present.



SKETCH MAP, based on the system of coordinates devised for Duxbury's model of Phobos, relates the *Viking 2* orbiter imagery to the map of the satellite's surface on the preceding page. Area in shadow lies east of boundary between light and dark hemispheres.

ameter; the diameter of Stickney is thus about 40 percent of the maximum diameter of Phobos itself.

In addition to calculating the ellipsoidal shape of Phobos, Duxbury has made a surface map of Phobos from the *Mariner 9* imagery [*see illustration on page 33*]. Since the coverage of Deimos was limited, no map of the outer satellite has yet been produced. Detailed coverage of Deimos is a major objective of the current Viking orbiter missions to Mars. The surface of Deimos is much like that of Phobos, although it is perhaps a little less rugged. The largest crater on Deimos scanned by *Mariner 9* is an eroded structure two kilometers in diameter that has been named Voltaire. Close to it is a one-kilometer crater with a conspicuous rim that has been named for the other 18th-century literary personage who publicized Kepler's fictional moons, Swift. The contrast between the soft outlines of Voltaire and the sharp ones of Swift demonstrates the effectiveness of erosion processes even on such small bodies as this one. The principal forces responsible for crater obliteration on Deimos must be the pitting caused by low-velocity impacts and the blasting caused by high-velocity ones.



RELATIVE SIZES of the two Martian moons are apparent in this comparison of Duxbury's two models. The principal diameters of the Phobos ellipsoid are 27, 21 and 19 kilometers; those of Deimos are 15, 12 and 11 kilometers. The *A*-axis arrows label the side facing Mars; the *B* axes label the orbital plane. The similarity between the two moons' shapes is unexplained.

The impacts responsible for the largest craters on the moons of Mars have doubtless modified the shape of both satellites. For example, the collision that gave rise to Stickney must have generated severe shock waves throughout Phobos and probably even knocked off large chunks of it. The effects of such high-velocity impacts on small bodies have been simulated in the laboratory by Donald E. Gault and his co-workers at the Ames Research Center of the National Aeronautics and Space Administration. Working with spherical targets, they are studying the effects of impacts of various energies. Low-energy impacts leave a craterlike scar on the target, with the damage concentrated in the contact area. High-energy impacts cause large pieces of the target to spall off. The spalling is concentrated on the face of the sphere opposite the point of impact, and often the entire outer layer of the target is removed, leaving only the inner core. The shape of these inner cores is surprisingly like that of Phobos and Deimos. Both moons have sharp projecting edges, suggesting that their present form is the result of high-energy impacts.

In view of the likelihood that spallation accompanied the formation of the largest craters on Deimos and Phobos, it will be interesting to study the crater densities in the regions of the satellites that are opposite some large craters. The *Mariner 9* coverage is not adequate for this purpose, but some suitable data are beginning to come in from the Viking orbiters. For example, we now know that an area of abundant secondary cratering visible on a Viking image of Phobos lies on the side of the satellite opposite the major impact represented by Stickney.

The surfaces of both Martian moons, like the surface of the highlands of the earth's moon, are saturated with craters. On the basis of this observation James B. Pollack of the Ames Research Center has argued that Phobos and Deimos are at least 1.5 billion years old and may in fact date back to the birth of the solar system some 4.5 billion years ago. The sharp edges apparent on both moons suggest that on the whole they have the consistency of solid rock. Agglomerations of loose rubble, bound together only by small gravitational forces, would surely not shatter in this fashion.

At least the surface of the satellites, however, consists of the kind of impact-produced layer of rubble known as a regolith. Two kinds of evidence support such an interpretation. The first is optical evidence: how sunlight is scattered by the surface. The second is thermal evidence: how the surface heats up.

It was Benjamin H. Zellner of the University of Arizona who managed in 1971 to measure the degree of polarization of the sunlight scattered from the surface of Deimos; the flood of scattered light from Mars itself makes this an extremely difficult telescopic measurement. Zellner found that the surface of Deimos polarized sunlight in a way that was quite uncharacteristic of solid rock. Instead the polarization was like that of a surface composed of some dark powder.

At about the same time that Zellner made his observations known, instruments aboard *Mariner 9* recorded complementary evidence. One of the *Mariner 9* experiments was the measurement of the infrared radiation from Phobos before and after the satellite passed through the shadow of Mars in its quick journey around the planet. The question was: How would Phobos heat up after cooling off in the shadow? Would it do so slowly? Slow heating would be indicative of a compacted surface or perhaps even a solid one, characterized by high thermal conductivity. Would it heat up rapidly? Quick heating would suggest some kind of porous surface with low thermal conductivity. The infrared observations showed that the surface of Phobos heated up with remarkable rapidity after the satellite emerged from the shadow of Mars, indicating a surface layer with the extremely low thermal conductivity characteristic of a powder. The experiment was sensitive to the temperature of the uppermost millimeter or so of the surface; thus at least that much of the surface is evidently a powdery regolith.

Still further evidence from *Mariner 9* supports Zellner's telescopic observations. At Cornell University, Michael Noland and I have made use of *Mariner 9* data to analyze the light-scattering properties of the surface of Phobos and Deimos. Both surfaces scatter sunlight in a manner characteristic of a dark surface with an intricate structure. For example, when such a surface is observed at an angle equal to the angle of illumination, there is no gloss or increase in brightness. The light-scattering properties of Phobos and Deimos resemble those of certain areas on the earth's moon. In these areas the surface not only is dark enough to prevent the scattering of most of the impinging photons but also is so intricate in texture that each surface element has numerous nooks and crannies that trap most of the photons that do get scattered. Our study of the *Mariner 9* data suggests that both satellites of Mars are covered with a homogeneous layer of regolith possessing these light-absorbing properties. We have searched carefully for patches of exposed rock but so far have found none. It is probably unrealistic, howev-

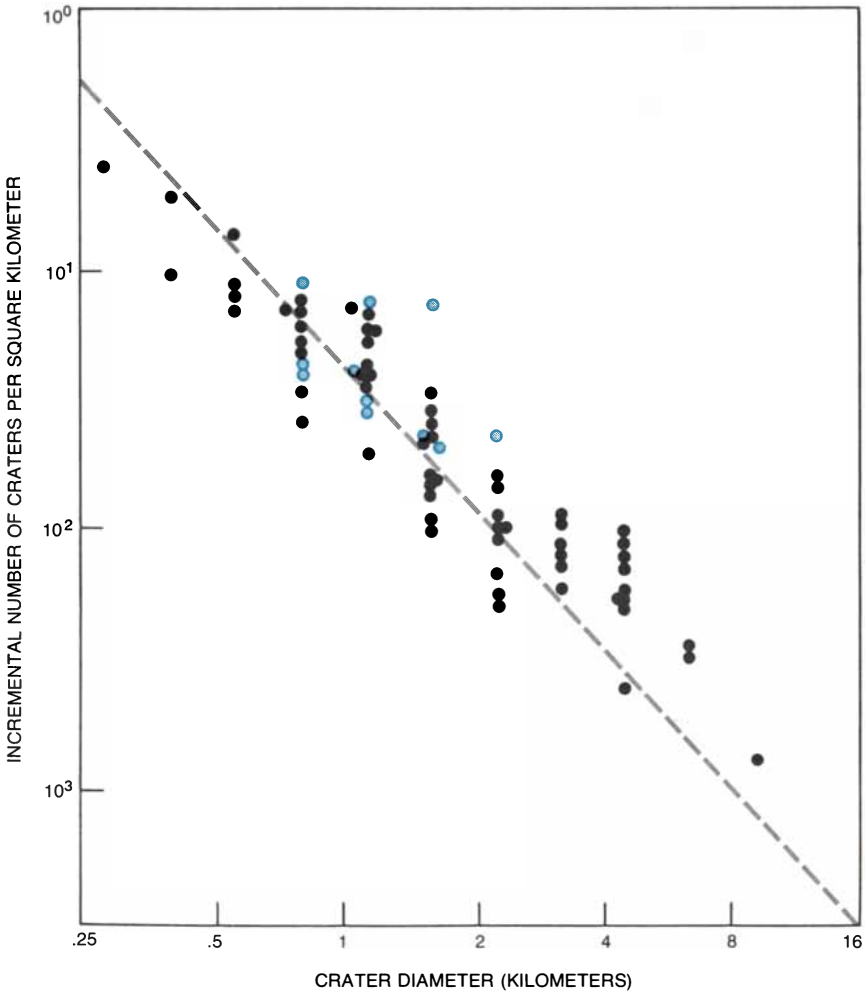
er, to think of the regolith on small bodies such as the moons of Mars as being exactly like the regolith of the earth's moon. Until we have sampled the surface layers of a few small bodies, however, we shall not know what the differences between the two classes of regoliths are.

How does a body as small as Phobos retain a regolith? No one is really sure. The most popular explanation involves what is called the low-velocity tail of the debris that is formed by impacts. Typically the impacting object imparts a wide range of velocities to the particles of the debris. If the velocity required for escape from the parent body is low, most of the flying particles will be lost to space. Some fraction of the debris, however, will not achieve escape velocity and will remain imprisoned by the gravity of the parent body. The captured fraction need not be large in order to cover the parent body with a layer of fine dust. Estimates of the precise fraction needed to form such a layer are being derived from the laboratory experiments with high-velocity impacts, but they remain uncertain. Nevertheless, the Viking-orbiter observations indicate that many of the craters on Phobos are secondary, that is, they were made by objects that were thrown up by primary impacts. These craters provide direct proof that some impact debris has indeed fallen back to the surface of the satellite.

It has been suggested that the reason Deimos and Phobos have a surface covering of regolith is that they are close to Mars. The argument goes on to conclude that similar small bodies in the asteroid belt between Mars and Jupiter would not have a regolith surface. In the case of the moons of Mars it is reasoned that if a particle of debris is to escape into space, it must have sufficient velocity to escape the gravitational influence not only of the parent satellite but also of Mars. If it lacks sufficient energy to escape Mars, the particle may go into orbit around the planet and eventually be captured by one moon or the other. Thus the moons of Mars have a chance to retrieve some of their own escaped debris. In the asteroid belt there would be no such opportunity for recapture.

The argument neglects the low-velocity-tail effect, which would hold some of the debris blasted from the surface of an asteroid as it presumably does on Phobos and Deimos. What is perhaps more important is observational evidence with respect to the asteroids themselves. For example, during the close approach to the earth in 1975 of the asteroid Eros, a body comparable to Phobos in size, several independent telescopic observations suggested the presence of a regolith surface. Such dust layers may in fact be an essential feature of all the solid surfaces in the solar system. Recent experiments conducted by Gault and his co-workers at the Ames Research Center show that for an impact of a given energy it is more difficult for debris to be ejected from a regolithlike layer of loose particles than it is for it to be ejected from a surface of solid rock. This suggests that once a regolith forms it tends to remain and to be self-perpetuating.

I have indicated that at the wavelengths of visible light the reflectance of Phobos and Deimos is about 6 percent, compared with a reflectance of 11 percent for the earth's moon. As far as reflectance is concerned the surface of Phobos appears to be homogeneous. On Deimos, however, there are some areas that are brighter than the rest. On the basis of *Mariner 9* data Noland and I have estimated that the brightness of one such patch is some 30 percent above average. This puts its reflectance somewhere around 8 percent rather than 6 percent, which would still make it a very dark surface.



CRATERING of the moons of Mars is compared with cratering of the earth's moon. The straight line shows the trend for the most heavily cratered uplands of the earth's moon, which are "saturated": the number of craters cannot increase because new craters only obliterate older ones. *Mariner 9* images indicate that Phobos and Deimos are also saturated. They show 62 craters on Phobos (*black*) and 11 on Deimos. Only one side of Deimos has been seen, however.

It is usually assumed that Phobos and Deimos have a common origin. No conclusive evidence supports this assumption, but one argument cited in favor of it is the similarity in the orientation of the orbits of the two moons. The similarity of their photometric characteristics is possibly even stronger evidence in favor of a common origin. Hypotheses of the Martian moons' origin fall into two main schools: capture and accretion.

Those who favor accretion hypotheses regard the two satellites as collections of material left over from the formation of Mars. One plausible capture hypothesis visualizes a large asteroid passing close to Mars and breaking up during its passage, after which at least two of its larger fragments are captured by the planet and remain in orbit around it. This hypothesis has simplicity in its favor, but it leaves certain technical questions unanswered. For example, how would such a breakup process work? Exactly how would the orbits of

the two fragments end up in the equatorial plane of the planet?

The truth is that not enough evidence is available for definitive theorizing about the origin of Phobos and Deimos. For example, the composition of the satellites' surfaces could provide important clues regarding their origin, but at this point no one knows what the surfaces are made of. The usual astronomical means of determining the composition of a solid object is to discover how the object reflects various wavelengths of electromagnetic radiation, including light. Adequate spectral reflectance measurements for Phobos and Deimos simply do not exist; at this stage all our arguments about their composition are indirect.

Since both moons are very dark, it is often stated that this fact alone makes it likely that the surface material is similar either to basalt, a dark igneous rock, or to the material of the class of crumbly meteorites known as carbonaceous chondrites. This kind of reasoning cannot be conclusive, since darkness by itself is not a diagnostic property of a surface. For example, the reflectance of a slate blackboard is about the same as that of Phobos and Deimos. Since slate is not known to exist in space, however, no one has suggested that the satellites are made of it.

To settle the question of origin we must find out what Phobos and Deimos are made of. If the material should prove to be basaltic, then the satellites are almost certainly fragments of a much larger body or bodies. The formation of basalt requires melting and mineral differentiation in a parent body, and it is unlikely that such processes could take place in objects as small as the moons of Mars. If Phobos and Deimos are indeed basaltic, this fact would favor their being fragments of a large (and therefore differentiated) moon of Mars, shattered long ago in some catastrophic collision. That they could be fragments of some other large and similarly shattered basaltic body or bodies, perhaps from the asteroid belt, is less likely because of the low probability that Mars would capture such fragments.

If the material should prove to be similar to that of the carbonaceous chondrites, then Phobos and Deimos need not be fragments of larger bodies. They could instead represent material left over from the formation of Mars itself. There is, however, some debate about whether or not Mars accreted much material of this kind during its formation. Some theorists maintain that such material could form only in the asteroid belt and not as close to the sun as the orbit of Mars. This seems to be almost certainly true of at least the carbonaceous chondrites classified as Type I, which are the richest in volatile components. If Phobos and Deimos should prove to be made of Type I material, then the two satellites are almost certain to be bodies captured from the outer half of the asteroid belt.

IMAGE OF DEIMOS obtained by *Mariner 9* has been specially processed in order to exaggerate differences in brightness. The central band was found to be about a third brighter than the rest of the satellite's surface. The brighter band, however, reflects only 8 percent of the sunlight that falls on it. The reflectance of the earth's moon, which is regarded as being low, is 11 percent. The three conspicuous dark-edged bright spots are artifacts of image processing.

Whatever their origin, Phobos and Deimos have given us our best glimpse of the kind of body that populates the asteroid belt in uncounted numbers. We have yet to study the topography of any asteroid in detail, but we now have a relative wealth of information on two bodies that surely resemble asteroids very closely. Like asteroids, the moons of Mars are small and their gravitational fields are almost insignificant. Bodies with weak gravitational fields share three important characteristics. First, they lack an atmosphere. Second, they continually lose mass as a result of the high-velocity impacts of interplanetary debris. Third, they tend to be irregular in shape because large impacts are likely to knock off large chunks of their surface. Because such bodies are too small to have the kind of internal pressure forces that would enable gravity and rotation to readjust their components into spherical form, they retain the irregular shapes they acquire.

The two Viking orbiters have been circling Mars since last summer. Among their most important tasks have been extending the picture coverage of Phobos and Deimos and making more refined measurements of the decaying orbit of Phobos. One of the orbiters is now making close approaches to Phobos. Imagery with a resolution that will record features only 10 meters in diameter should be possible, allowing a detailed study of many of the satellite's smaller craters. The same orbiter should also pass close enough to both moons to "feel" their gravitational pull. This, it is hoped, will make it possible to calculate their mass with an accuracy of plus or minus 10 percent. Knowledge of the satellites' mass will enable us to determine their mean density, and that in turn should narrow the range of guesswork about their possible constitution. For example, knowledge of the satellites' mean density may make it possible to eliminate from the running either carbonaceous-chondrite material of Type I, with a mean density of about 2.3 grams per cubic centimeter, or basalt, with a mean density of 2.9 grams.

The Viking-orbiter images have already led to better counts of crater density on both Phobos and Deimos and also to the discovery of enigmatic grooves on the surface of Phobos [*see illustrations on page 34*]. The nature and origin of these peculiar parallel markings remain to be explained, but one exciting possibility is that they reflect layering, perhaps representing successive lava flows, on the surface of a much larger parent body of which Phobos is merely a fragment.

VINDOLANDA EXCAVATION, here seen from the air, has traced the outline of a Roman fort (*top*) built in about A.D. 160, its central headquarters and two fortified gates in the north (*left*) and west walls. Outside the west gate stood civilian settlements. Most of the walls visible in outline are those of Vicus II, the settlement built in about A.D. 275, when the last Roman occupation of Vindolanda began. Below Vicus II the excavators are continuing to uncover the ruins of the preceding civilian community, Vicus I. Near the west gate a deposit of even earlier remains has been unearthed: five successive periods of construction in wood. These wood forts sheltered the first Vindolanda garrison from perhaps A.D. 90 until as late as A.D. 130, when the garrison shifted north to one of the forts on Hadrian's Wall.

A Frontier Post in Roman Britain

Vindolanda, near Hadrian's Wall, was a Roman garrison from the first century to the fifth. Oxygen-free burial has preserved a remarkable trove of wood, leather, textiles and writing in ink

by Robin Birley

For much of the first five centuries of the Christian Era the northernmost frontier of the Roman Empire lay where the boundary between Scotland and England runs today. Tradition has characterized the border as a savage territory kept under control only by the iron discipline of the Roman troops who garrisoned a chain of lonely forts along Hadrian's Wall. In the past six years archaeological investigations at one such garrison, named Vindolanda, have yielded some notably revealing details of Roman frontier life. As an example, it is now known that the garrisons along the wall were far from lonely. At Vindolanda, starting soon after the building of Hadrian's Wall and continuing until the collapse of the Roman northern frontier some four centuries later, the garrison lived close to a lively civilian community. Moreover, the civilian community probably enjoyed a standard of living higher than that of any other people in the area until the middle of the 19th century. There is good reason to believe the same was true of all the other garrisons along Hadrian's Wall. Another example of what has been learned is the curious outcome of two activities, separated in time by some 19 centuries, that combined to preserve and expose a large number of perishable artifacts and organic remains that are unique in the archaeological record of Roman Britain. This double accident of preservation and exposure has provided a surprising glimpse of Roman army life late in the first century.

Rome's first military contacts with Britain were the raids conducted by Julius Caesar in 55 and 54 B.C. Not until nearly a century later was a serious effort made to annex the island. In A.D. 43 four legions under the direction of the emperor Claudius landed in Kent; three years of campaigning brought all of Britain south of the Humber River and east of the Severn under Roman control. It was not, however, until Wales and Yorkshire were added to the Roman sphere during the succeeding decade and the ill-fated uprising of Queen Boadicea was crushed that an effort was made to establish a northern frontier.

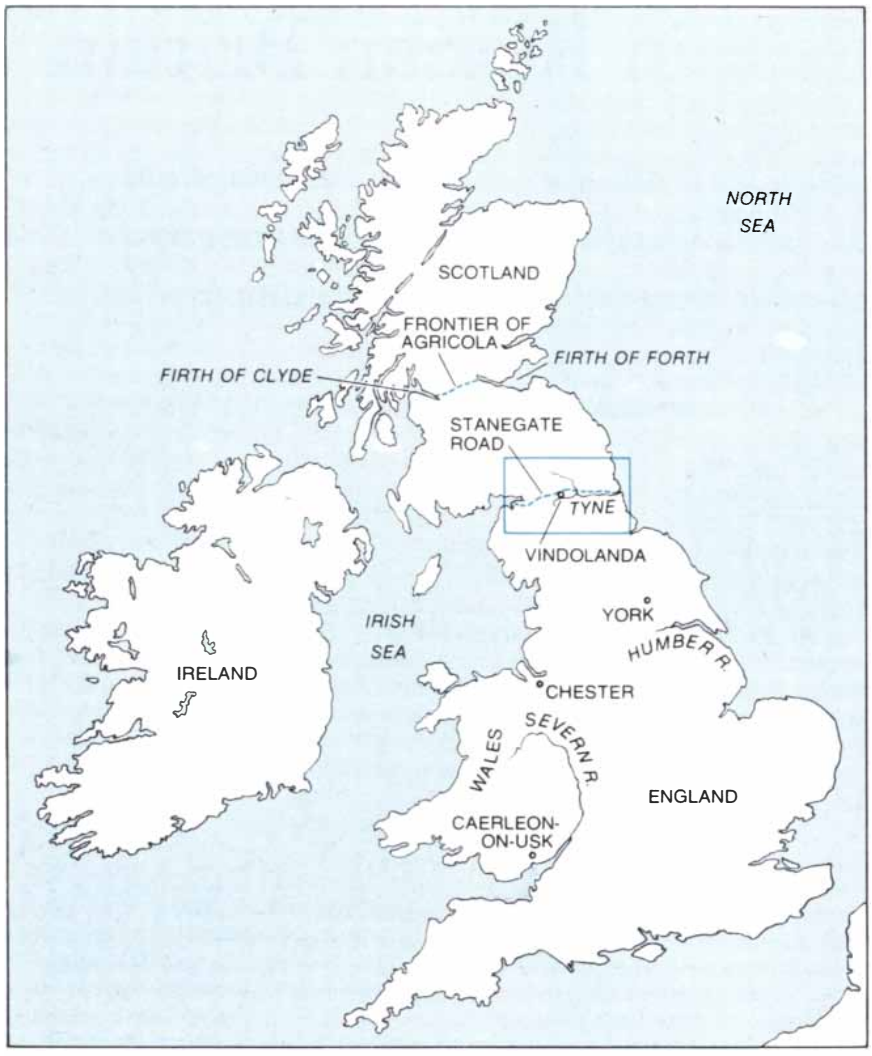
A skilled general, Julius Agricola, thrust north of York in A.D. 80 and established a line of forts across the narrow isthmus between the Firth of Clyde and the Firth of Forth. At the same time Agricola improved his line of communications by constructing a lateral road some distance to the south. The road ran from the mouth of the Tyne River on the east to the Solway coast on the west. This military route is now known as the Stanegate Road. Some 10 years after Agricola's thrust north the Clyde-Forth line was abandoned and the Stanegate line became the new frontier. Forts were built from coast to coast at intervals of about seven miles. One of them near the center of the line was Vindolanda.

For some 30 years, from about A.D. 90 to 125, a succession of wood buildings housed the Vindolanda garrison. It is not clear whether the frontier was peaceful at that time, but trouble was definitely brewing to the south. An uprising in about A.D. 120 prompted Hadrian, the second Roman emperor to cross the Channel, to strengthen the frontier, and he set his engineers to building the wall that still bears his name. It ran from Bowness in the west to Wallsend in the east, generally paralleling the Stanegate line. It passed about a mile north of Vindolanda, following a stony ridge. In about A.D. 130 the Vindolanda garrison was moved forward to man one of the new forts along the completed wall, and the wood buildings at Vindolanda were left to decay for some 40 years.

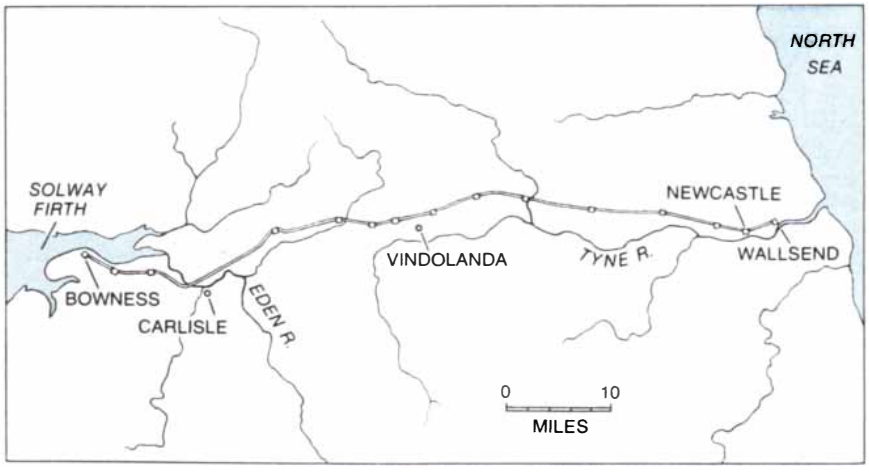
Today much of the old frontier lies concealed under modern roads and towns, but its central section, crossing the lovely moors of Northumberland, is sufficiently well preserved to attract visitors by the thousands. In addition to viewing the great wall itself, with its ditches, mile castles and turrets, they can see traces of the Roman roads, signal stations, permanent forts and route-march camps, a complex of works that made this frontier one of Rome's most ambitious. It is ironic that such a monument of empire is virtually undocumented in those annals of Roman Britain that have survived. Most of what is known about the wall comes from what archaeologists have unearthed on the spot and have managed to transform into history of a kind, working with such evidence as the inscriptions that are preserved on monuments, foundation stones and coins.

Even the archaeological knowledge of Hadrian's Wall comes largely from fieldwork done decades ago, long before the era of controlled excavation programs and the multidisciplinary analysis of findings. In the case of Vindolanda, for example, the fact that the garrison had been established at least as early as A.D. 90 was demonstrated in 1930. My father, Eric Birley, was then reconnoitering the site. He located a military ditch containing a deposit of kitchen trash. The pottery fragments in the deposit proved to be typical of the pottery in use in Britain toward the end of the first century. Such work brought a great deal to light, but the need for large-scale excavations has been obvious for years.

The obstacles to such investigation are severe. Few landowners in Northumberland are prepared to sacrifice rich farmland for the sake of historical research. At the same time it has become increasingly clear to both historians and archaeologists that the true story of the frontier is a good deal more complicated than it seemed in the 1930's. As an example, aerial photography before and after World War II has revealed that there are substantial ruins around each fort on the wall. Who occupied these developed areas? Not so long ago scholars could maintain without fear of contradiction that the frontier region of Roman Britain was devoid of a civilian population. Even today the predominant impression one gets on a visit to the wall is that it was associated with a military society. Yet the aerial reconnaissance, and even some test excavations, suggested a civilian presence. Questions



NORTHERN FRONTIER of Roman Britain was first established across the narrow isthmus between the Firth of Clyde and the Firth of Forth by the Roman general Julius Agricola in A.D. 80. Agricola also improved frontier communications by building a lateral artery, the Stanegate Road, from the Tyne River to the west coast. When Agricola's frontier was abandoned in about A.D. 90, the Stanegate line became the new frontier, fortified at seven-mile intervals. The first fort at Vindolanda was located near the center of the Stanegate line. The three legions that held Britain for Rome were stationed at Caerleon-on-Usk, at Chester and at York.



HADRIAN'S WALL was built in the years after A.D. 122, generally along the Stanegate line. Following a stony ridge in its central portion, the wall passed about a mile north of Vindolanda. The garrison stationed there was moved to one of the new forts on the wall in about A.D. 130. Following a rebellion in Britain the emperor Septimius Severus rebuilt Hadrian's Wall early in the third century. His imperial successors made the wall Rome's best-fortified frontier.

such as this one could be resolved only by intensive field studies.

In 1970 the land where Vindolanda lay was given to an archaeological trust. The prospect of just such a study—the total excavation of a 20-acre site on the wall, including both the fort and the adjacent ruins—thus became a serious possibility. When I was appointed to undertake it, I estimated that an examination of the developed area alone might require 15 years to complete and an examination of the fort six years more. Today, some seven years later, this assessment seems a rash underestimate. We now know that under the turf at least seven forts lie one above the other and that in some places the debris of occupation goes down more than five meters below the surface. In the adjacent settlement area we have so far uncovered two successive frontier towns, or *vici,* associated with the later of the forts. What other settlements may be buried under the towns has yet to be determined. I now calculate that the complete examination of Vindolanda by a team of 10 to 15 working six-month seasons would take well over 100 years.

Most of our work at Vindolanda has been concentrated on the two *vici.* The earlier of the two dates from the middle of the second century. At that time, after some 40 years at a fort on the wall, the garrison—the Fourth Cohort of Gauls, part infantry, part cavalry and 500 strong—returned to the deserted site. A new fort, built of stone, rose on the eastern part of a level plateau. The enclosure was oblong; at the north and south ends the fort's massive walls, broken by central gates, run 85 meters; on the east and west sides the length of the walls is just under 150 meters.

The overgrown ruins of the last wood fort at Vindolanda, abandoned 40 years earlier, stood just beyond the west wall of the new fort. Here the garrison engineers must have dumped many cartloads of clay in the process of covering up the earlier structures and preparing a level site for the stone foundations of what we call Vicus I. On both sides of the main road leading from the west gate were erected a series of long barrackslike buildings; the masonry was dressed stone bound with lime mortar. The largest barracks was nearly 40 meters long, and all of them seem to have been about five meters wide. We deduce that the structures were one story high and probably served as quarters for married soldiers. They were divided into single rooms, one to a family, by partitions spaced about seven meters apart. There was probably storage space under the roof, and a veranda outside each room would have provided cooking space. The four barracks we have located so far could have housed 64 families. The British army in India offered almost identical housing to the

CENTRAL SECTION OF HADRIAN'S WALL is still fairly well preserved, although much of its original 66 miles has been covered by modern road and town construction. Shown here is a section of the wall in Northumberland where it followed the local high ground.

families of its Indian soldiers. Smaller buildings, possibly housing for the families of noncommissioned officers, stood nearby.

The two major structures of Vicus I might have been expected. One is a military bathhouse of the kind that was probably to be found outside every fort in the Roman Empire. Within the building off-duty soldiers found not only the amenities one associates today with an elaborate Turkish bath but also rooms for the purposes of relaxation and refreshment. Trapped in the bath sewers we found articles of feminine attire—beads, hairpins and wood combs—indicating that the civilian residents of Vicus I, as well as the garrison troops, made use of the building.

The other major structure is a *mansio,* a government-sponsored inn or rest house for official travelers. Such facilities were normally to be found at intervals along the main Roman roads, catering to the needs of military and civil officials whose duties entailed travel. The *mansio* of Vicus I had six guest rooms, a heated dining room, a small bath suite and a kitchen.

As the excavation of Vicus I continues we expect to unearth not only other residences and inns but also stores, workshops and even temples. From what we have exposed so far it is clear that the civilian population lived remarkably well. Many of the houses had windows made of glass, an unusual extravagance at this date, and the household utensils, made of both bronze and iron, were of excellent workmanship. The enameled pieces are particularly fine. The available local food was enhanced with sauces and spices, and the olive oil used by the cooks was imported from Spain. The meals were served on imported crockery brought to the frontier both from the south of Britain and from the Continent.

Vicus I housed the families of the Fourth Cohort of Gauls for 70 or 80 years. Then in about A.D. 240 or 250 Vindolanda was abandoned. There is no evidence of destruction, and existing historical records suggest no reason for the move. Indeed, during the early decades at Vicus I life must have been quite peaceful. Under the emperor Antoninus Pius a second advance to the Clyde-Forth line had been made in A.D. 142, reestablishing Agricola's frontier. A rampart and a ditch were built across the isthmus, guarded by a dozen forts along a lateral road, and there the frontier evidently stood until a rebellion in A.D. 180 or 185. The civil wars that raged in Roman Europe during the decade that followed left the Romans with few resources to keep up military works in Britain. Not until A.D. 208 could the able emperor Septimius Severus turn his attention to the frontier. Like Claudius and Hadrian before him, he crossed over to Britain and had his engineers rebuild Hadrian's Wall from end to end. From A.D. 211 to 235 his imperial successors added to the wall's defenses. Why it was that soon after the wall had been renewed the garrison of Vindolanda abandoned its post remains unknown. Perhaps the troops were once again ordered to take up a station at one of the wall forts.

In any event, 30 or 40 years later, toward the end of the third century, Vindolanda was reoccupied. The buildings of Vicus I were leveled and the rubble was packed with clay to provide the foundations for a second town. The new occupants' style of building was totally different. Instead of dressed masonry huge, irregular lumps of sandstone were used for foundations, and the structures they supported had walls of timber. One can only guess that the Romans had imported an entirely fresh levy of troops from some remote corner of Europe, together with their families and civilian followers, and that the new settlers built in their own traditional style. So far we have unearthed nothing that reveals the garrison's place of origin.

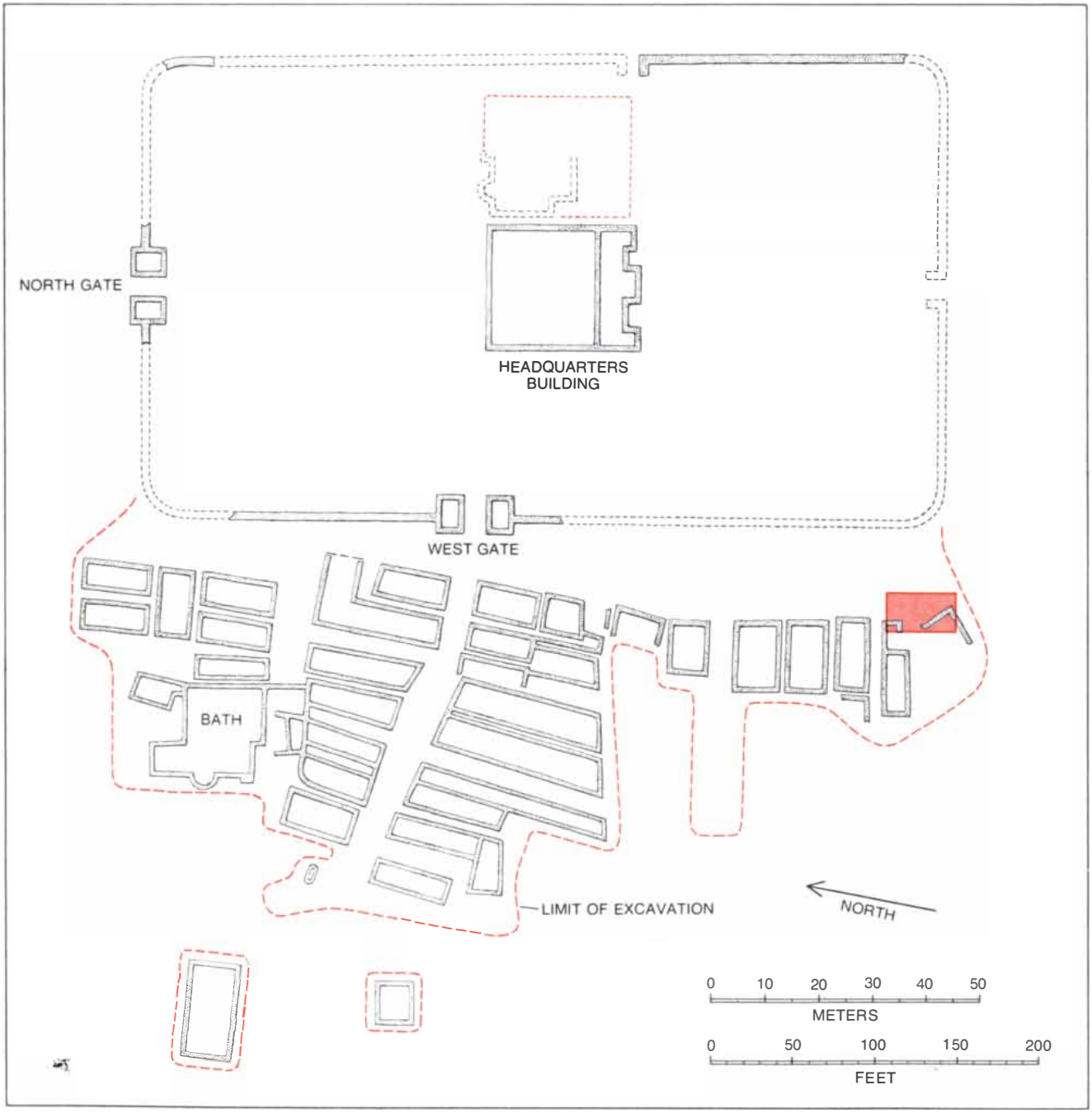
It is not only architecture that suggests a different identity for the inhabitants of Vicus II. Indoors we find workbenches, hearths, crucibles and accumulations of slag, indicating that most of the structures were workshops for the production of articles made of bronze and iron. Nothing of this kind has yet been discovered at Vicus I. It appears that for the first time the settlers were making use of the rich mineral deposits of Northumberland.

Compared with Vicus I, Vicus II is not only more industrial but also cruder. The few bronze articles we have come on are purely functional, the coin finds are few and window glass is entirely absent. Even so, Vicus II was larger than Vicus I and lasted for a much longer time. It is difficult at present to assign precise dates to the final occupation levels in Roman Britain, and so we cannot be certain that Vicus II was inhabited after A.D. 400. Whenever the end came, it was peaceful. The settlers seem to have left gradually rather than all at the same time.

Many scholars who are imbued with

the traditional view that the wall garrisons were exclusively military societies still regard the evidence of a civilian presence on the frontier as something of an irrelevance: an untidy, primitive adjunct to the regimented and efficient Roman army. Others, myself among them, hold the opposite view. Without its civilian "tail" the Roman army could scarcely have maintained its position on the frontier for more than three centuries. Some of the civilians were farmers; some were craftsmen, priests and slaves. The labors of all of them helped to provide the garrison's amenities. Still others were the soldiers' wives, daughters and sons. Without the civilian population the army would have been forced to do without much of its food, most of its manufactured articles and all of its diversions. Without the civilian males, most of them the sons of soldiers, the army would have been hard-pressed to fill its ranks with recruits when they were needed. Throughout the Roman world local recruitment to fill regimental vacancies had been the practice since the earliest days of the Empire. The resident civilians' greatest impact, however, must have been on army morale. At a frontier post in the Roman period the civilian and the soldier were not only equal in importance but also mutually supportive.

Our excavations in the civilian area of Vindolanda disrupted the existing system of field drains, so that in 1972 water accumulated in the southern part of the settlement after every rain. By late fall that year we were obliged to lay a modern drainpipe, leading from the



OVERALL PLAN OF VINDOLANDA as it appeared in the years after its reoccupation in A.D. 275 is based on the first few seasons' work at the site, beginning in 1970. The excavation effort has been concentrated on the civilian settlements outside the fort; the structures shown are those of Vicus II, the last Roman settlement. Rectangle (*color*) locates area where the contents of the earliest structures were found in a remarkable state of preservation. Much remains to be excavated; for example, the dashed extensions are conjectural.

heart of the settlement to a steep slope, in order to keep the excavation areas dry. We took great care in selecting a route for the pipe that would not interfere with any Roman works. Since we believed the Vicus buildings in this part of the site were standing on an undisturbed substrate of natural boulder clay, we hardly expected to gain any archaeological information while trenching through a sterile zone.

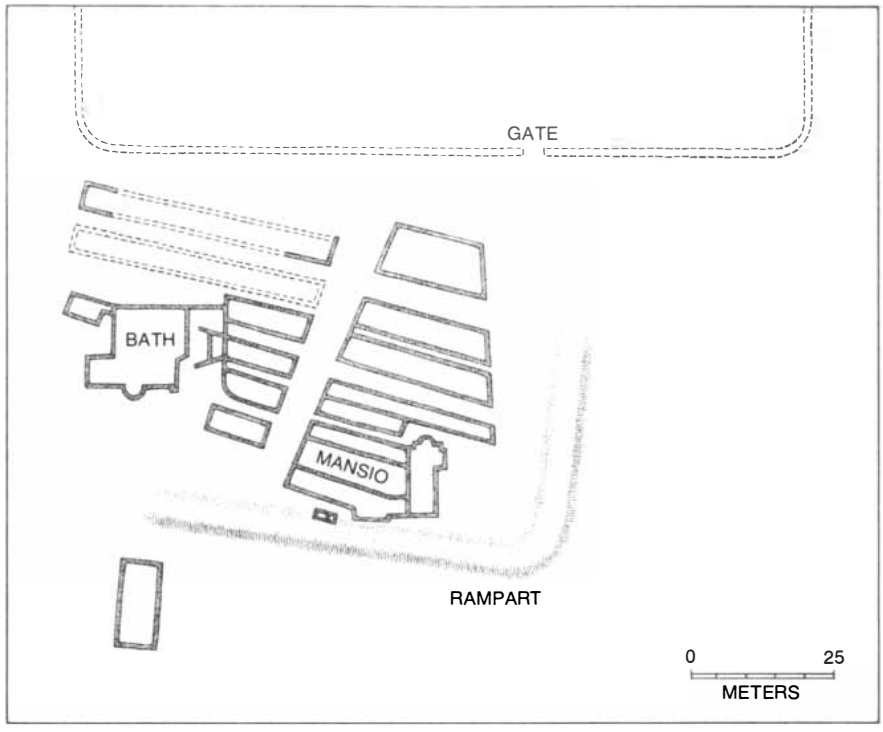
To the amazement of all concerned, after the excavators had cut through some 70 centimeters of clay they broke into an extraordinary deposit, nearly two meters deep and packed with the best-preserved organic material from Roman times ever seen by modern man. Several weeks passed before the full implication of the discovery became apparent, but by then we realized that we had accidentally encountered the superposed remains of five successive wood forts of the pre-Hadrianic period, dating from about A.D. 85 to 125–130, when the garrison of Vindolanda had left its Stanegate quarters to occupy one of the new wall forts.

The excavation of the organic deposit presented many difficulties. The water table at Vindolanda lies 115 to 130 centimeters below the modern turf line, and the bottom of the deposit was nearly four meters deeper. Water seeped continuously through the sides of our trenches and bubbled up from the floor; lest the sodden trenches collapse we had to emplace heavy timber shoring. To keep the trenches dry underfoot constant pumping was essential. Even so a thin film of liquid mud usually covered each level of the excavation.

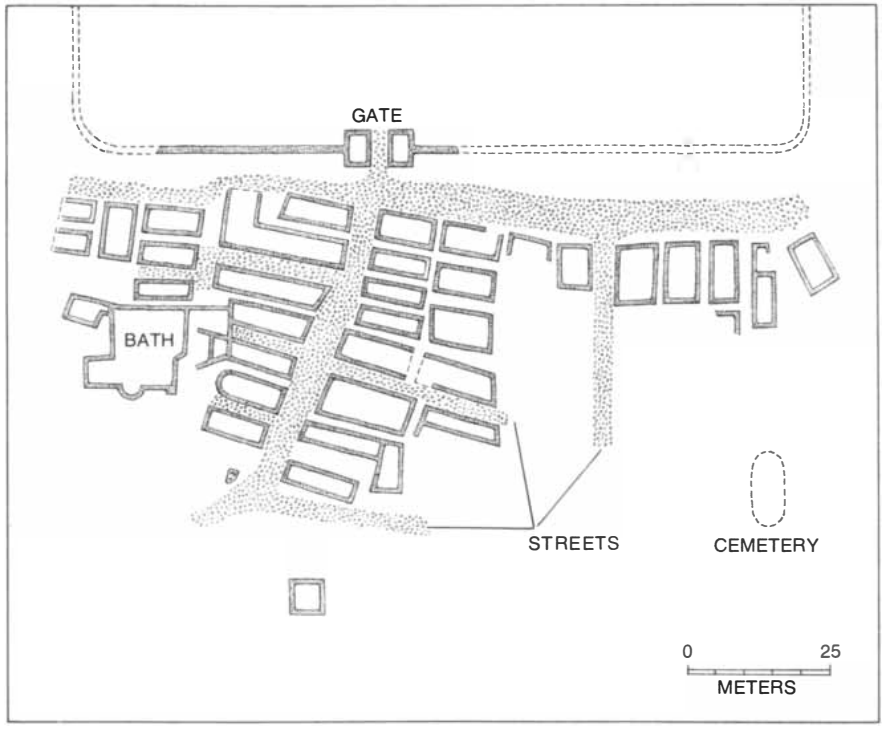
The greatest problem arose from the nature of the deposit. It consisted for the most part of successive layers of "Roman carpet": a flooring composed of twigs, coarse ferns, mosses and straw, compacted into a mass as much as 50 centimeters thick. The plant material was so well preserved that the compacted mass could not be taken apart with a trowel; we had to abandon normal procedures and cut up the flooring with sharp spades, much as one cuts peat, passing each square up to the surface where it could be peeled apart by hand.

In these layers of flooring the Romans had buried, accidentally and deliberately, much of the refuse of their daily lives. Some of the castoff material was of enormous archaeological interest, and its retrieval and preservation called for the greatest care. It was necessary to enlist the help of a large number of colleagues in the environmental sciences so that the most significant specimens could be quickly isolated and given laboratory protection, and we were fortunate in securing the cooperation of scholars from a dozen British and continental universities.

We identified five distinct occupation



VICUS I, the settlement built outside the west gate of Vindolanda in about A.D. 170, when the post was occupied by the Fourth Cohort of Gauls, included among its amenities a bathhouse (*left*) and a *mansio,* or rest house for official travelers (*center*). The long narrow structures nearby, some not yet fully excavated, were built on a foundation of dressed stone bound with lime mortar; they were divided into one-room accommodations, probably for soldiers' families. Smaller buildings may have housed the families of noncommissioned officers. Vicus I was built on clay fill overlying ruins of five pre-Hadrianic forts; only part of the earlier area has been excavated. Further digging, particularly to the south, is expected to expose additional structures.



VICUS II, the last civilian settlement at Vindolanda, also had a bathhouse. The site of the *mansio,* however, was occupied by a less ambitious structure. Construction standards were lower than those in Vicus I: the foundations were irregular lumps of sandstone, the walls were wood and window glass was not used. The presence of crucibles, slag, hearths and workbenches in many of the buildings indicates an emphasis on work in bronze and iron, utilizing the rich local mineral resources. The date when Vicus II was abandoned, perhaps about the close of the fourth century, is not precisely known, but the process seems to have been a peaceful one.

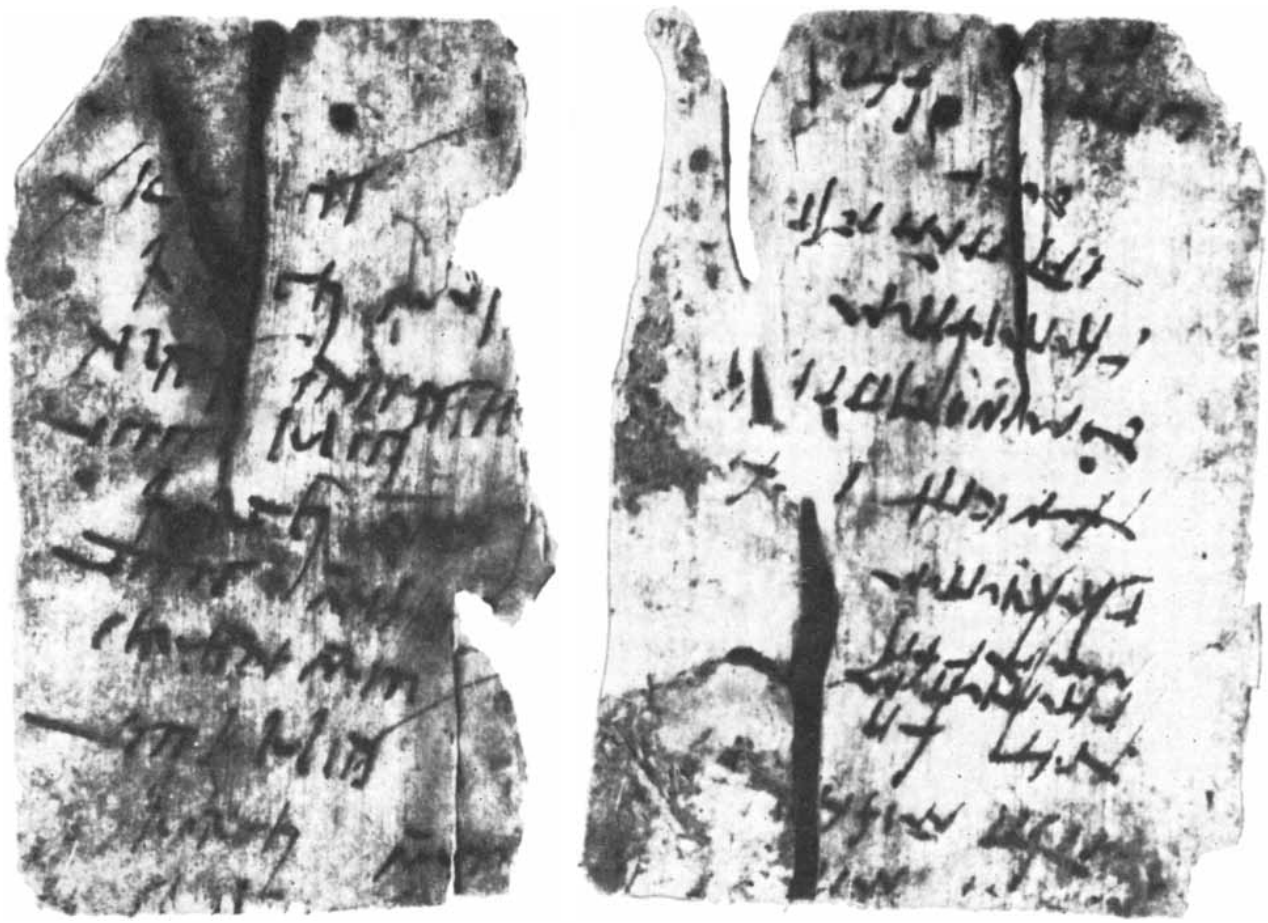
levels. It was in the earliest two that the most important concentrations of carpet were found. Here the flooring material was almost entirely coarse fern; the plants were present in such large quantities that they had themselves contributed to the special preservative qualities of the layers. The flooring was damp but not waterlogged, and it was quite devoid of oxygen; as a result everything was preserved in virtually its original state. Mosses were still green and leaves were yellow and brown; many of the ferns looked as if they had been cut only a few weeks before. Within minutes after excavation the colors disappeared as atmospheric oxygen reached the plant material and turned all of it a uniform black. This meant that when it was necessary to sketch some special feature or collect samples for analysis, one had to move quickly.

To judge from the flora, the climate of Vindolanda at the end of the first century was much like the climate of today. The same trees and shrubs were present, the only significant difference being that oaks were much more plentiful and pines were very scarce. We recovered numerous insect specimens in excellent condition from the flooring; an entomological analysis is awaited. Among the specimens were a great many pupal cases of the stable fly. Some of the cases contained fully formed flies that had failed to emerge.

The artifacts embedded in the flooring are as well preserved as the plant material. Stored for nearly two millenniums under acid-free and anaerobic conditions, objects made of iron and bronze remained uncorroded. We have retrieved a fine selection of hammers, knives, spearheads, catapult bolts, brooches, keys and coins. Well-preserved articles made of wood include barrel staves, bungs, hide-scrapers, spatulas and combs. Some of the combs still contained strands of hair. On analysis the hair proved to be from cattle rather than from human beings, indicating that the combs were tanners' tools.

Four other categories of particularly important material have now been established: animal remains, leatherwork, textiles and inscribed tablets. To summarize under each heading in order, animal bones appear in large quantities at all the levels. Most of them are from meat animals; beef seems to have been the most popular, followed in order by pork, venison and mutton. Fowl bones, mostly from chickens but a few from larger birds, are found in small numbers. There are no fishbones; they either were never present or were not preserved. There are, however, the shells of oysters and mussels. Some of the animal bones apparently represent tannery rubbish: skulls and foot bones of oxen, sheep, deer and horses, and a few bones from pigs and dogs.

Examples of leatherwork that have been preserved number in the thousands. The most unusual is a fine slipper made after a Persian design and stamped with the die of one Lucius Aebutius Thales, son of Titus and evidently a shoemaker of some repute. Other examples of footwear range from massive men's boots to children's shoes so small that their wearers were probably not old enough to walk. Three-fourths of the footwear are for women and children; not only the men's boots and shoes but also many of the women's and children's are heavily studded with iron nails. One surprise in the collection are wood slippers that scarcely differ in form from those sold under a famous



ROMAN DOCUMENT, one of more than 200 recovered from the earliest levels at Vindolanda, was written with pen and ink on paired wafer-thin slats of wood, each six by 10 centimeters in size, which were then placed face to face to protect the writing. The language is not orthodox Latin but a mixture of dialect and army slang, written phonetically. The documents translated so far include quartermaster records, military orders and private correspondence. Shown here is part of a stores ledger listing the rations issued in one summer week.

brand name today; these alone have built-up heels.

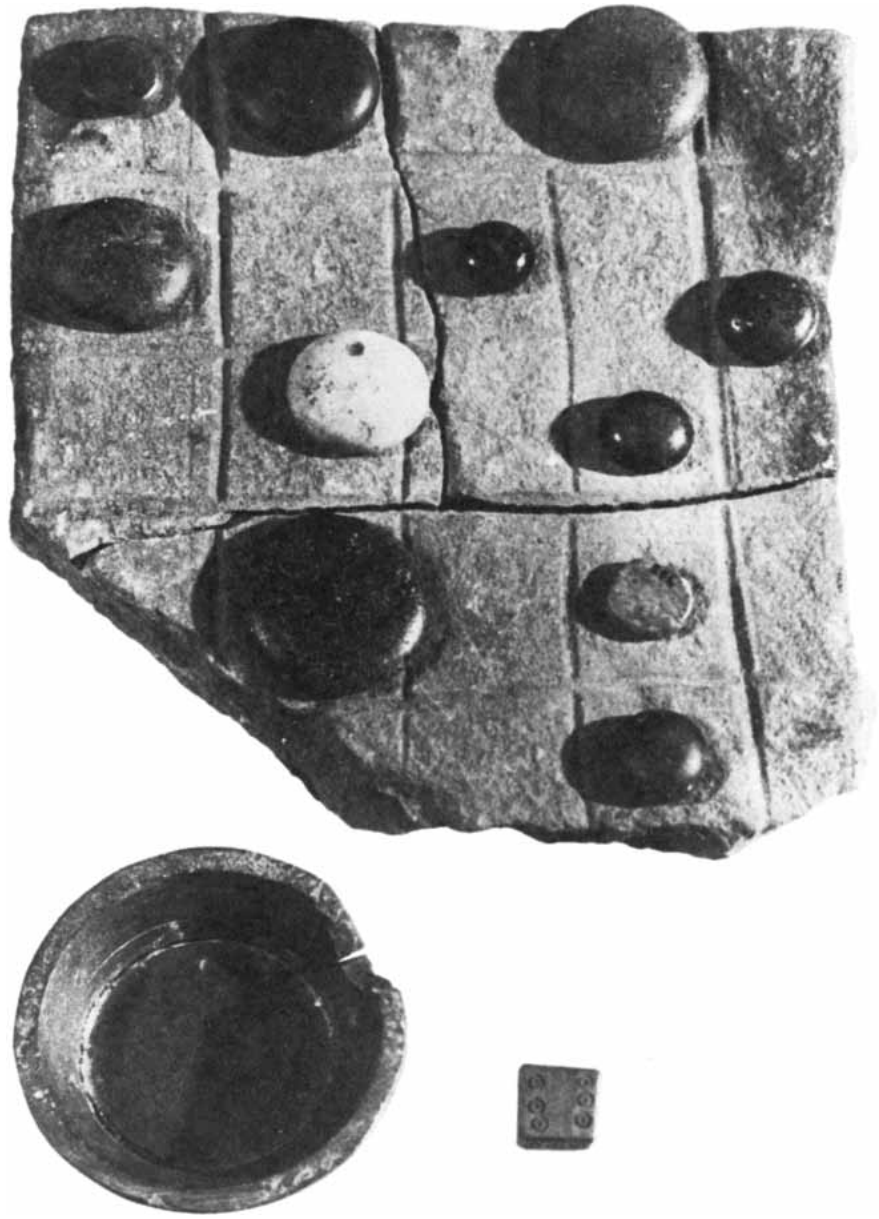
Other leather goods, most of them represented only by fragments, include bits of tenting, saddle cloths, harness, jerkins and perhaps leather trousers. Most of the leather was ox hide, although some deerskin and pigskin is present. The quality of the tanning was inconsistent, and much of it was not up to modern standards. Skinning was casual, dehairing was inefficient, tanning was too rapid and skins from diseased animals were evidently acceptable.

When we first came on these great quantities of leather, we thought we might have unearthed a leatherworker's shop. Our colleagues in the environmental sciences reported, however, that the flooring was saturated with urine and that feces, at least some of them human, were also present. This indicates not a shop but a tannery; such excreta are used in hide preparation to this day. Our revised interpretation has since been supported by the discovery of several wood half-moon hide-scrapers.

The flooring of the two lowest levels contained more than 100 fragments of woven wool; the majority of the specimens are almost perfectly preserved, and they range in size up to 200 square centimeters (about six inches square) and even more. The deposit represents the first substantial group of Roman textiles ever found in Britain, and it doubles the number of Roman textile specimens from all of western Europe. All the best-known Roman weaves are included, the quality ranging from coarse homespun to intricate first-class tweed. All the specimens appear to have been woven from the kinds of wool that would have been readily available along the frontier. Among the crafts of the period the textile industry was probably second in importance only to agriculture. Heretofore it has been virtually impossible to study the industry in Roman Britain because so few examples of its products have survived. The variety of Vindolanda textiles should provide a base for many further investigations.

The discovery of Roman documents at frontier posts is a rare event. Some have come from the sands of Egypt and others from the great Roman fortress in Syria, Dura Europos, but such finds have consisted mainly of fragments of papyrus and an occasional stylus tablet made of wax-covered wood. In western Europe papyrus, if it was ever used, would soon have rotted away. The wax has disappeared from the few stylus tablets that have been found; only if the scribe was heavy-handed enough to scratch the wood under the wax does something remain that can be read. At Vindolanda some stylus tablets have been uncovered, but the bulk of the Roman writings we have found are of a different form. They are smooth, wafer-

LEATHER SLIPPER, modeled after a Persian original, was one of hundreds of well-preserved leather articles that have been found in the earliest levels at Vindolanda. Most of the shoes and slippers were made for women and children; many of the children's shoes were in infant sizes.



FRONTIER PASTIMES are suggested by the recovery of articles such as these at Vindolanda. The broken gaming board is made out of stone, some of the counters are clay and some are pebbles, the dicebox is made out of clay and the die is bone. It is loaded in favor of sixes and ones.

thin slats of wood, some six by 10 centimeters in size, written on with a quill pen dipped in carbon ink.

The first slats were recovered from a mass of wood remains in the flooring of the second level from the bottom. A single slat first caught the excavators' eye and was put to one side. It seemed too small to be part of an artifact but too regular to be only a wood shaving; it also differed from the rest of the wood in looking rather slimy. Nothing was visible on its surface, and it was almost discarded. Soon afterward two more slats were found stuck together. When they were peeled apart, we could perceive a spidery handwriting in what appeared to be an unknown script. To our horror, after some 10 minutes' exposure to the air the writing faded away. We thought we had lost a priceless treasure, but then access to the photographic facilities at the medical school of the University of Newcastle upon Tyne showed that the ink was still visible at infrared and ultraviolet wavelengths.

Since then we have recovered more than 200 inscribed slats. Many are only fragmentary, and several show signs of fire; apparently a deliberate attempt was made at some time to incinerate old files and correspondence. Each new discovery goes first to Alison Rutherford of the University of Newcastle for photocopying. (Even when the writing is preserved, it shows up more clearly in photographs at nonvisual wavelengths than it does on the wood.) The photographs are then sent for interpretation to Alan Bowman of the University of Manchester and David Thomas of the University of Durham.

The handwriting on the slats is in a cursive script [*see illustration on page 44*]. Its interpretation has been a slow and painstaking task, because the writers were not setting down the orthodox language of Rome. What appears instead is a combination of dialect and army slang. To complicate matters further, everything is written phonetically. Nevertheless, work on nearly half of the slats has now been finished, and it seems that the documents fall into three categories: army stores lists (probably the quartermaster's records), official military correspondence and private letters.

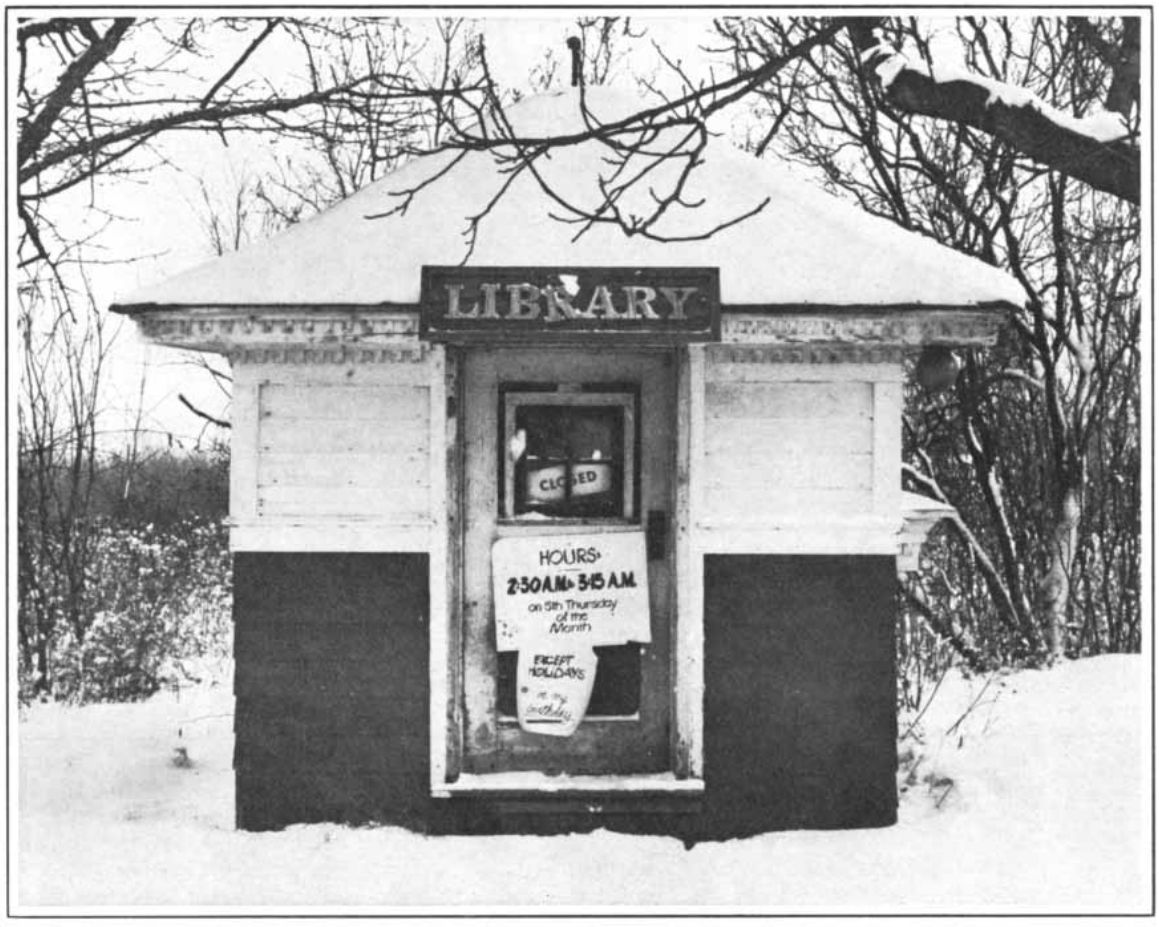
The stores lists are particularly illuminating on the standard of living in a frontier garrison. One series of lists records the commodities dispensed during a week in June. The year is not specified, but it was probably A.D. 101, 102 or 103. The meat issue included beef, mutton, pork, ham and venison. This documentary evidence, along with the many animal bones we have unearthed, should dispel the old myth that Roman soldiers were vegetarians. Salt, fish sauces and olive oil were also issued. For drink the soldiers received wine and what is referred to as Celtic beer.

As for the official correspondence, the addresses written on the back of several slats confirm that the post was indeed called Vindolanda in Roman times, and one fragmentary text provides a secure date for the deposit as a whole. It refers to one Neratius Marcellus, *vir clarissimus* (that is, most distinguished man); this must be the same Marcellus who governed Britain in about A.D. 101. The correspondence also names commanding officers, identifies units and gives details of troop movements.

The private correspondence will probably prove of greater value to paleographers and linguists than to historians. It nonetheless provides some homely details of army life to put flesh on the bare bones of archaeology. To give a single example, a letter accompanying a gift package to one of the troopers establishes the fact that even 1,900 years ago well-wishers sent socks to the lads in the service. The same gift package also included underpants (*subligaria*) and, what is more surprising in view of all the leatherworking that was being done locally, shoes.

The discovery of these written records is an event of major significance in the investigation of Britain's history. The period from A.D. 90 to 125 has been marked by a paucity of inscriptions and until now a total absence of literary records. There seems little doubt that many more of these unique documents will be found as the work continues at Vindolanda. We estimate that the pre-Hadrianic deposits probably occupy four acres of the 20-acre site. So far all our findings from this early period have come out of an excavation less than 10 square meters in size. It is not too much to say that when the excavations at Vindolanda are completed, it will be necessary to rewrite the history of the early Roman frontier in Britain.

OXYGEN-FREE DEPOSIT, covered by a layer of clay in about A.D. 170, yielded the almost perfectly preserved organic remains from the pre-Hadrianic period at Vindolanda. The deposit stratum visible in the foreground, some five meters below the surface, dates to about A.D. 90.



Easy way to run a library

If you let it grow and invite use, you create problems.

That became obvious in the 2nd century B.C. when the scholar Callimachus decided to catalog some of the more than 400,000 scrolls and codices in the pigeonholes (*nidi*) in the Great Library of Ptolemy II at Alexandria, with its hordes of slave librarians.

When that world was succeeded by the businesslike world of the Romans, record-keeping seemed so important that papyrus from the marshes of North Africa was worth carrying across the Mediterranean, the Alps, the Channel, and the length of today's England to the outposts on today's Scottish border in order that the written word and numeral stand guard against deceit and faulty memory.

The penchant for putting things down on paper brings the need later to find the right piece of paper. A librarian is the person to facilitate that for both the scholarly and the business-minded library users, and there has been a tendency to emancipate librarians from slavery. Where once they saw themselves as guardians of paper, many now claim that in a library big, active, and complete enough to serve for more than casual browsing and relief from tedium, more and more paper must go and be replaced with microforms.

"WHY?" bellow the users.

Answer: Retrievability to fit the need.

If all the literature or administrative records or whatever the library specializes in were microfilmed and the reels of microfilm were kept in old shoe boxes, it would save a lot of valuable space, but the users might be incensed enough to burn down the library, as Ptolemy's was (in 47 B.C. by Caesar, a practical man).

At the other extreme, the users might be quite pleased with a system which instantly reproduces full-sized hard copies of the ten most recent works on any question that can be expressed to a computer—pleased until the inevitable announcement that there is no money left for salaries.

Following are some retrieval techniques worthy of consideration in the light of an individual library's reason for existence, but if and only if they will serve the user quicker or better (or both) than paper will:

ROLL MICROFILM
- Flash Target Indexing
- Eyeball Coding
- Odometer Indexing
- Code Line Indexing
- Image Control Indexing
- Coding for KODAK MIRACODE and KODAK ORACLE Retrieval Equipment

MICROFICHE
- Title and Index
- Title and Index, Frame Eyeball Coding
- Column Eyeball Coding
- Automated Microfiche Retrieval

The best way to understand what these terms mean is to let an up-to-date, emancipated librarian explain them and their relative merits. Librarians who want to check on whether they are up-to-date may wish to request "Retrieval Techniques" from Kodak, Dept. 55W, Rochester, N.Y. 14650.

Kodak

SCIENCE AND THE CITIZEN

Ambiguities of Mars

The pause in the flood of data from the Viking landers on Mars, necessitated by the planet's going behind the sun late in November, gave investigators a chance to reflect on the results of observations from the two spacecraft, the first of which reached the Martian surface safely on July 20 of last year and the second on September 3. The lander of *Viking 1* touched down in the Chryse Basin, some 20 degrees north of the equator, a low region into which several ancient channels appear to have drained. The lander of *Viking 2* came down at Utopia Planitia, nearly 180 degrees away from the site of the first lander and about 28 degrees farther north. The Utopia region, part of the vast plains that occupy much of the northern hemisphere of Mars, is volcanic terrain. The Viking findings up to the time of the planet's conjunction with the sun are summarized in a series of papers in *Science*.

In spite of their geological dissimilarity the two landing sites look remarkably alike in pictures taken on the surface. Both boulder-strewn sites are red to orange in color; the sky above is pink. The bright rust color of the landscape is evidently caused by a thin coating of iron oxide (perhaps goethite or hematite) on surface rocks and particles. The analysis of the surface particles suggests that the main components are silicon oxide (SiO_3), 45 percent, and iron oxide (Fe_2O_3), 18 percent, together with 5 to 8 percent each of oxides of aluminum, calcium, magnesium and sulfur. The sulfur content is 10 to 100 times higher than that of typical terrestrial or lunar soils, and about the same as that of chondritic meteorites, which are thought to be representative of the primitive materials from which the inner planets were formed. All in all, the composition of the Martian soil is unlike that of any simple or abundant type of rock or soil found on the earth or the moon. It thus appears that Mars may not have become chemically differentiated as the earth and the moon have.

As was expected, the lander observations show that the Martian atmosphere contains 95 percent carbon dioxide and less than .5 percent oxygen. The finding of 2 or 3 percent nitrogen, however, lays to rest the hypothesis that the gas might be totally absent. The overall makeup of the atmosphere suggests that gases trapped in the interior of Mars have been released more slowly than gases in the earth. The weather at the two lander sites is described as "repetitious and mild." The daily temperature ranges from about −85 to −30 degrees Celsius (about −120 to −20 degrees Fahrenheit). Wind gusts up to 19 meters per second (42.5 miles per hour) have been recorded, too low to raise much dust.

The three experiments designed to detect life on Mars have yielded provocative but inconclusive results. The most general of the three experiments, the gas-exchange experiment, measures long-term compositional changes in the gas above a soil sample following addition of an aqueous nutrient medium. The samples have given off substantial quantities of carbon dioxide and oxygen and smaller amounts of nitrogen. Although it is possible that the carbon dioxide is produced by a biological oxidation process, inorganic production of the gas seems much more likely.

The carbon-assimilation, or pyrolytic-release, experiment measures the capacity of the Martian soil to convert carbon monoxide or carbon dioxide, labeled with the radioactive isotope carbon 14, into organic matter. The soil sample is placed in a test chamber containing an atmosphere of the two labeled gases and is exposed to simulated Martian sunlight, that is, light rich in ultraviolet. After 120 hours the atmosphere is removed from the chamber and the soil is heated to 625 degrees C. to volatilize any organic compounds that may have been formed. The volatile products, together with the unreacted carbon monoxide and carbon dioxide, are transferred to a column that separates them into two fractions: peak 1, which contains carbon monoxide, carbon dioxide and methane (CH_4), and peak 2, which contains any organic molecular fragments larger than methane. Thus the radioactivity of peak 2 would represent carbon compounds synthesized in the Martian soil. Three samples at the first landing site, Chryse, gave significantly high counts for peak 2. A fourth sample, which got 10 degrees hotter than was intended during incubation (26 degrees C. instead of 15 to 17 degrees), showed a weakly positive peak 2. A control sample of Chryse soil, sterilized by heat before the start of incubation, showed no significant counts in peak 2.

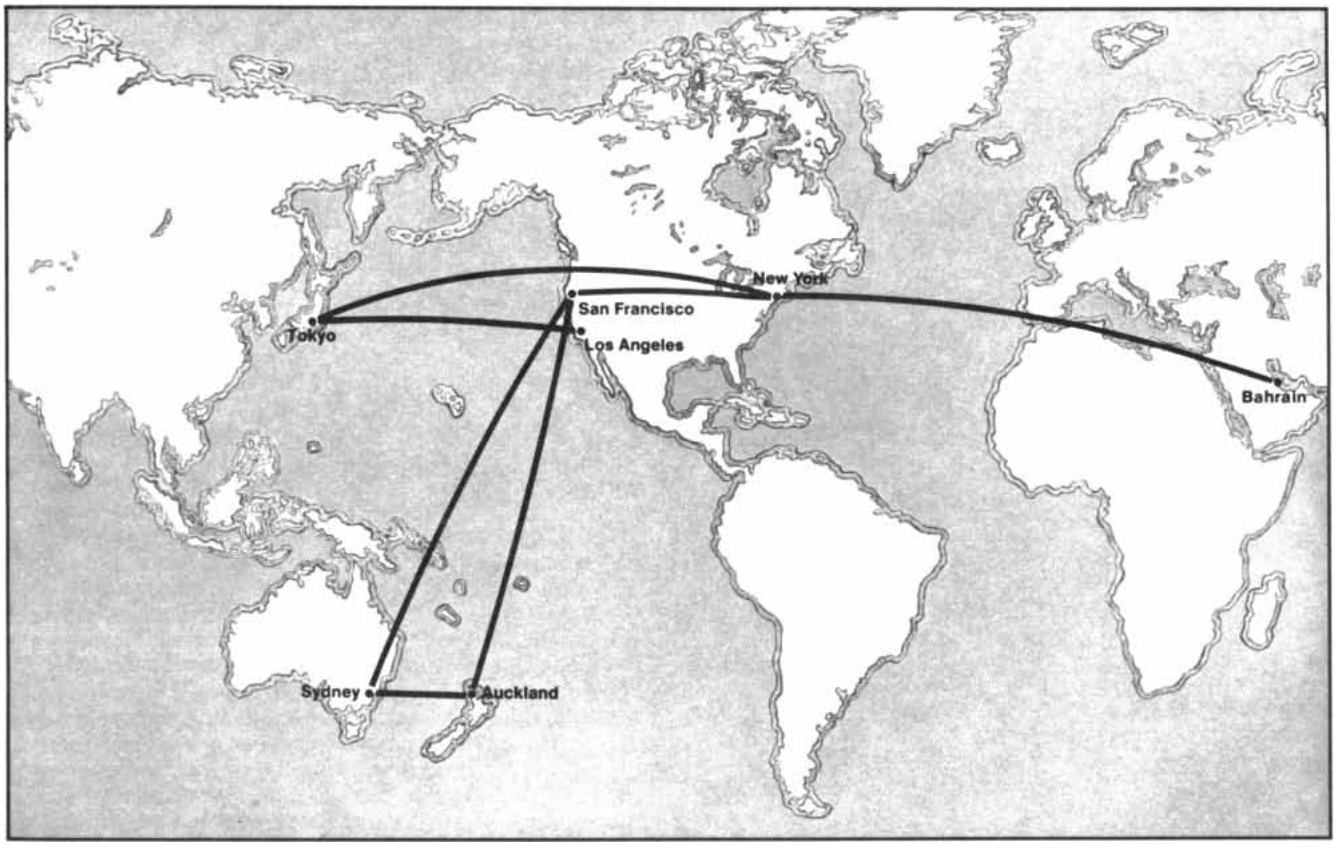
Three samples were tested at the Utopia site. One, incubated in the dark, gave a weakly positive result. A second, incubated under light but with water vapor added to the experimental atmosphere, gave a distinctly negative result. A third sample, taken from under a rock, was also incubated in the dark and gave a negative result. The investigators conclude "that an organic synthesis from atmospheric CO or CO_2 occurs in the Martian surface material. The synthesis is weak compared with that found in biologically active terrestrial soils and, unlike the latter, is inhibited by small amounts of water. It resembles a biological reaction in being thermolabile, although there is room for doubt that the synthesis was completely abolished in the Chryse [sterilized] sample."

The third test for Martian life, the labeled-release experiment, seeks to detect the presence of metabolism, with or without growth, by monitoring the evolution of gas containing carbon 14 from a soil sample to which has been added a nutrient containing seven organic substrates (formate, glycolate, glycine, *D*-alanine, *L*-alanine, *D*-lactate and *L*-lactate) labeled with carbon 14. The total oxidation of the carbon at any one of 17 labeled molecular positions would result in a gas yielding about 15,000 carbon-14 counts per minute. Two tests with active soil and one with heat-sterilized soil have now been conducted at each landing site. The four tests with active soil all released gas giving 10,000 to 15,000 counts per minute. The two tests with sterilized soil (heated to 160 degrees C. in one test and to 50 degrees in another) showed little or no activity above the background levels in the released gas. The investigators note that the results could be produced by inorganic substances in the Martian soil that had been activated by exposure to ultraviolet radiation. "As yet, however, no chemical experiment has quantitatively reproduced the [labeled-release] Mars data. Thus... the distinct possibility remains that biological activity has been observed on Mars."

A fourth experiment, not designed explicitly as part of the search for life, has probably had the most to do with making the investigators cautious in interpreting the three biology experiments. This is the experiment in which soil samples are analyzed by a combination of gas chromatography and mass spectrometry. The GCMS experiment, as it is called, can detect organic compounds present in a few parts per billion. Surprisingly, no organic compounds of any kind have been found in the Martian samples. Only water, carbon dioxide and traces of known terrestrial contaminants have been detected. One would expect Martian organisms, if they exist, to leave behind a measurable debris of organic matter. In a sample of soil from the earth's Antarctic, for example, believed to contain fewer than 10,000 microorganisms per gram, more than 20 organic compounds were found in concentrations ranging from one part per million to one part per 100 million.

Various explanations have been proposed for the absence of organic compounds in the Martian soil. If the soil

Pan Am's got the longest legs in the business.



While they may not reach directly to your front door, no matter where you live in the U.S. you can benefit from Pan Am's new long distance flights. Just catch a domestic flight to one of our gateway cities.

From New York you can fly non-stop to Bahrain (a 6,601 mile leg) and to Tokyo (a 6,754 mile leg). New Zealand is only one stop away, then on to Sydney. Returning from Sydney, you're still only one stop away from New York. (The stop in both directions is San Francisco.)

From San Francisco you can fly non-stop to New Zealand, then on to Sydney, and non-stop back from either country. (San Francisco to Auckland, a 6,754 mile leg. Sydney to San Francisco, a 7,400 mile leg, is the longest scheduled non-stop flight in commercial aviation history.)

From downtown Los Angeles, you're only a non-stop away from Tokyo. (That's a 5,478 mile leg.)

All these flights are made possible by our long-range 747 SPs. Besides the SP, Pan Am has the world's largest fleet of 747s and serves 91 cities in 61 countries, on 6 continents.

And you'll get all the comforts Pan Am passengers can take for granted. Choice of meals, choice of movies, and plenty of room to live in.

You might even find that when it comes to flying long distances, our competition hasn't got a leg to stand on.

PAN AM

America's airline to the world.

See your travel agent.

Wanted: Innovations In the Drug, Personal Care And Toiletries Field

Are you an inventor in search of a licensee? Or, does your company own a technology that you'd like to sell, license, sub-license or otherwise make money on?

In either case, you should know about a search, now under way, for new inventions and developments in the drug, personal care and toiletries field. Wanted are:

- New end-products
- New processes
- New compositions
- New dispensing systems
- New packaging innovations

The search is being conducted by Product Resources International, Inc., as a service for a group of top U.S. manufacturers of drug, personal care and toiletries items.

These companies have subscribed to the search for two reasons. It can give them a wider choice of new products to market. It can give them ways to improve existing brands.

The report on the search, published in book form, is scheduled for delivery to the companies in mid-1977. The companies will then contact directly the owners of innovations that interest them.

There is no charge to you, now or ever, for items included in the book, which will be entitled "The Product Innovation Source Book". You may submit as many items as you wish, but only those will be published that PRI judges to be novel, useful and feasible.

For full details, including the correct submission procedure, write to "Editor, Source Book" at the address below. Please do *not* include any disclosures with your letter, except, if you wish, issued patents. To protect the interests of all parties, disclosures, when made, will be on a non-confidential basis.

PRODUCT RESOURCES INTERNATIONAL, INC.
P.O. Box 1931
Grand Central Station
New York, N.Y. 10017

contained no more than, say, 1,000 microorganisms per gram, their constituents would escape detection in the GCMS experiment. Moreover, dead organisms might not accumulate to detectable levels if they were highly biodegradable in the Martian environment of strong ultraviolet radiation combined with metal-oxide catalysts in the soil. A new series of experiments, now under way at Chryse and Utopia, may yet resolve the ambiguities.

Computer Privacy

In the Privacy Act of 1974, which dealt mainly with the right of individuals to obtain information about the data on themselves stored in Government files, Congress also stipulated that the Federal agencies with such data must act to prevent the misuse of it. Since large and increasing amounts of the data are stored in computers, the agencies are having to take steps to ensure the security of their computers. To this end the National Bureau of Standards is issuing this month two documents: a guideline for controlling access to computer networks and a standard that agencies must observe if they want to protect computer data by cryptographic techniques.

The problem of controlling access to computers arises particularly with the many computers that can be operated by terminals in remote locations and that deal with a number of people on a shared-time basis. It is necessary to ascertain that a person undertaking to use the computer has the right to do so and is the person he says he is; it is also necessary that his access to the computer be limited to the parts of its memory and programs that are his business. These are the objectives that the "Guideline on Evaluation of Techniques for Automated Personal Identification" being issued by the National Bureau of Standards seeks to achieve.

According to the guideline, the "three basic methods of establishing identity" are by means of something the prospective user knows, something he possesses or something about him. The first category includes such information as a password, the combination to a lock and facts about the person's life (his birthday, for example). The second category includes a badge, a pass and a card that can be read by the computer. The third category includes such personal characteristics as the user's face, voice and fingerprints.

Everything in the first two categories can be compromised, the guideline says, in that they can be lost, stolen or yielded to an unauthorized person under duress. In the third category the main problem is obtaining repeatable results. For example, an identification system employing "voiceprints" is likely to reject an authorized user who is under stress or has a cold, and a system employing fingerprints is likely to fail if the user presses his finger on the identifying device too hard or too lightly. A promising approach, according to the guideline, is a system that senses the dynamic motions a person makes while signing his name. "These motions are highly characteristic of the individual and would be extremely difficult for an impostor to perceive or duplicate. It appears that sufficient information for the identification process can be obtained by extracting a few hundred data samples during the signing process, which typically takes four to five seconds."

The second document being issued by the National Bureau of Standards is a "data-encryption standard." It specifies a mathematical algorithm whereby binary-coded information that is stored in a computer or transmitted between a computer and a user can be cast in an unintelligible form and then, at the appropriate time and for an authorized user, restored to intelligibility. The objective of the algorithm is to provide "adequate protection" of the stored or transmitted information "from theft and misuse."

Internal Opiates

Morphine is the parent of a large family of analgesic (pain-killing) drugs known collectively as opiates. In 1973 Solomon H. Snyder and Candace B. Pert of the Johns Hopkins University School of Medicine showed that opiates produce their pharmacological effects by acting on receptors, or highly specific sites, in the brain. Since morphine is not normally present in the body, and since the receptors are presumably serving some natural function, this discovery prompted a search for an internal morphinelike substance that might normally occupy the receptor sites. The results have exceeded all expectations: not one compound but four, having both opiatelike analgesic activity and a high affinity for the opiate receptor, have been isolated from the brain and the pituitary.

The first morphinelike substances were discovered by John Hughes and Hans W. Kosterlitz of the University of Aberdeen, and independently by Rabi Simantov and Snyder at Johns Hopkins, after both groups observed that extracts of brain tissue could mimic the action of opiates in pharmacological tests. The Scottish and American investigators subsequently purified the active factor and found that it was a mixture of two short peptide chains. Both peptides are made up of five amino acid units that are identical in sequence except for the terminal amino acid. Termed enkephalins, from the Greek for "in the head," these peptides appear to behave like neurotransmitters: they are concentrated in the terminal fibers of certain nerve cells

Experience the excitement of owning the finest *personal* computer – IMSAI 8080

Waiting for you – all the incredible performance and power of the IMSAI 8080. And at a price you would normally pay for a home music system: $699 in kit; $931 assembled.

WORLD OF USES

The IMSAI 8080 is a superbly engineered, quality computer. It is versatile, expandable and powerful, putting literally hundreds of applications and uses at your fingertips. Imagine sitting at your desk and enjoying interaction with your IMSAI 8080! Press the *on* switch and you're ready for game playing, research, education, business applications, or for laboratory instrument control. It has all the power you need, and more, to make your application ideas come alive.

GROWS WITH YOU

The IMSAI 8080 is designed for many years of pleasure. With its open-chassis engineering you can expand your system by adding peripherals and interfaces. The 22-slots and 28 amp power supply mean that you can plug-in today's, plus *tomorrow's* modules.

Right now you can add a module for displaying color graphics and characters on TV; a ready-to-use keyboard; small and large printers, and a single interface that lets you attach multiple devices including a cassette tape recorder. Expect the latest, exciting equipment from IMSAI. We are committed to leadership in this expanding technology.

EASY TO PROGRAM

With our BASIC language you can operate the IMSAI 8080 quickly and easily. Technically knowledgeable? Use our assembly language to develop sophisticated and unique software.

If you're thinking personal computer, treat yourself to the very best – IMSAI 8080

Send for free four-color brochure or $1 for catalog. Call or write for name of nearest dealer.

IMSAI

IMSAI Manufacturing Corporation
14860 Wicks Blvd
San Leandro, CA 94577
(415) 483-2093
TWX 910-366 7287

European Distributor
Harper Industry Products, Ltd
6079 Sprendlingen 2
West Germany

Prices: USA Domestic

"You can't tell a customer we're short of No-nox because of a foggy day in the Azores."

"That doesn't sound like much of a problem, does it?" says Operations Planning Supervisor Wayne Broussard. "A tanker delayed by fog.

"But for any refinery—even one as modern as Gulf's Alliance Refinery—a constant crude oil supply is essential. To meet customer demand for gasoline and fuel oil, it's necessary to have 200,000 barrels per day of crude oil supply.

Uninterrupted supply

"So even if a ship's held up only a few hours, you may be short several hundred thousand barrels of crude. The whole process depends on an uninterrupted supply. So you have to talk to the transportation and supply people to make other arrangements for crude oil delivery.

"And to make sure we meet product quality specifications, you have to refine different crudes or crude mixtures in different ways. That means changing process operations and product blends.

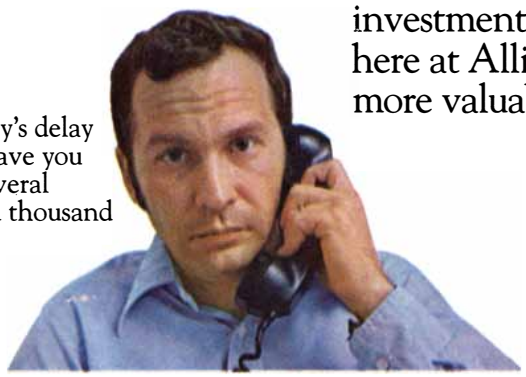
People vs the elements

"There's an enormous investment in hardware here at Alliance, but even more valuable are the people who make it all happen. Bad weather is just one of the challenges our people meet. But every day, all year long, we maintain the crude supply to produce 200,000 barrels of products.

"It's a real challenge—but that's the job: meeting the challenge, and doing it right."

Gulf

Gulf people: meeting the challenge.



"One day's delay could leave you short several hundred thousand barrels."

"You have to refine different crudes different ways to get the same product."

Gulf Oil Corporation

Lancia

The Lancia Coupe. Superbly designed. Incredibly agile. Everything you'd expect in a grand touring car that grew out of 70 years of international racing and car building experience. A test drive will confirm its high standards of engineering, performance, styling, comfort. Lancia. The intelligent alternative to the average and the overpriced automobile.

LANCIA

The intelligent alternative.

Lancia Scorpion, HPE Estate Wagon, Coupe, Sedan. Now at your nearest Lancia dealer. Call toll free (800) 447-4700 or in Illinois (800) 322-4400.

in the brain and spinal cord and inhibit the firing rate of other cells, apparently by modifying the permeability of the target-cell membrane to sodium ions. Enkephalins are degraded rapidly by protein-cleaving enzymes, so that it is difficult to evaluate their analgesic potential when they are injected into animals intravenously or even injected directly into the brain. With enkephalin analogues that resist metabolic breakdown, however, it has been possible to show that enkephalins have an analgesic potency similar to that of morphine.

The correlation between the distribution of enkephalins and the major brain pathways involved in the perception of chronic pain and its associated emotional states has suggested that the enkephalins might be involved in a natural pain-inhibiting system. Opiate drugs might thus exert their effects simply by filling normally unoccupied enkephalin receptors, potentiating the analgesic and euphoric effects of the enkephalin system. One can speculate that regular administration of opiates would overstimulate this system and perhaps cause it to compensate biochemically, thereby giving rise to the symptoms of addiction.

The interest of many investigators shifted to the pituitary gland when it was realized that the amino acid sequence of one of the enkephalins was identical with a short segment of the pituitary hormone beta-lipotropin, which stimulates the metabolism of fat. Choh Hao Li of the University of California at Berkeley subsequently found that a fragment of beta-lipotropin 31 amino acid units long possessed a high degree of analgesic activity. Designated beta-endorphin, for "endogenous morphine," it was 48 times more potent than morphine when injected directly into the brain and three times more potent when injected intravenously. Roger Guillemin of the Salk Institute also isolated a pituitary peptide with analgesic effects. Designated alpha-endorphin, it was 16 amino acid units long.

The relation between beta-lipotropin, the pituitary endorphins and the brain enkephalins is still obscure. Since biologically active peptides are usually synthesized by being cleaved from larger precursor peptides, it is conceivable that beta-lipotropin or some partial sequence of it could serve in the brain as the precursor to the enkephalins. This seems unlikely, because both beta-lipotropin and the endorphins are abundant in the pituitary but scarce in the brain, whereas the enkephalins are abundant in the brain and spinal cord but scarce in the pituitary. Since the analgesic and euphoric effects of opiates are clearly mediated in the brain and spinal cord and not in the pituitary, the analgesic effects of the endorphins are most likely unrelated to their normal actions. They probably serve as hormones that have so

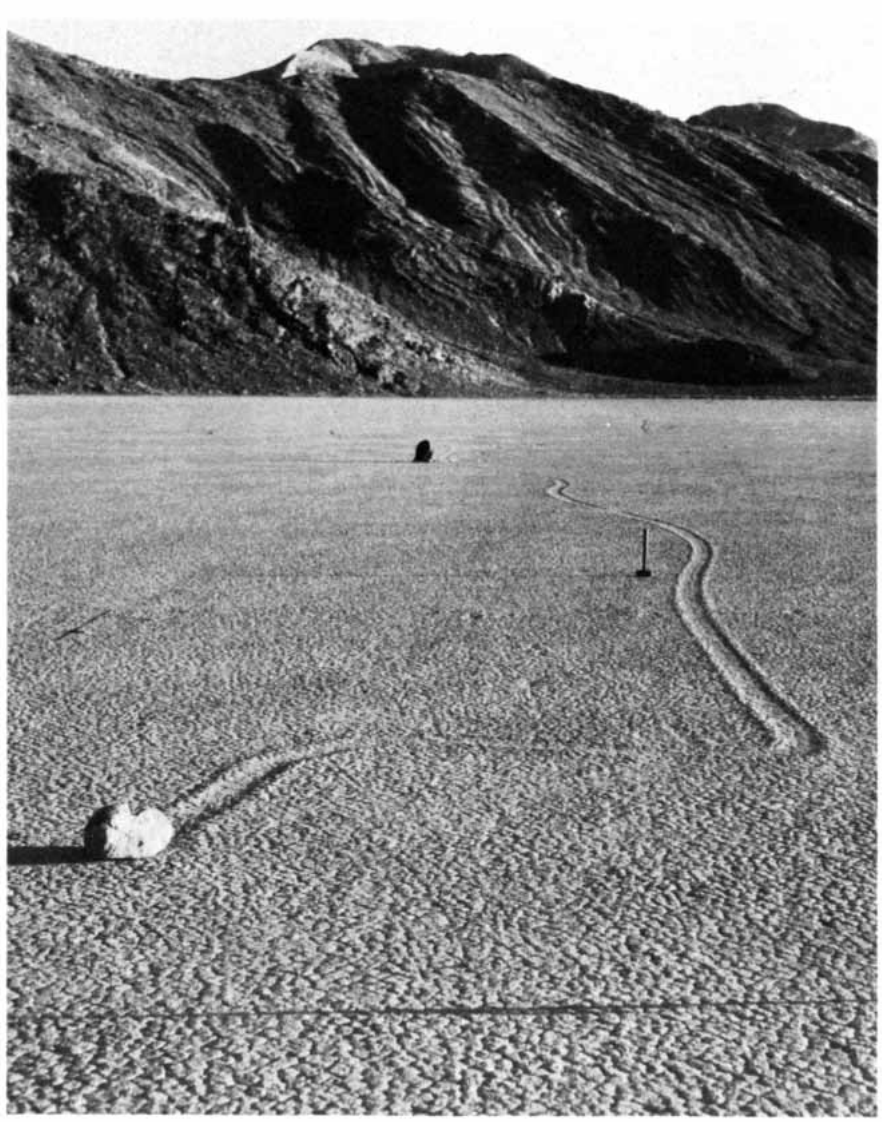
far unidentified effects on other target organs.

The pain-relieving power of the opiatelike peptides has given rise to hopes that appropriate analogues might be the long-sought nonaddictive analgesic drugs. Here there has been an unexpected problem: when rats are regularly treated with enkephalins or endorphins, they develop many of the symptoms of opiate addiction. Nevertheless, if the addiction produced by the opiatelike peptides turns out to be qualitatively milder than that produced by opiate drugs, then enkephalin analogues may still hold promise as ideal analgesics, possessing the beneficial properties of morphine but lacking its dangers.

Whatdunit

A small but fascinating geological mystery has been the cause of the spontaneous movement of stones on at least nine normally dry lake beds in California and Nevada. Stones ranging in weight from less than a pound to more than a third of a ton have been found resting at the end of tracks several hundreds of feet long. Intrigued by the mystery and dissatisfied with the hypothesis that the stones may have been transported in winter by a moving sheet of ice, Robert P. Sharp of the California Institute of Technology and Dwight L. Carey of the University of California at Los Angeles have monitored the positions of 30 stones at Racetrack Playa in Death Valley National Monument in California over a period of seven years. From their observations they have found the culprit.

Sharp and Carey recount their detective work in a recent issue of *Geological Society of America Bulletin*. Each stone they chose had made a prominent track. First they labeled the stones, identifying each with a letter and a name: *A* (Mary Ann), *B* (Ruth) and so on. With the exception of one unusually large (320-kilogram) boulder designated *J* (Karen), the monitored stones ranged in weight



Stone* R *(Hortense) rests at end of track made by sliding 820 feet across Racetrack Playa in 1970

After people learn what we've done, no one will heckle our speakers.

We're as close to the impossible as possible.

Our new speakers color sound.

Anybody's do.

Should they tell you otherwise, they speak with forked frequency response.

We at Sony developed the SSU-2000 with this grim reality in mind.

Our goal was to create a line of speakers with a minimum of coloration. With a frequency response flat and wide. With low distortion. And with repeatability. Which means each speaker we make will sound like the one before and the one after.

Searching and researching.

Before you can make a good speaker you have to make a lot of bad ones.

We turned out dozens of prototypes that were made with the same specs, but sound like they weren't.

That's because your ear is more sophisticated than our measurements.

You can hear how pure water is, for example.

The purity of the water in which the pulp for the speaker cone is pressed influences the sound.

But it would hardly change the frequency response—or any other measurements.

Now there are dozens and dozens of elements that interact this way.

Changing one changes the other and almost changed our minds about going into the speaker business.

But we stuck it out. Applying the age-old technique of trial and error.

That's why we labored for three years to bring you our speakers. While other manufacturers rushed frantically to market with theirs.

We keep the whole world in our hands.

Understanding how to control the sound of our speakers, we realized we had to control what went into them.

So we did the only logical thing.

We built a plant. Which does nothing but produce—under outrageously close control—the components for our speakers.

Few companies watch what you hear so carefully.

Don't judge a bookshelf speaker by its cover.

As you can see, a lot goes into producing a speaker that's not easily seen. (One beautiful exception—the handsome finish on our cabinets.)

Suggested retail prices: SSU-2000 $150 each; SSU-1250 $100 each; SSU-1050 $130 a pair.

That includes the carbon fiber we mix into the speaker cone paper.

Carbon fiber is light and strong. Light, so our speaker needs less power to operate it, and is therefore more efficient.

Strong, so the cone won't bend out of shape in the high frequency range.

Moreover, carbon fiber won't resonate much. It has a low Q, and it took someone with a high IQ to realize it would absorb the unwanted vibration.

Unwanted vibration is also reduced by our cast aluminum basket, which is superior to a cheap stamped metal one.

We're confident that the results of our three year effort will be clear after three minutes of listening.

At which point, far from heckling our speakers, you'll be tempted to give them a standing ovation.

SONY®

from 170 grams to 25.4 kilograms. Sharp and Carey marked the position of each stone by a metal stake; in several instances they surrounded a stone with seven metal stakes driven into the dry lake bed, forming a corral 168 centimeters across but leaving enough space between the stakes for the stone to move out of the corral if it was so inclined. The purpose of the corral was to test the possible role of ice in moving the stones. "A sheet of ice from the outside would have trouble getting to the stones," they reasoned, "and any *in situ* ice incorporating the stones would be anchored down by the stakes or would become too badly fragmented to hold the stones if moved."

Over the seven-year period 28 of the 30 monitored stones slid away from their stakes across Racetrack Playa, leaving distinct tracks. They moved mainly during the winters of 1968–1969, 1972–1973 and 1973–1974. Some stones moved in all three episodes, some moved in only one or two and a few moved on other occasions. Generally the stones traveled in a net north-northeasterly direction, and the tracks 10 of them left were at least 60 meters long. The greatest distance covered in one episode was 201 meters, a record held by stone *H* (Nancy), a 250-gram cobble of syenite. From the nature of the tracks Sharp and Carey estimate that the stones move at a remarkably good clip: between .5 and one meter per second.

Sharp and Carey have not found any authenticated record of someone actually seeing a stone move on Racetrack Playa or any other dry lake bed. ("Some immutable law of nature probably prescribes that movements occur in the darkness of stormy moonless nights, so that even a resident observer would see newly made tracks only in the dawn of a new day.") Nevertheless, they conclude that the stones are individually skidded and rolled across the wetted surface of the playa by the wind. For the wind to be able to push the stones the playa need be wetted only to the extent that a thin layer of slippery water-saturated mud overlies a still-firm base, a condition that is usually attained within an hour or two after water gathers on the surface. Most of the stones seem to have moved only long enough after flooding for the finest clay in the water to have settled out of suspension. These fine particles seem to be an important factor in the lubrication of the surface. Powerful gusts of wind are needed to dislodge the stones from their resting place, but once they are under way they literally sail across the surface. "It is concluded," Sharp and Carey state in resting their case, "that wind moves the stones when conditions are just right, that this normally happens at least every one to three years on Racetrack Playa, and that ice sheets are not required."

Unique full-function 8-digit wrist calculator... available only as a kit.

A wrist calculator is the ultimate in common-sense portable calculating power. Even a pocket calculator goes where your pocket goes—take your jacket off, and you're lost!

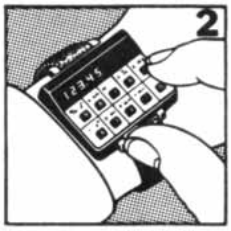
But a wrist-calculator is only worth having if it offers a genuinely comprehensive range of functions, with a full-size 8-digit display.

This one does. What's more, because it *is* a kit, supplied *direct* from the manufacturer, it costs only a very reasonable $19.95. And for that, you get not only a high-calibre calculator, but the fascination of building it yourself.

How to make 10 keys dothe work of 27

The Sinclair Instrument wrist calculator offers the full range of arithmetic functions. It uses normal algebraic logic ('enter it as you write it'). But in addition, it offers a % key; plus the convenience functions $\sqrt{x}$, $1/x$, x^2; plus a full *5-function* memory.

All this, from just 10 keys! The secret? An ingenious, simple three-position switch. It works like this.



1. The switch in its normal, central position. With the switch centered, numbers—which make up the vast majority of key-strokes—are tapped in the normal way.

2. Hold the switch to the left to use the functions to the left above the keys...

3. and hold it to the right to use the functions to the right above the keys.

The display uses 8 full-size red LED digits, and the calculator runs on readily-available hearing-aid batteries to give weeks of normal use.

Assembling the Sinclair Instrument wrist calculator

The wrist calculator kit comes to you complete and ready for assembly. All you need is a reasonable degree of skill with a fine-point soldering iron. It takes about three hours to assemble. If anything goes wrong, Sinclair Instrument will replace any damaged components free: we want you to enjoy assembling the kit, and to end up with a valuable and useful calculator.

Contents

Case and display window.
Strap.
Printed circuit board.
Switches.
Special direct-drive chip (no interface chip needed).
Display.
Batteries.

Everything is packaged in a neat plastic box, and accompanied by full instructions. The only thing you need is a fine-point soldering iron.

All components are fully guaranteed, and any which are damaged during assembly will be replaced free.

The wrist-calculator kit is available only direct from Sinclair Instrument. Take advantage of this 10 day money-back offer.

Send the coupon today.

Sinclair Instruments Inc.
6 Commercial Street
Hicksville, N.Y. 11801

To: Sinclair Instruments Inc.
6 Commercial Street
Hicksville, NY 11801

Please send me

_____ Sinclair wrist calculator kit(s) at $19.95 $_____

Sales tax (NY residents) _____

Shipping & handling ($2.50 per unit) _____

Enclosed is check/MO (payable to Sinclair Instruments Inc.) TOTAL $_____

Name _____

Address _____

City _____

State _____ Zip _____

I understand that you will refund the purchase price of the kit in full if I return it in saleable conditiion within 10 days of receipt.

Global Satellite Communications

A 12-year-old system provides more than 400 microwave pathways to 80 countries. Its eight satellites stationed over three oceans now account for some two-thirds of all transoceanic communications

by Burton I. Edelson

In the dozen years since the launching of *Early Bird,* the world's first commercial communications satellite, the exploitation of space for communications purposes has grown from one small satellite with a capacity of 240 two-way telephone circuits to an integrated network in which eight satellites in orbit furnish a combined capacity of some 40,000 circuits to six continents. In 1976 the International Telecommunications Satellite Organization (Intelsat), a group of 95 nations that operates the network, had revenues of more than $140 million. Full-time telephone, telegraph and data-transmission services account for 86 percent of the global satellite traffic. Television, occasional and special services make up the remainder. Intelsat's total investment is a little more than $650 million. An investment of about the same amount has been made by participating countries in earth stations and supporting facilities. When *Early Bird* (*Intelsat I*) first made possible the commercial transmission of live television across the Atlantic in June, 1965, the network charge for one hour of prime-time color transmission was $22,350. Since then the charge has been reduced almost 80 percent to $5,100.

The use of satellite platforms for the relaying of radio signals was first proposed in 1945 in an article in *Wireless World* by Arthur C. Clarke, then an unknown engineer working for the British Post Office. A dozen years later, now famous as a writer of science fiction, Clarke repeated the prophecy. (As it happened, it was just a few weeks before the launching of the first *Sputnik*.) "It may seem premature, if not ludicrous, to talk about the commercial possibilities of satellites," he wrote in 1957, "yet the airplane became of commercial importance within 30 years of its birth, and there are good reasons for thinking that this time scale may be shortened in the case of the satellite, because of its immense value in the field of communications."

In the U.S., John R. Pierce, a physicist at the Bell Telephone Laboratories, writing without knowledge of Clarke's words, independently suggested global relay systems operating with either multiple satellites in low-altitude orbits or three satellites in higher stationary orbits. Pierce was impressed with the fact that the first 36-channel submarine cable between North America and Europe, just then being laid under the Atlantic, would cost some $35 million. He asked: "Would a channel 30 times as wide, which would accommodate 1,080 conversations or one TV signal, be worth 30×35 million dollars, that is, a billion dollars?" Pierce foresaw that satellites would surely offer a much cheaper technical solution. Twenty years later the first Intelsat IV-A, with a capacity of 6,000 telephone circuits, was built by the Hughes Aircraft Company. Intelsat paid $23 million for the satellite and another $23 million to the National Aeronautics and Space Administration to boost it into orbit.

Early Experiments

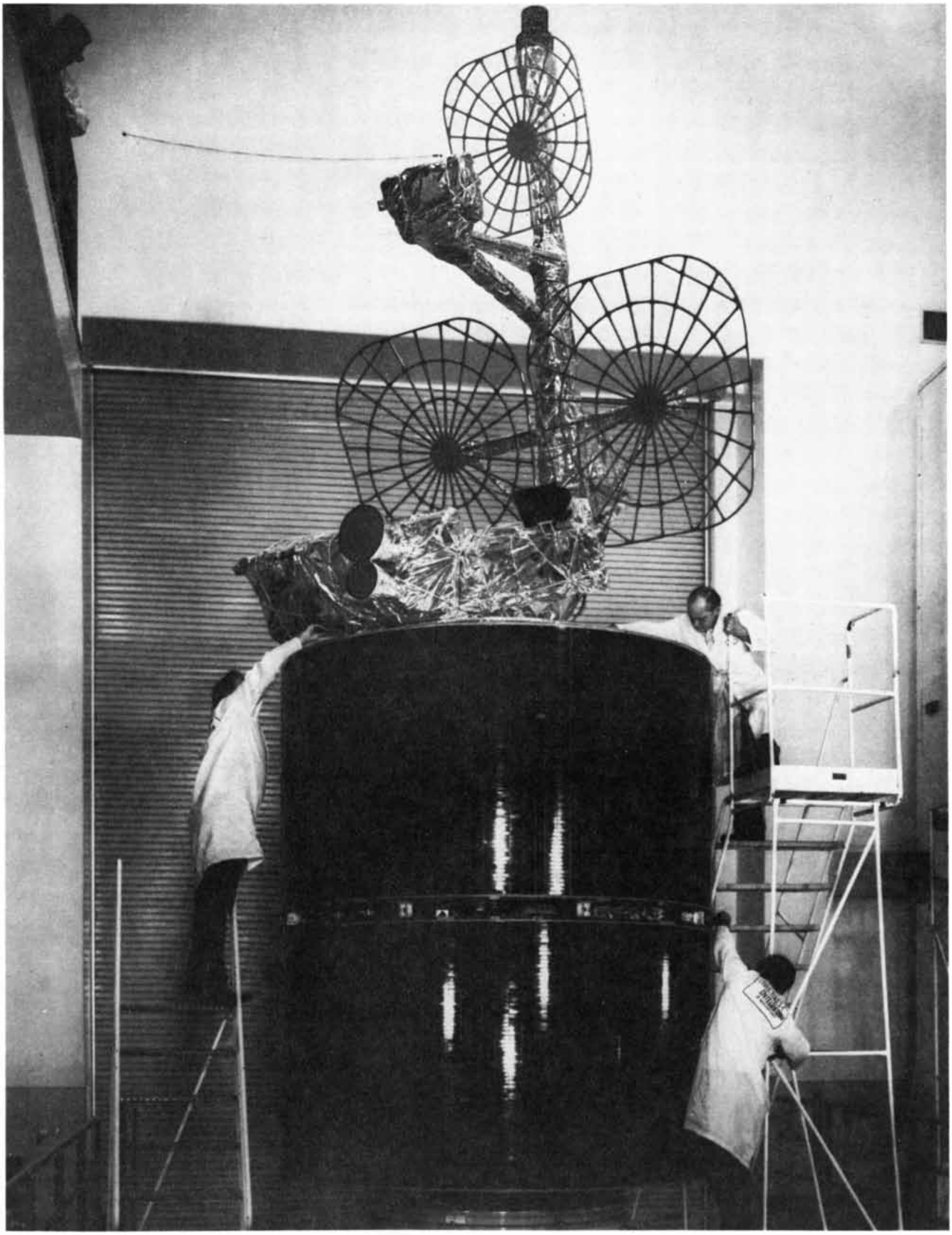
The present Intelsat network is the fruit of a vigorous experimental program in satellite communications conducted in the U.S. in the years immediately following the first *Sputnik* with funds provided by both Government and industry. The first significant experiments were performed as early as 1960 with *Echo,* an aluminized balloon 30 meters in diameter that served as a passive reflector of radio signals from an orbit 1,000 miles above the ground. *Telstar,* an active communications satellite built by the American Telephone and Telegraph Company, was launched in 1962. Two years later *Syncom,* built by NASA, was the first communications satellite to be placed in a synchronous equatorial orbit. Traveling 35,800 kilometers above the Equator, *Syncom* had an orbital period that exactly matched the rotational period of the earth and thus appeared to be fixed in the sky.

Even before this experimentation was completed the outlook for operational communications by satellite became so attractive that in July, 1961, President Kennedy issued a statement proclaiming it to be U.S. policy to create a global communications satellite system as soon as it was technically feasible. Although the policy favored private ownership and operation of the system, it provided that the public interest be adequately protected through opportunities for foreign participation, nondiscriminatory use of the system and equitable access to it, and effective competition in the acquisition of equipment and in the structure of ownership and control. In rapid succession Congress passed the Communications Satellite Act of 1962; the Communications Satellite Corporation (Comsat) was formed in 1963; the international consortium, Intelsat, was organized in 1964, and the first commercial satellite, *Intelsat I,* was placed in orbit to provide commercial communications between North America and Europe in 1965.

In the decade since then satellites have changed the pattern and pace of global communications. They have become the most obviously practical of all space benefits, providing high-quality, reliable and cost-effective telephone, television and data-transmission services. In addition to the Intelsat global system domestic systems are operating in several countries, and so is a maritime system to provide satellite communications for ships at sea. Special-purpose systems, including systems for business and aeronautical communications, are being established. I shall describe some of these systems here, but first let us look at the Intelsat system in some detail: its technology, its performance and reliability, its cost-effectiveness and the institutional arrangements that have made it all possible.

Relay Stations in Space

Communications satellites are radio-relay stations in space. They serve much the same purpose as the microwave towers one sees along the highway. The satellites receive very faint radio signals transmitted from the ground, amplify them, translate them in frequency and retransmit them back to the ground.



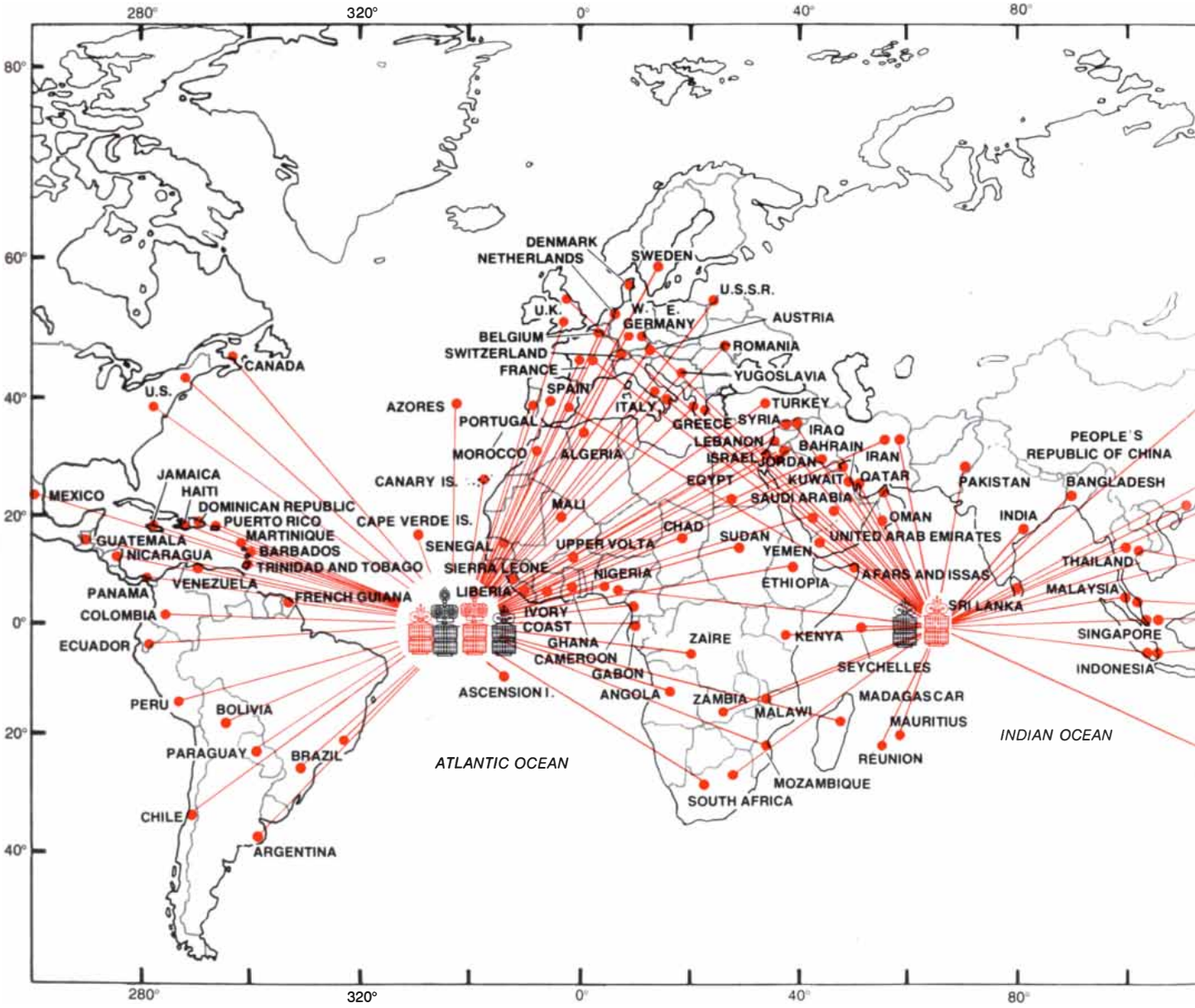
INTELSAT IV-A, the latest in the Intelsat series of communications satellites, is shown in the plant of its builder, the Hughes Aircraft Company. The first two Intelsat IV-A's were placed in geostationary orbits over the Atlantic in 1976, one of them serving as a spare. (A satellite in geostationary orbit travels around the earth once every 24 hours and hence remains stationary over one point on the earth's surface.) Each Intelsat IV-A has a capacity of 6,000 telephone circuits and two television channels. Also operating over the Atlantic is an Intelsat IV and its spare, each with a capacity of 4,000 telephone circuits and two television channels. The body of the Intelsat IV-A is covered with 16,852 silicon solar cells, which provide 500 watts of power. The design lifetime of the satellite is seven years.

Since the satellites are at high altitude, they can "see" across half of the earth. This gives them their principal communications advantage: insensitivity to distance. Another major advantage is that they can see all the microwave transmitters and receivers (earth stations) on about a third of the earth. Thus they can connect any pair of stations or provide point-to-multipoint services, such as television. Ground links, such as microwave relays and cables, are inherently limited to providing single-point to single-point services.

All Intelsat satellites operate in synchronous equatorial orbits, which makes possible uninterrupted reception and transmission with minimal tracking by earth stations. The satellites receive signals transmitted from the ground on frequencies in the six-gigahertz (six billion cycles per second) band and retransmit them back to the ground on frequencies in the four-gigahertz band. All the Intelsat satellites launched so far have been spin-stabilized, so that they maintain their orientation in space by means of a rotation of the body of the satellite along an axis parallel to the earth's axis. All have been powered by arrays of silicon solar cells mounted on the spinning body.

The satellite body serves as a platform for the communications payload, which is "despun" in order to maintain its earth orientation. The communications payload includes the receivers, amplifiers, transmitters and antennas. The rotating outer structure carries with it the electric-power system, the stabilization system (including its fuel tanks) and a solid-fuel rocket engine to provide the necessary "kick" at the apogee of the satellite's transfer orbit to place it in a circular equatorial orbit with essentially zero inclination. The apogee engine and its propellant weigh about as much as the rest of the satellite components put together.

The stabilization system depends on infrared sensors to determine the direc-



GLOBAL NETWORK OF INTELSAT, the International Telecommunications Satellite Organization, is built around eight satellites positioned in three groups 35,800 kilometers above the Atlantic, Pacific and Indian oceans, where they serve as relay stations for radio signals to and from 150 earth stations in 80 countries. The Intelsat IV's, which still provide all the service over the Pacific and Indian oceans, have two receiving and two transmitting horn antennas that cover the entire earth visible below the satellite. Each Intelsat IV also has two steerable transmitting spot beams that provide additional gain and therefore more power in certain geographical areas. In the larger and more capacious Intelsat IV-A satellites separate beams cover Europe and Africa in the Eastern Hemisphere and North and South

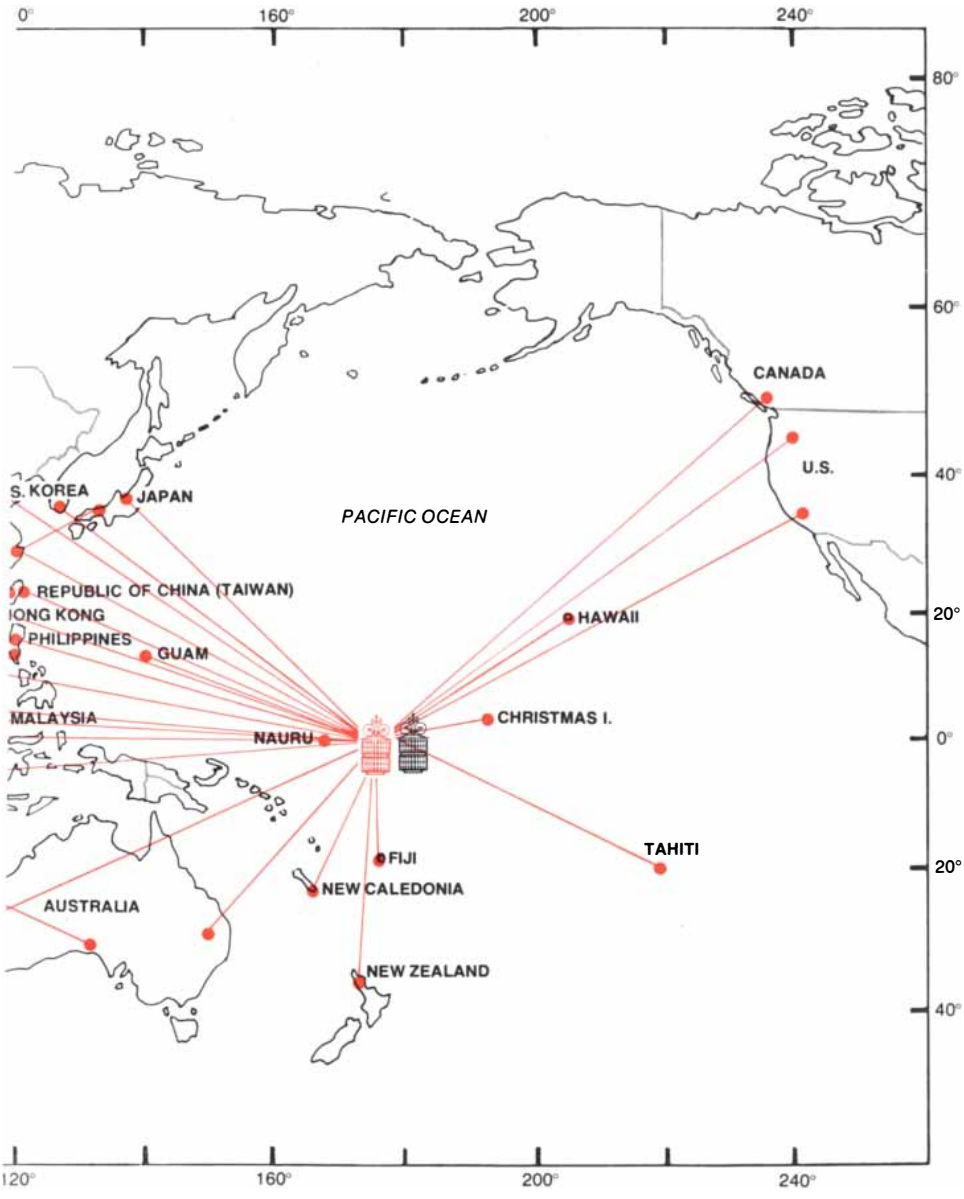
tion of the earth and on small thrusters to align the satellite spin axis properly and keep the antenna beams pointed earthward. For orbital station-keeping it is necessary to minimize the satellite's tendency to drift along its orbit because of the gravitational perturbations due to the oblateness of the earth. The satellite is carefully tracked by ground stations, the propulsion vector needed to compensate for drift is computed and the appropriate thrusters are fired by radio command. The thrusters, fueled by hydrazine, generate the reaction force necessary to adjust the satellite's position. With them the stabilization system can control the attitude of the spin axis, move the satellite in the east-west direction and counteract the gravitational influence of the sun and moon, which tends to increase the inclination of the satellite. The correction for inclination consumes a major fraction of the hydrazine fuel and is therefore closely related to the effective life expectancy of the satellite.

It is also necessary to monitor the condition of the various systems and devices in the satellite and to take corrective action in the event of a malfunction. This is accomplished through telemetry in which a variety of sensors detect temperatures, voltages and other conditions, which are transmitted to special earth stations through a radio link. The information is subsequently sent to the control center, where it is processed for evaluation and displayed. If any out-of-tolerance condition is detected in the satellite, corrective action can be taken by radio command from the same special stations.

Significant progress was made in the technology of the Intelsat system during the 10-year period from 1965 to 1975. The effectiveness of a communications satellite is measured not only by its lifetime but also by its capacity, which in turn depends on radiated power and bandwidth. As the technology developed during the past decade the Intelsat satellites were improved in all three areas: lifetime, power and bandwidth.

More powerful launch vehicles placed bigger satellites in orbit, providing a greater area for solar cells and thereby more electric power for radio transmission. With increased power and more sophisticated transponder design more of the allocated bandwidth was utilized. Improved components, devices and design, together with more effective quality-assurance techniques, all improved satellite reliability and operating lifetime.

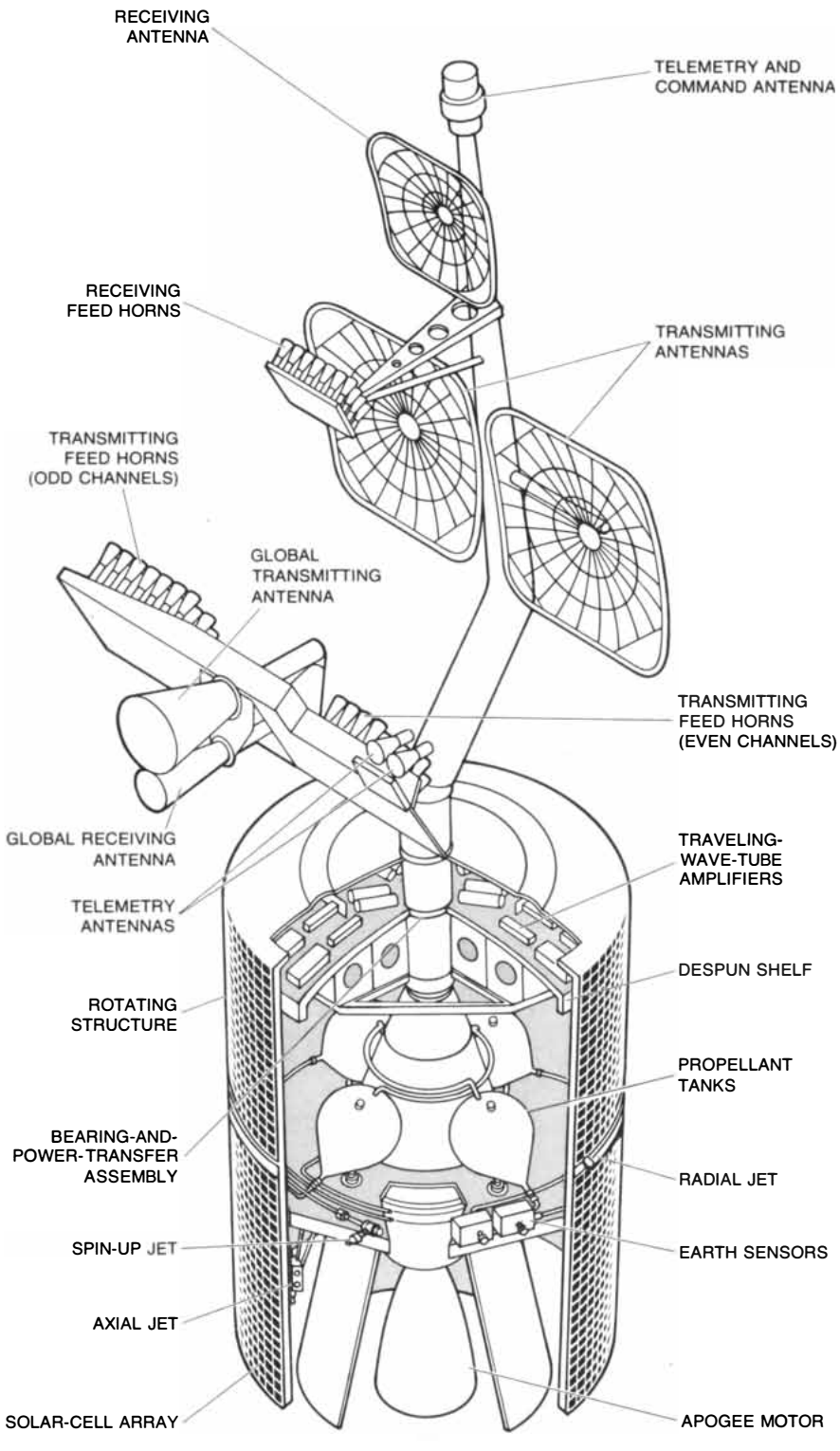
Intelsat I, with its capacity of 240 telephone circuits, weighed 38 kilograms. The latest generation of satellites to be launched, the improved Intelsat IV-A, measures 5.9 meters from top to bottom, weighs 790 kilograms and handles 6,000 simultaneous telephone circuits. (The word "circuit" implies a dual connection for two-way speech and thus calls for two one-way telephone channels.) Lifetime in orbit also advanced during the decade, from 1.5 to seven years. As a result of these various improvements the investment cost per circuit-year in orbit of Intelsat IV-A is only about $1,100, compared with $32,500 for *Intelsat I.*



America in the Western Hemisphere, supplementing the global beams. In the illustration operating satellites are in color and spares are in gray. In the Atlantic region one Intelsat IV-A, acting as the primary-path satellite, connects small and large users and carries some of the heavy traffic between large users. An Intelsat IV, the major-path satellite, handles the remainder of the traffic between large users. Spare transmitting tubes in each satellite are available in case of a partial failure. Spare satellites would cut in quickly in the event of a total failure.

Earth Stations

An earth station transmits powerful radio signals to a satellite and receives very weak signals from it. Earth stations in the Intelsat system also serve to connect the global satellite network to the ground-communications network of various countries, usually through microwave links. The earth station must reorganize the various incoming signals from ground networks for voice, television and data communications into suitable groups for satellite transmission. Each group is modulated onto a radio-frequency carrier wave in the six-gigahertz band. The power needed for transmitting the signal to the satellite is developed by an amplifier that can produce up to 12 kilowatts; hence a typical incoming signal is amplified about 320,000 times before it is fed to a parabolic antenna about 30 meters in diame-



MAJOR COMPONENTS OF INTELSAT IV-A are identified. The long axis of the satellite is maintained parallel to the axis of the earth by the rotation of the outer structure, which spins at about 50 revolutions per minute. A drawback of this stabilization scheme is that fewer than half of the solar cells are in sunlight at a given instant. The antenna mast and the rest of the communications package are "despun" so that they point steadily at the earth. The despinning is accomplished by a small electric motor in the bearing-and-power-transfer assembly. Hydrazine fuel is used in the small jets that control the orientation of the satellite around three axes (pitch, roll and yaw) and keep the satellite in its desired orbital location. Signals are radioed from the earth as needed, usually every month or so, to hold the satellite within .1 degree (60 kilometers) of its assigned station. The fuel supply places the main limitation on satellite life. The apogee motor is used only once, at launching, to provide the final "kick" that propels the satellite from the apogee of its transfer orbit into its circular equatorial orbit. The next generation of Intelsats will have a body stabilized by internal reaction wheels, which will allow solar cells to be mounted on winglike panels that rotate once a day and face the sun continuously.

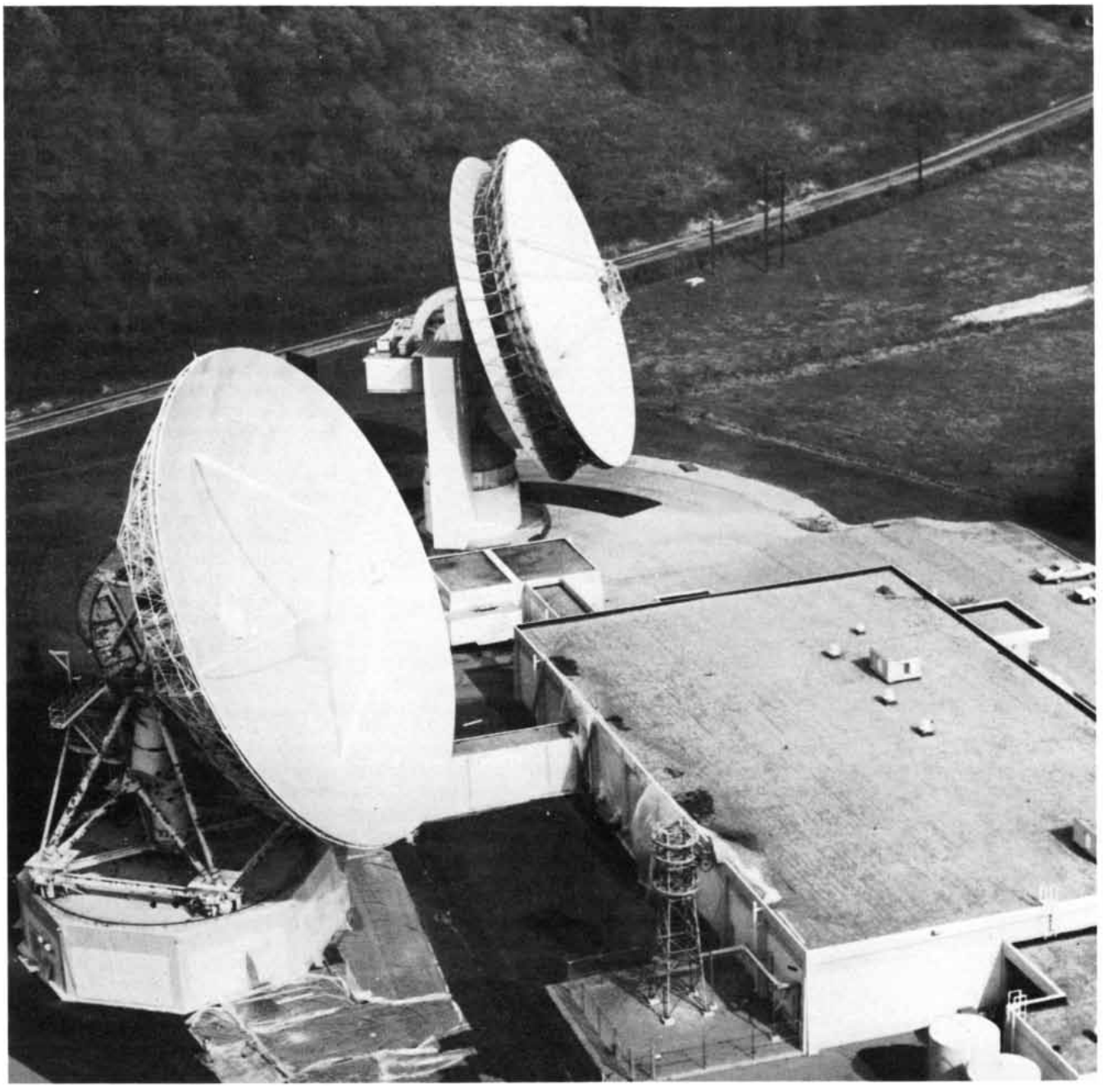
ter. The function of the antenna is to confine the radiated energy to a narrow beam aimed at the satellite. If the energy from the earth station were radiated in all directions instead of being focused, some 630 megawatts would be needed for transmission instead of the several hundred watts actually transmitted. The value of 630 megawatts is referred to as the equivalent isotropically radiated power.

After traveling 35,800 kilometers through space the signal received at the satellite has a strength of only seven picowatts (7×10^{-12} watt). The satellite amplifies this tiny signal, translates it into a frequency in the four-gigahertz band, boosts it up to an equivalent isotropically radiated power of 500 watts and beams it back to the ground. At the earth station the 30-meter dish antenna collects a scant three picowatts of energy and feeds it into a low-noise receiver. There it is amplified to about one milliwatt, a suitable amount for feeding into the local distribution network. In the time a signal has entered one earth station, made a round trip to an Intelsat satellite and emerged at another earth station it has been amplified by a factor of about 10^{40}, which is equivalent to 400 decibels.

About as many improvements have been made in earth-station technology as have been made in satellites, but they tend to seem less glamorous, perhaps because they are introduced routinely in one station at a time and are not launched by a rocket. For example, over the past 10 years narrow-band klystron amplifiers in earth-station transmitters have given way to wide-band traveling-wave-tube amplifiers. In the same period maser receivers have been replaced by low-noise parametric amplifiers. Antenna reflectors, feed systems and tracking mechanisms have all been greatly simplified and improved in performance. Perhaps the greatest advance in earth-station technology has been in reliability. The lifetime of equipment has been extended from tens of hours to thousands of hours through careful design and the use of ultrareliable components. Redundant equipment and automatic switching to spare units in the event of failure have reduced the rare outage times in earth stations to seconds. The future of unmanned earth stations for some applications seems assured.

Transmission Systems

A signal traveling from a source on the ground to an earth station to a satellite to a second earth station to a destination on the ground is processed in a number of ways. The primary initial step involves multiplexing, or combining the incoming signals of various types so that they can modulate a single wideband six-gigahertz signal, which is am-



EARTH STATION at Etam, in a "radio quiet" valley in the northeastern part of West Virginia, is the principal U.S. installation for relaying signals via satellite across the Atlantic and is the busiest earth station in the global Intelsat network. Etam handles more than 1,000 telephone circuits to more than 40 destinations in Europe, Africa, the Middle East and Latin America. A station of comparable size at Andover, Me., handles the balance of the Atlantic traffic and serves as a backup for Etam. The two large dish antennas at Etam are some 30 meters in diameter. Station is owned jointly by the Communications Satellite Corporation (Comsat) and four other American companies.

plified and beamed at the satellite. At the receiving earth station the reverse processes apply, that is, amplification and translation from high frequency to low frequency, demodulation, demultiplexing and processing for ground transmission.

Let us follow what happens when we see the words "Live via satellite" displayed at the bottom of our television screen. From its point of origin the television signal has been transmitted by coaxial cable and microwave link through ground networks to an earth station in the Intelsat system. At the transmitting earth station the signal is modulated onto a radio-frequency carrier in the six-megahertz band. Although the bandwidth of the television signal is normally only about five megahertz, a wide-deviation frequency-modulated signal with three to six times the bandwidth transmits it to the satellite. The frequency modulation considerably improves the signal-to-noise ratio and satellite power is conserved. The satellite amplifies the signal and retransmits it to the ground in the four-gigahertz frequency band. The earth station amplifies and demodulates the television carrier and sends it on through a ground network to a local television station, where it is broadcast or sent by cable to individual television receivers. Often, as in news events, the Olympic games and other programs of international interest, a single television carrier is broadcast by the satellite on the global beam so that it can be received by all its earth stations. For events of global interest several satellites in different positions broadcast the signal.

In order to provide interconnections among many earth stations using the same satellite it is necessary that some

technique be employed to enable the satellite to receive and transmit a large number of radio-frequency carriers. This has been done in the Intelsat system through the technique of frequency-division multiple access (FDMA). Frequency-modulated carriers bearing a single television channel or multiple voice or data channels are transmitted on assigned frequencies that are separated sufficiently to avoid interference between carriers [*see top illustration on page 66*]. The carriers have assigned bandwidths and power levels appropriate to their information content. In the interest of efficiency in the utilization of both the spectrum and the equipment, multidestination carriers are usually employed. That is, traffic intended for several earth stations is transmitted on the same carrier. Earth stations then have one set of receiving equipment for each distant location with which they would like to communicate. They may use a single set of transmitting equipment, however, for several destinations.

An alternative to frequency-division multiple access is a digital communications technique known as time-division multiple access (TDMA), which has a higher capacity and more flexibility than the frequency-division mode. In the time-division system a number of earth stations work with the same satellite repeater by transmitting their signals in short bursts that are timed precisely so that the signals arrive at the satellite in sequence. An advantage of the time-division mode is that only one carrier at a time need be present in the satellite amplifier. The amplifier can then be op-

YEAR OF FIRST LAUNCH
HEIGHT (CENTIMETERS)
MASS IN ORBIT (KILOGRAMS)
LAUNCH VEHICLE
PRIMARY ELECTRIC POWER (WATTS)
EFFECTIVE BANDWIDTH (MEGAHERTZ)
CAPACITY (TELEPHONE CIRCUITS)
DESIGN LIFETIME (YEARS)
INVESTMENT COST PER CIRCUIT-YEAR

FOUR GENERATIONS of communications satellites, plus a major modification, were introduced in the decade 1965–1975. A fifth generation is due in 1979. As the satellites became bigger, heavier and more powerful they

erated at maximum power, which is not possible in the frequency-division mode because nonlinearities in the amplifier give rise to intermodulation noise when several carriers are present. Time division is also more flexible than frequency division because the timing and spacing of bursts are much easier and faster to change than the bandwidth and frequency assignments of transmitting and receiving equipment.

Operations and Economics

The Intelsat system has grown rapidly over the decade. During its first year, 1965, one satellite and five earth stations were operating in the Atlantic region, carrying 65 two-way circuits. Since the satellite had no multiple-access capability only one path could be served, that is, only two earth stations could be connected, one in North America and one in Europe. Earth stations in Germany, France and Britain took turns carrying all satellite traffic for Europe on a weekly basis. A station in Italy was assigned the weekend traffic. Today the satellites are provided with multiple access so that all earth stations can operate simultaneously.

At present four Intelsat satellites cover the Atlantic region, two operating satellites and two spares. There are also an operating satellite and a spare in the Pacific region and an operating satellite and a spare in the Indian Ocean region. They make possible a global communications network that carries traffic over 400 paths that link together 150 earth stations in 80 countries. In addition to carrying 7,700 full-time telephone circuits the Intelsat network provides the equivalent of several thousand circuits for television and data transmission. In some years of the past decade the number of earth stations and the number of circuits carried have more than doubled. Much of this growth, of course, has simply been the result of introducing reliable communications service in new regions that had had little or no service before.

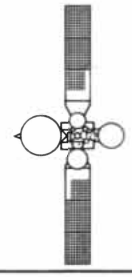
The reliability of global satellite communications is now quite impressive. In the early 1960's we hoped that satellites would operate for two years. With the Intelsat IV series we are quite confident of achieving a seven-year service life. Earth stations in the system routinely achieve 99.99 percent reliability (outage less than one hour per year). Continuity of service for the entire global system exceeds 99.9 percent.

Over the decade the Intelsat system has attained economic advantages both through improved technology and through economies of scale. Although the cost of building and launching satellites has increased with time, technology has more than offset the cost inflation by providing higher satellite-communications capacity through longer lifetime and more effective utilization of power and bandwidth. As more satellites have been placed in orbit the operating overhead of the system has represented a declining fraction of the investment, and since the system carries a steadily increasing amount of traffic, there are more circuits to bear the overhead. Thus the cost per circuit-year should be expected to decrease. Indeed, the actual 1976 charge to users of the system is a fourth of the 1965 rate in spite of a 100 percent increase in the costs of most other goods and services resulting from inflation.

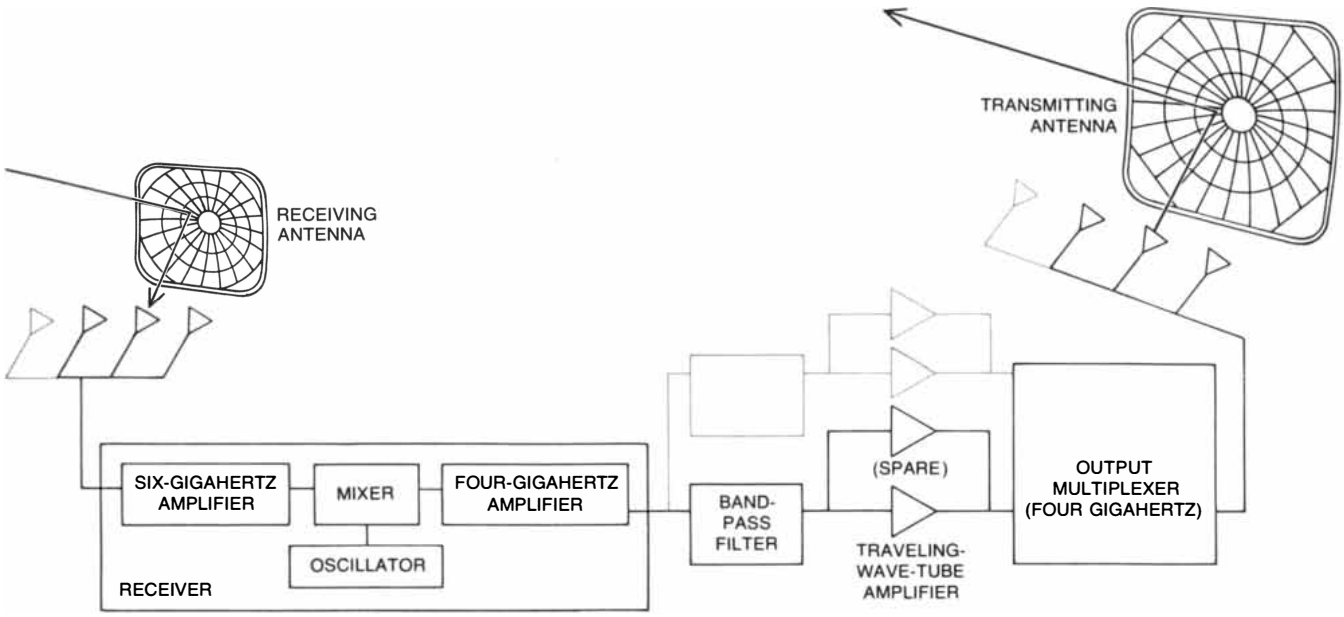
As I have noted, the revenues now exceed $140 million per year. The total revenues received for all traffic routed by satellite, however, a figure no one tallies, is a much larger one, undoubtedly now exceeding $1 billion per year. Intelsat pays its member countries a 14 percent return on their investment. This, plus the profits on earth-station operations, enables overseas telecommunications agencies in most countries to operate well in the black. The global system seems profitable on all counts.

International Arrangements

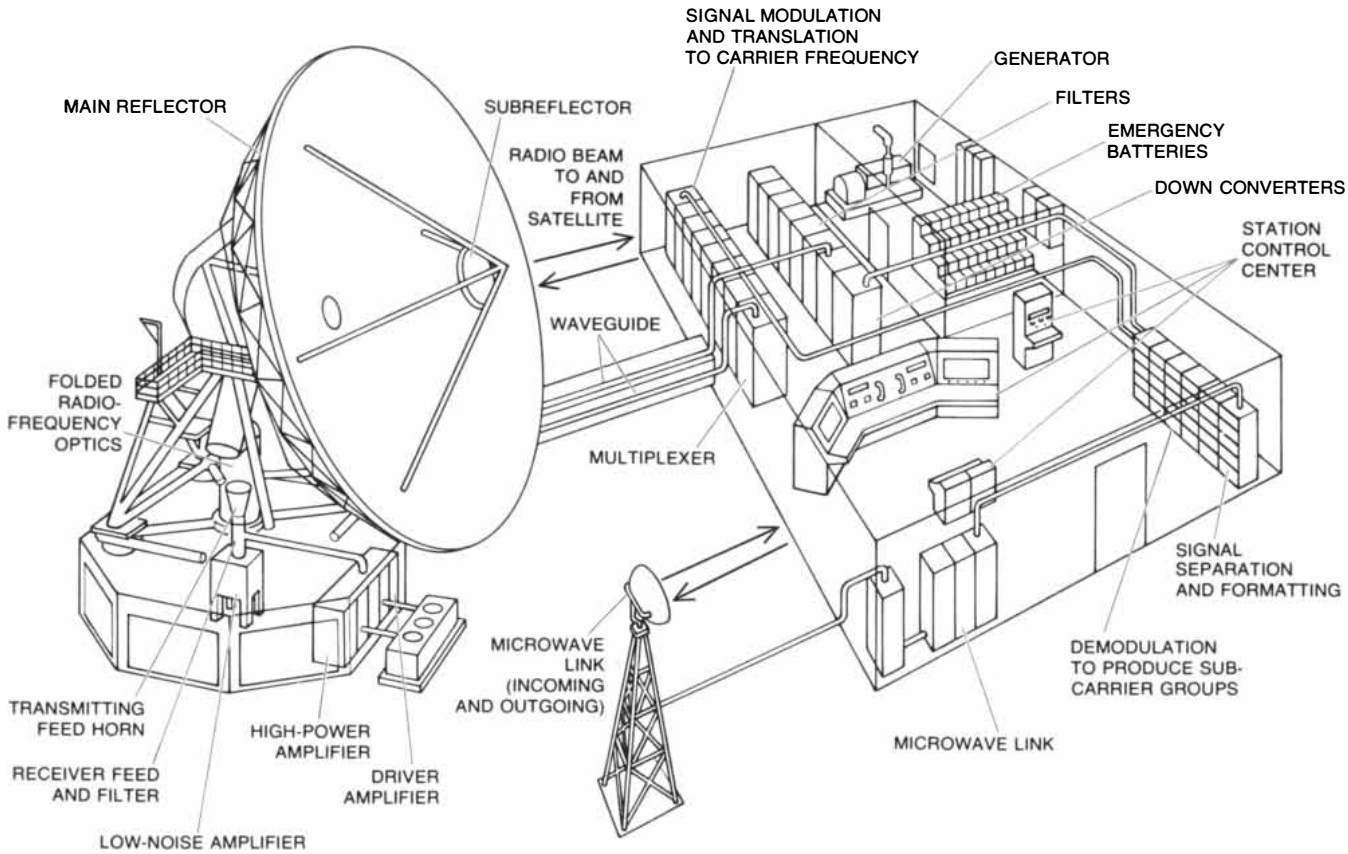
One of the most remarkable aspects of Intelsat is the international arrangement that makes it possible. It is no small accomplishment for 95 nations to be joined together in a peaceful, purposeful endeavor working cooperatively and profitably. The countries of Intelsat range alphabetically from Afghanistan to Zambia and represent almost every race, religion and economic system. Most of the countries are represented in Intelsat by a government agency, but a few are represented by private corporations, of which Comsat, representing the U.S., is one. A few other countries (such as the U.S.S.R.), although not members of the organization, are regular users of its services. The fact that the system works so well in spite of the geographi-

INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV	INTELSAT IV-A	INTELSAT V
					
1965	1967	1968	1971	1975	1979
59.6	67.3	104	528	590	1,570
38	86	152	700	790	967
THOR-DELTA	THOR-DELTA	THOR-DELTA	ATLAS-CENTAUR	ATLAS-CENTAUR	ATLAS-CENTAUR
40	75	120	400	500	1,200
50	130	500	500	800	2,300
240	240	1,200	4,000	6,000	12,000
1.5	3	5	7	7	7
$32,500	$11,400	$2,000	$1,200	$1,100	$800

required larger launch vehicles. Satellite capacity has grown from 240 two-way telephone circuits in *Intelsat I* (*Early Bird*) to 6,000 in Intelsat IV-A and a planned 12,000 for Intelsat V. The entire *Intelsat I* satellite, including its antenna, was spun on its axis for stability. Intelsat III was the first of the series in which the antenna was despun to point at the earth. The satellites of the Intelsat V series will be body-stabilized, with their entire body fixed in space along three axes. Although the costs of the satellites and their launch vehicles have increased steadily, the investment cost per circuit-year has steadily decreased. That cost is now less than 5 percent of the original amount.



COMMUNICATIONS SYSTEM OF INTELSAT IV-A includes 20 transponders, or separate radio-frequency channels. Each channel has a bandwidth of 36 megahertz, sufficient to accommodate two television channels or 600 two-way telephone circuits. Here the path through one transponder is shown. The receiving antenna on the satellite picks up the signal from the earth and feeds it into a receiver, which amplifies it and then translates it from six gigahertz to four gigahertz, the frequency used for retransmission to the earth. The band-pass filters keep the 20 transponder frequencies separated from one another. The signal is boosted by a traveling-wave-tube amplifier and passed to one of the output multiplexers, where signals from several transponders are combined and fed to the appropriate antenna.



SIGNAL PROCESSING IN AN EARTH STATION is necessarily more complex than the processing carried out aboard a communications satellite. The various kinds of signals (voice, television, data and so on) that pour in from ground networks must be separated and reassembled into a format that is suitable for satellite transmission. Signals grouped by destination are modulated and translated to a carrier frequency assigned to that destination. This "up conversion" produces carriers whose frequencies lie between 5.925 and 6.425 gigahertz. A multiplexer combines the carriers and feeds them by means of a waveguide to the driver amplifier and the high-power amplifier. The greatly amplified signal passes through the transmitting feed horn and on to the main reflector, which focuses the energy in a beam aimed at the satellite in orbit some 35,800 kilometers away. The signals received from the satellite are collected by the same reflector that is used for transmitting and pass through a sequence of processing steps that are essentially the reverse of those followed to prepare the outgoing signal. Troubleshooting, satellite-tracking and station-checkout operations are performed from the station control center.

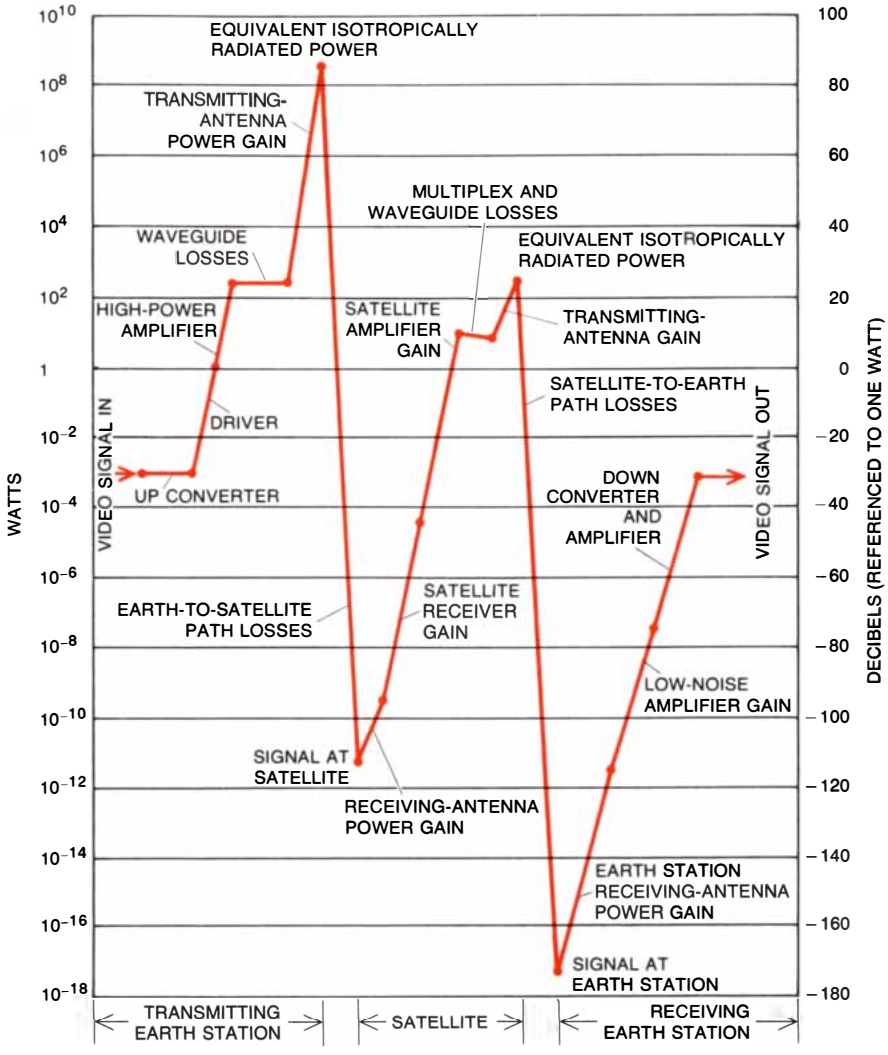
cal dispersion and political disparities of its members is testimony to the universality of technology.

Now that the Intelsat network is a mature operating system its growth along existing communications paths probably will average between 15 and 20 percent per year. New technology will be introduced to provide increased capacity, efficiency and reliability of service, but the system's days of explosive growth are probably over. Its principal concerns must be for reliable operations and continuity of service. Decisions on the introduction of new technology to meet growing requirements must, as with all operating systems, achieve a balance between new capabilities and amortization of investment in existing plant facilities.

Intelsat is anticipating the introduction of a new satellite series, Intelsat V, in 1979. That would be eight years after the introduction of Intelsat IV, whereas three generations of new satellites were introduced in the first six years of the system's existence. The Intelsat V satellite will have a capacity of 12,000 circuits, three times the capacity of Intelsat IV and twice that of Intelsat IV-A. The new satellite is also designed to make more efficient use of the six- and four-gigahertz frequency bands through polarization discrimination. Each band will carry two sets of signals, one set circularly polarized in the left-hand sense and the other set circularly polarized in the right-hand sense, thus providing double utilization of frequencies in each geographical area.

Intelsat V will also inaugurate a new frequency band: from the ground to the satellite in the region of 14 gigahertz and from the satellite to the ground in the region of 11 gigahertz. Each of these frequency regions provides a bandwidth of 500 megahertz. By the use of two spatially separated spot beams the effective bandwidth will be raised to 1,000 megahertz. The addition of circular polarization will then raise the total bandwidth to the equivalent of about 2,300 megahertz.

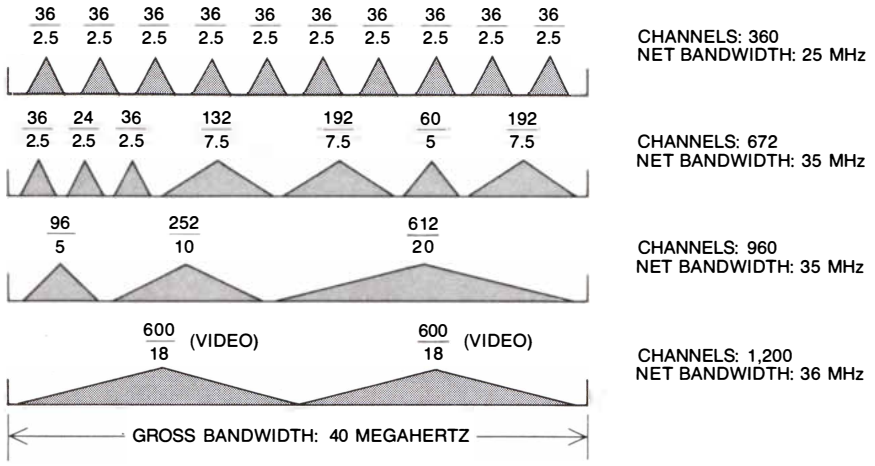
Until recently Intelsat has required all its earth stations to employ reflectors with a diameter of about 30 meters, which provide a very high ratio of received power to thermal noise in the receiver, expressed as the ratio of gain to noise temperature. Most Intelsat earth stations have been built to operate at a ratio expressed as 40.7 decibels per Kelvin, which requires a 30-meter antenna. As the satellites have become more powerful and the number of earth stations operating in the system more numerous it has become increasingly evident that smaller, less expensive earth stations could be more cost-effective for some traffic streams. An earth-station owner must strike a balance among various factors, such as the initial cost of the station and its operating expenses, circuit charges for the use of the system and the number and distribution of earth stations in the geographical area for which the owner is responsible.



GAINS AND LOSSES IN THE POWER of a typical television signal from the time it enters one earth station, makes a round trip to a satellite and back and finally leaves another earth station cover a dynamic range from less than 10^{-17} watt to the effective equivalent of nearly 10^{9} watts, or one gigawatt. Translated into decibels relative to one watt, the range extends from roughly −170 decibels to more than 80. The biggest losses occur, of course, on the 35,800-kilometer path between the earth and the satellite. The largest single gains are produced by the 30-meter antennas at the earth station. On the outgoing trip the big earth-station reflector boosts the amplified signal by a factor of about a million, from a few hundred watts to an "equivalent isotropically radiated power" of several hundred megawatts, which represents the power that would be required at the earth station if the signal were being radiated equally in all directions instead of being focused. Another reflector at the distant earth station picks up the faint four-gigahertz signal from the satellite and provides another gain of nearly a million.

Smaller earth stations are less expensive to build, but the circuit charge is slightly higher. Another consideration is the fact that the width of the transmitted beam is inversely proportional to the diameter of the earth-station reflector. Therefore an earth station with very small reflectors could give rise to interference with nearby satellites in orbit and limit the orbital spacing. (Intelsat satellites serving the same routes are now spaced about 2,500 kilometers apart.) Intelsat recently approved the use of earth stations with reflectors about 10 meters in diameter. The initial cost of such a station should be about a third that of a station with a 30-meter reflector, and the satellite utilization charges would be only about 50 percent higher. Hence smaller earth stations can be expected to become commoner.

Another trend in the Intelsat system is the growing application of digital techniques. Time-division multiple access should be in widespread service in the 1980's. Television and telephone signals, which originate in analogue form, will be converted into digital form for transmission over satellite circuits. A number of powerful digital coding and processing techniques are available for bandwidth compression. This, added to increased transmission of computer and other data signals, already in a digi-



PACKAGING OF SIGNALS in the Intelsat system is known as frequency-division multiple access (FDMA). In this technique each transponder in a satellite handles a signal with a passband of about 36 megahertz. Within that passband individual carriers are assigned bandwidths ranging in size from 2.5 megahertz up to 36. The illustration shows how four of these transponders might be subdivided into carriers of different sizes with different channel capacities. The lower number above each carrier "tent" represents bandwidth; the upper number is the channel capacity. Hence a passband subdivided into 10 2.5-megahertz carriers will have a total capacity of 360 channels. On the other hand, a passband subdivided into fewer larger carriers will be able to handle a greater number of channels. Each carrier is identified by the earth station that transmitted it and may contain groups of telephone channels destined for several countries. Thus the carrier from Italy, say, may hold traffic for Canada, Mexico and the U.S. One transponder can also handle two television carriers, each equivalent to 600 telephone channels.

ALTERNATIVE TRANSMISSION TECHNIQUE coming into use is called time-division multiple access (TDMA). In this method the bandwidth capacity of a transponder is utilized by having the transponder handle a sequence of signals, all on the same frequency but separated in time, rather than by placing the signals side by side at different assigned frequencies as in the frequency-division technique. The time-division technique makes it possible for many earth stations to time-share one transponder, each transmitting on the same frequency in short bursts synchronized so as not to overlap when they arrive at the satellite. The transponder output is a stream of time-separated signals. Time division not only is more flexible than frequency division; it also has the advantage that with only one carrier signal in transponder at any instant, transponder can work at full power without "cross talk," or interference, between signals.

tal format, will speed in satellite communications what has become known in ground communications as the digital revolution.

Other Systems and Services

The Intelsat system is serving its intended role very well, interconnecting the ground communications networks of many nations. The current international utilization of the system, however, really takes advantage of only one of the several principal attributes of satellite communications: the ability to readily connect points that are widely separated. Not drawn on nearly as much are two other inherent advantages of satellite communications over ground communications: the ability to carry multidestination traffic and the ability to serve specific requirements as they are determined by the user's location, size or shape and degree of mobility. Other satellite systems that take good advantage of all three capabilities for commercial purposes are coming into being. They include domestic systems to provide communications within the boundaries of one country, mobile communications satellite systems to serve ships, aircraft and land vehicles, and special-purpose systems for television distribution and computer communications.

The U.S.S.R. was the first country to establish an independent domestic communications satellite system. The Russian system, which has several dozen earth stations, is employed largely for television distribution. Canada was second; its Telesat system furnishes television and voice communications throughout the country. At present three systems of commercial communications satellites are providing domestic service in the U.S. The first domestic satellite in operation was the Western Union *Westar;* the second was the RCA *Satcom;* the third and most recent system employs Comstar satellites provided by the Comsat General Corporation with earth stations built by the American Telephone & Telegraph Company and the General Telephone and Electronics Corporation.

The domestic systems have benefited from technology developed by Government space programs and by the Intelsat system. Since the domestic systems are new, they can introduce technology quickly without concern for the replacement of existing plant facilities. For example, the RCA system has made major strides in satellite technology in its first generation. The entire RCA *Satcom* satellite is stabilized in space along three axes by a set of momentum wheels inside the satellite. The body-mounted antenna array can thus be pointed accurately at the earth, and the solar-cell array can be oriented toward the sun to generate the maximum power per unit area of the array. The communications

I always drink Cuervo Gold. Now & then.

Cuervo Especial. Tastes somewhere between the smooth of scotch and the mellow of really good cognac.

When you're feeling a bit bored by your usual—try it on the rocks. If you're more bored than usual—try it in a snifter.

Of course, when you raise your glass, you'll also raise a few eyebrows. But surely you've done that before.

Try it on the rocks.

CUERVO ESPECIAL® TEQUILA. 80 PROOF. IMPORTED AND BOTTLED BY © 1976 HEUBLEIN, INC., HARTFORD, CONN.

The January Honda: 54 mpg highway. 41 mpg city.*

For as long as the EPA has been testing cars, 50 miles per gallon has been a magic number, a record to shoot for. Like 60 home runs or the 4-minute mile.

Now our 1977 Honda Civic CVCC® 5-Speed has become the first car sold in America to do the impossible. According to EPA estimates it got 54 mpg for highway driving, 41 mpg city.*

See your Honda dealer and test drive the car that broke the Mileage Barrier. The 1977 Honda Civic 5-Speed. It's brand new. But already it's a very rare car.

			EPA Mileage Estimates*	
Civic CVCC 1488cc		Price**	Highway	City
Hatchback	(5-Speed)	$3599	54 (51)	41 (34)
	(4-Speed)	$3299	50 (46)	39 (35)
	(Hondamatic)	$3449	37 (34)	32 (28)
Sedan	(4-Speed)	$2999	50 (46)	39 (35)
Wagon	(4-Speed)	$3549	41 (37)	30 (28)
	(Hondamatic)	$3699	32 (32)	27 (25)
Civic 1237cc (not available in Calif. and high altitude counties)				
Sedan	(4-Speed)	$2779	43	28
Hatchback	(4-Speed)	$3049	43	28
	(Hondamatic)	$3199	29	23

CVCC, Civic and Hondamatic are Honda trademarks. © 1977 American Honda Motor Co., Inc.
*EPA ESTIMATES. The actual mileage you get will vary depending on the type of driving you do, your driving habits, your car's condition and optional equipment. For high altitude models, see your dealer for EPA mileage estimates. Calif. mileage shown in parentheses.
**Manufacturer's suggested retail price plus freight, tax, license and optional equipment. High altitude models $35 extra.

JANUARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SAT	SUN	MON	TUES	WED	THURS	FRI	SAT	SUN	MON	TUES	WED	THURS	FRI	SAT	SUN	MON

HONDA CIVIC
What the world is coming to.

18 TUES 19 WED 20 THURS 21 FRI 22 SAT 23 SUN 24 MON 25 TUES 26 WED 27 THURS 28 FRI 29 SAT 30 SUN 31 MON

Loud and Clear.

Harris "TC-80"
Color Television Camera

"System 90" Radio
Program Automation Equipment

Superior signal quality is a powerful advantage in broadcasting. With advanced solid-state technology built into equipment from Harris, television and radio broadcasters worldwide deliver a better sound and a clearer picture to over half a billion people every day.

Write: Harris Corporation,
55 Public Square, Cleveland, Ohio 44113

HARRIS

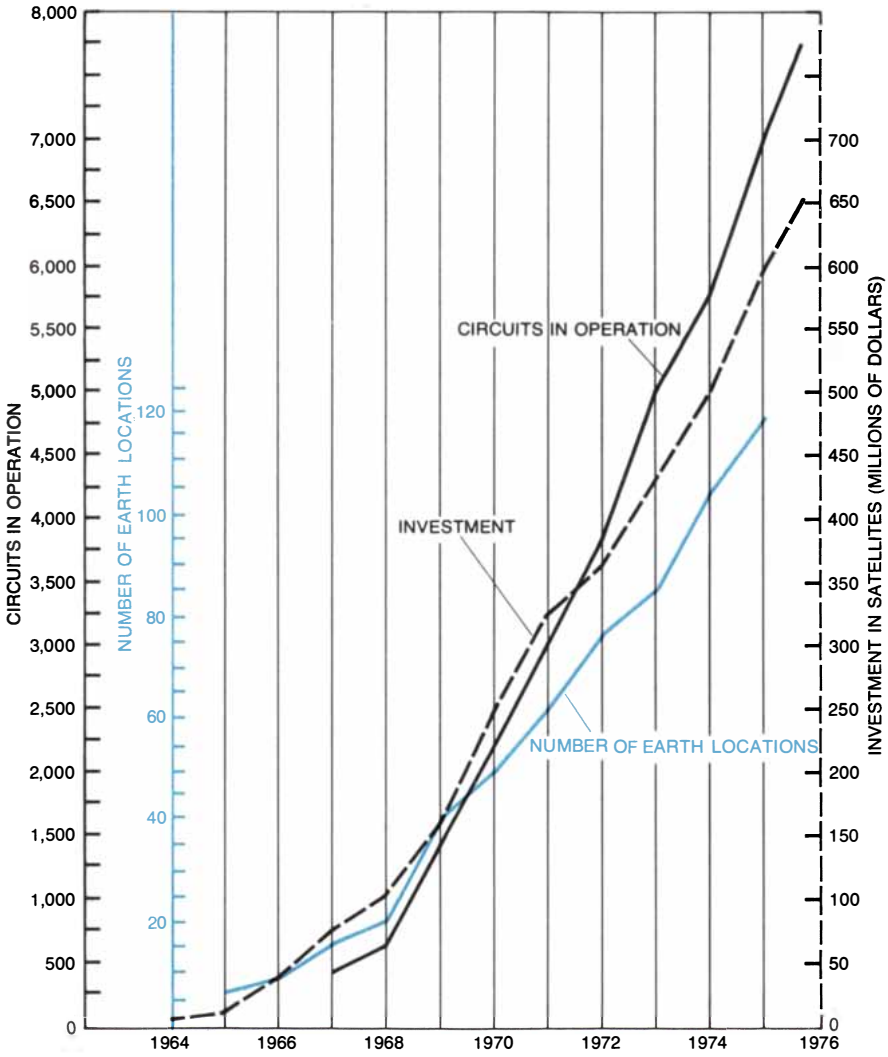
COMMUNICATIONS AND INFORMATION HANDLING

system of *Satcom* is channelized into 24 transponders, 12 polarized in each of two senses, thereby providing a bandwidth of 1,000 megahertz.

The RCA and other domestic systems have taken some significant steps in approaching the ultimate customer for communications service. Whereas the Intelsat system serves countries, domestic systems are now serving states and cities and even smaller communities such as towns and isolated areas. Such service places some special design requirements on satellites, and the modification of earth stations must be even greater.

Some interesting adaptations of small earth stations have been made for unique customer requirements. They allow satellite communications to reach the customer directly no matter how remote or mobile he may be, or how difficult his terrain or mounting platform. For example, remote mountain villages in Alaska are served today by domestic stations specially built to withstand storms and snow. Other stations are being built to fit on the roof of the customer's building in congested areas. Earth stations have been converted into sea stations by redesigning them to fit on the superstructure of ships. Some stations are being made so small and portable that they can be lifted by one person and transported in a jeep or a station wagon.

As a result of such adaptations it is possible to provide a wide range of special services: multiple- and single-circuit telephone service, global television relay combined with local-area television distribution, computer-data transfer and remote access, facsimile and "electronic mail." The future holds many opportunities for significant expansion of all these services and others still to be developed.



GROWTH OF INTELSAT SYSTEM is depicted in terms of dollars invested, circuits in operation and number of earth stations. The investment figure refers only to the outlay for space equipment, primarily satellites and the cost of launching them. Owners of the 150 earth stations at 119 locations in 80 countries have made a comparable investment. Over the past five years traffic carried by system has tripled, and growth is expected to continue at 15 percent per year.

The Origin of Atherosclerosis

The monoclonal hypothesis, which holds that the proliferating cells of an atherosclerotic plaque all stem from one mutated cell, suggests new lines of research on the causes of coronary disease

by Earl P. Benditt

Cardiovascular disease has become the major cause of death in the U.S. and other Western countries not just because people are living longer but because some unknown aspects of modern life are increasing the incidence of atherosclerosis, the chronic arterial disorder that is the major cause of heart attacks and strokes. We cannot identify those aspects until we know the true nature of the characteristic atherosclerotic lesion. The atherosclerotic plaque, a lumpy thickening of the arterial wall, narrows the passageway and initiates the formation of a blood clot that can ultimately close down a critical artery.

In the past 15 years it has become clear that the plaque is characterized by an accumulation of smooth-muscle cells. The important question is: Why do the cells accumulate? Some of us now think the cells of a plaque are the progeny of a single mutated smooth-muscle cell from near the site of the plaque. If that is so, the plaque is comparable to a benign tumor of the artery wall. And if it is comparable, then the search for initiating factors should be directed toward the genetic and environmental factors that cause mutation—the same kinds of agents and conditions that transform cells and thus initiate cancers. Here I shall review the theories that have governed thinking about atherosclerosis until recently. Then I shall report some experiments that led to the new single-cell hypothesis and the evidence that tends to confirm it, and discuss some implications of the proposed new approach.

Arteries are conduits with a specialized cell composition and structure that enable them to conduct blood under pulsing pressure and to maintain and repair themselves. The artery wall has three layers: the intima, the media and the adventitia. Lining the inner surface of the intima is a single layer of endothelial cells, which hold the blood cells within the artery and modulate the passage of water and other substances from the blood plasma into the tissues. The composition of the remainder of the intima varies. It may consist only of noncellular connective-tissue fibers or it may include cells, depending on the type of artery and the age and sex of the individual; the intima of coronary arteries tends to be thicker in males than in females, and the thickness and the number of cells increase with age in both sexes. It is in the intima that atherosclerosis has its effect.

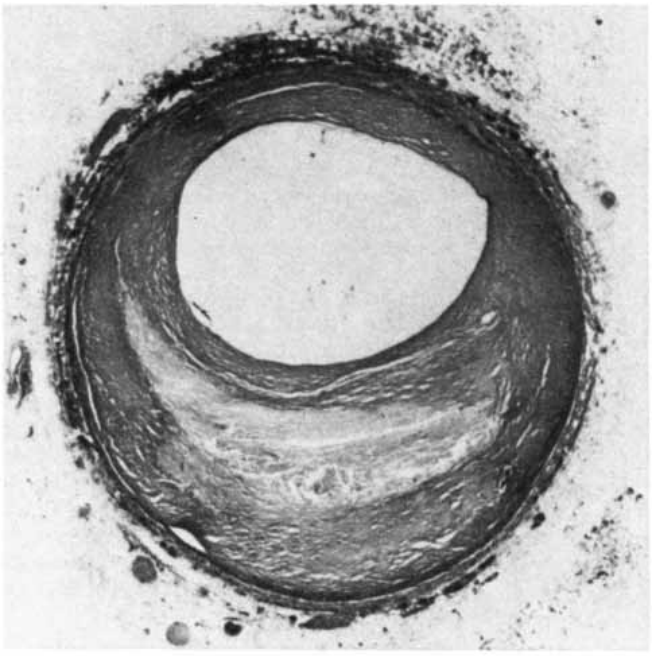
A prominent region of elastic tissue called the internal elastic membrane separates the intima from the media, the artery's main supporting layer. The cells of the media are smooth-muscle cells, so designated because their contractile fibers lack the striated pattern of skeletal-muscle cells. In elastic arteries such as the aorta the cells of the media are arranged in small groups that spiral between the coarse elastic fibers supporting the artery wall; arteries that supply organs, such as the coronary arteries, have a similar structure but less elastic tissue and relatively more cells. The fibrous proteins elastin and collagen and the carbohydrates (glycosaminoglycans) of the media are all secreted by the smooth-muscle cells.

The outermost layer of the artery wall, the adventitia, is composed of the cells called fibroblasts and their associated intercellular collagen and glycosaminoglycans. The adventitia carries the blood vessels that nourish the outer layers of the artery wall and also anchors the wall to the surrounding tissues.

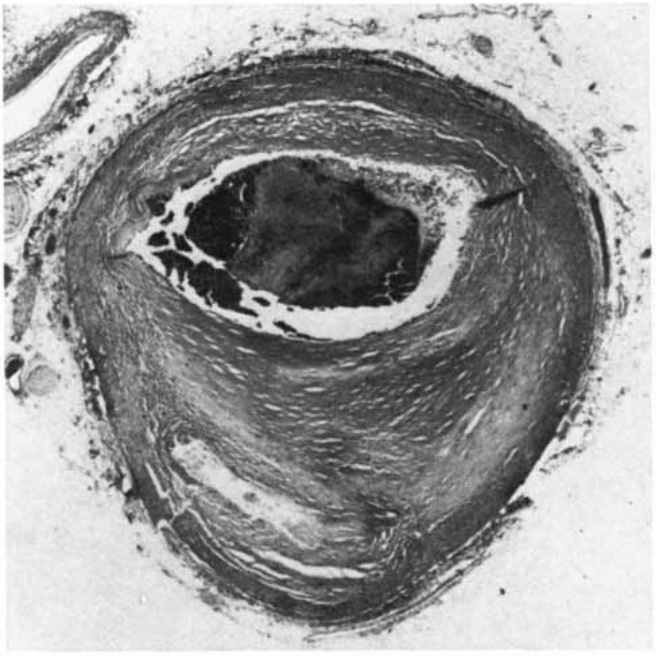
Like any other tissue the arteries are subject to various disease processes such as the reaction to injuries and their repair, infections, inflammations and tumors. It has been difficult to categorize these disease processes because many of them look alike in their end stages and one is able to examine the minute structure of their lesions on only two occasions: at autopsy and, less frequently, during surgery. One can differentiate among various disease processes either by following their development from their inception, examining tissue samples with a microscope, or by looking for special features that distinguish one process from another. That is done by studying animal diseases that mimic human ones. Much can be learned from animal models, but there is always the question of how well a particular model parallels the similar process in human beings.

The characteristic lesions of atherosclerosis, at least as they are seen at autopsy, are the raised fibrous plaques. They appear (in the dissected, undistended vessel) as discrete lumps, elevated above the unaffected regions of the intima and ranging in color from pearly gray to yellowish gray. The main cellular component of the plaque is, as I have indicated, a smooth-muscle cell very similar to the major cell of the normal artery wall; macrophages and other white blood cells also infiltrate the plaque's dense connective tissue, which consists largely of collagen fibers. The plaque usually contains glycosaminoglycans and sometimes elastin and such blood proteins as fibrinogen. Lipoproteins, the carriers of cholesterol in the blood, are found both inside and outside cells. Deep in the lesions there are debris from dead and dying cells and varying amounts of lipids (fats); crystals of cholesterol can sometimes be seen even with the unaided eye in the softened debris in advanced lesions. It is this fatty debris that suggested the name atherosclerosis, from the Greek *athera* (gruel) and *sclerosis* (hardening).

The atherosclerotic plaque can close down an artery by itself, but more often its harmful effect is to predispose the artery to occlusion by thrombosis, which represents an aberration in the delicately balanced blood-clotting system that is essential for temporarily patching leaks and injuries in blood vessels. A thrombus is a complex aggregation of blood platelets, white cells and red cells in a network of fibrin, the main

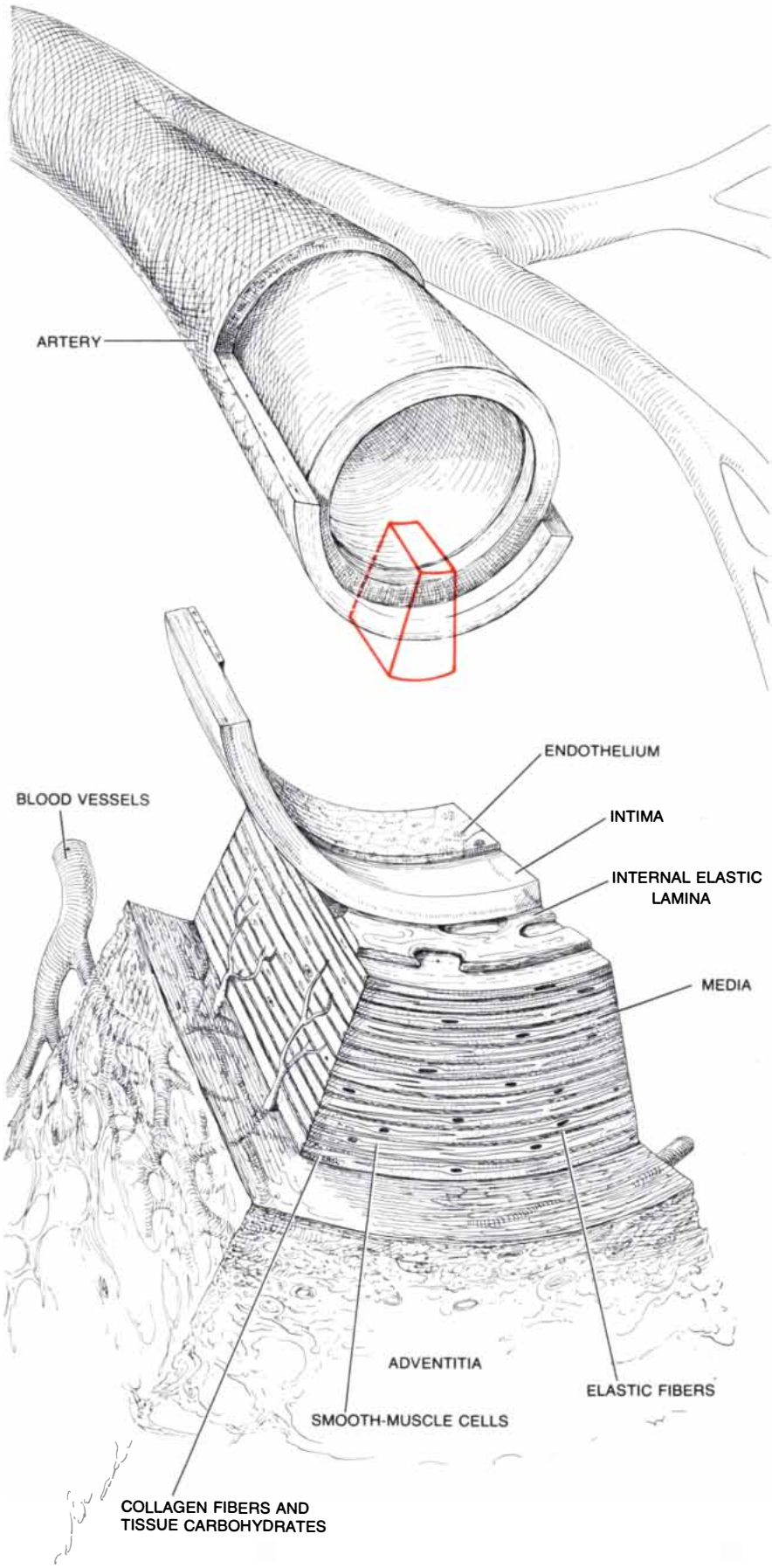


ATHEROSCLEROTIC PLAQUE narrows the lumen, or passageway, of a human coronary artery, enlarged 19 diameters in this photomicrograph made by the author. The plaque is a thickening of the artery wall composed mainly of connective tissue and smooth-muscle cells, with a region of cellular and fatty debris (*lighter gray areas*).



THROMBUS that formed just downstream of the narrowing caused by an atherosclerotic plaque blocked a coronary artery, shutting off the blood flow to part of the heart muscle and leading to a fatal heart attack. The darker regions of the thrombus are composed of red blood cells and the lighter regions contain white blood cells and platelets.

ATHEROSCLEROTIC INNER SURFACE of an artery is seen at about two and a half times natural size in this photograph of a human-aorta segment that has been slit open. The plaques are seen to be discrete lumps that bulge into the lumen of the dissected artery.



ARTERY WALL is built up of several layers, whose precise composition varies with the particular artery. A segment of a major elastic artery of the type of the human aorta is diagrammed.

clotting protein. Thrombosis is common in the veins of the leg, but for a thrombus to form in the rapidly flowing bloodstream of an artery it appears that special conditions are required: either a slowing of the flow or a region of turbulence in it; injury to the inner lining of the vessel, causing platelets to stick to it, and perhaps increased stickiness of the platelets themselves. Such conditions may be found on the downstream side of a plaque, where there is a region of turbulence and sometimes an ulcerated endothelial surface. Platelets stick to the surface and aggregate into a mass that appears to successively recruit white blood cells, initiate the formation of fibrin from fibrinogen in the plasma and then recruit more platelets as well as red cells. The layered mass thus built up may remain a relatively flat mural thrombus or may grow to become an occluding thrombus that blocks the passage of blood.

The theories that have guided the investigation of atherosclerosis until recently are versions of two basic approaches with origins in the 19th century. The dominant theory is associated with the German pathologist Rudolf Virchow. It holds that the infiltration of fatty substances from the bloodstream into the artery wall gives rise to deposits of cholesterol that act as an irritant, causing inflammation and the proliferation of cells. This insudation theory would appear to be supported by the increased rate of coronary heart disease among people with higher than normal levels of cholesterol in their blood. Elevated cholesterol levels have in turn been correlated geographically with diets that are high in food fats and cholesterol, a finding that has given rise to efforts to prevent atherosclerosis by regulating the diet. The insudation theory seemed to be further reinforced by the experiments of the Russian investigator N. N. Anitschkow early in this century. He found that a disease resembling human atherosclerosis could be produced in rabbits by adding egg yolks or cholesterol to their diet and hence raising their blood levels of fat and cholesterol. In the experimental rabbit disease, it should be noted, the lipids appear in the lesions early and can be shown to arise from the blood lipids. The rabbit model and its data have strongly influenced investigators' perceptions of the human disease.

The fact that autopsies of infants and young children show small fatty deposits in the major blood vessels has given further credence to the lipid-insudation theory. It has also led people to assume that the natural history of atherosclerosis involves an evolution from the fatty streaks of childhood to the fully developed fibrous plaques of the adult disease. The trouble with such an assumption is that the fatty streaks appear to be

Energy... Canned in America.

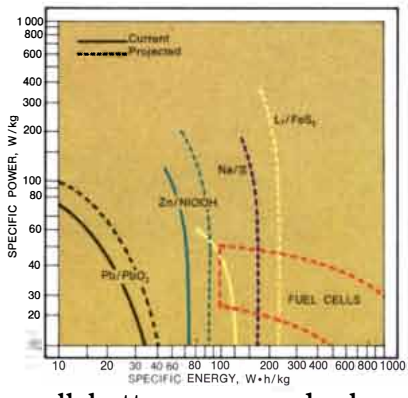
A practical electric car could go a long way toward reducing America's dependence upon foreign oil. To satisfy a large fraction of U.S. urban driving needs, such a car should double or triple the range of present electric vehicles. Urban driving ranges of 30-50 kilometers are now offered by improved lead-acid batteries with specific energies of about 35 watt-hours per kilogram.

The Research Laboratories at General Motors recently has moved more energetic batteries a step closer to reality. Our Electrochemistry Department successfully developed and tested a compact lithium/iron sulfide cell that achieved a maximum specific energy of 115 W·h/kg. This cell is only one-sixth the size and weight of a lead-acid unit with the same capacity.

During a continuous test of more than 14 months, the cell underwent more than 700 deep discharge and recharge cycles. As far as we know, that's some kind of world's record for a high-temperature battery. (It operates at 425-500° Celsius—about the same as a self-cleaning oven.)

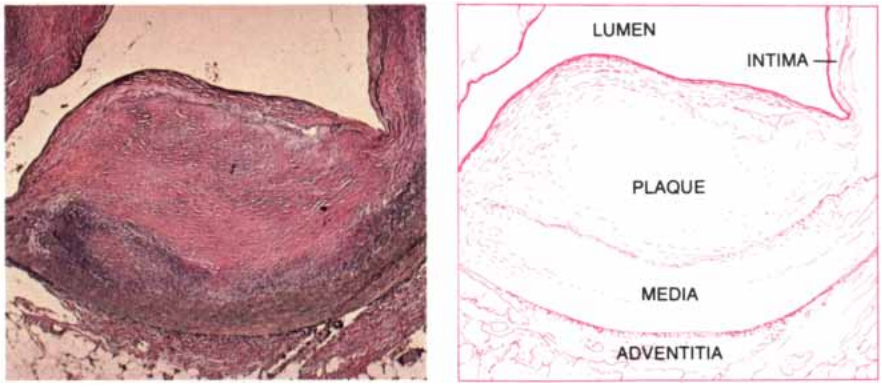
Future high-temperature batteries could increase the range of battery-powered vehicles to 300 km. Electric utilities could use such batteries for storing energy generated during low-demand hours to be used during peak periods.

The performance of other electrical energy systems we're studying is shown in the graph. Much closer to commercial application are our ambient-temperature batteries of zinc/nickel oxide. These may almost triple the range of small, battery-powered urban cars.

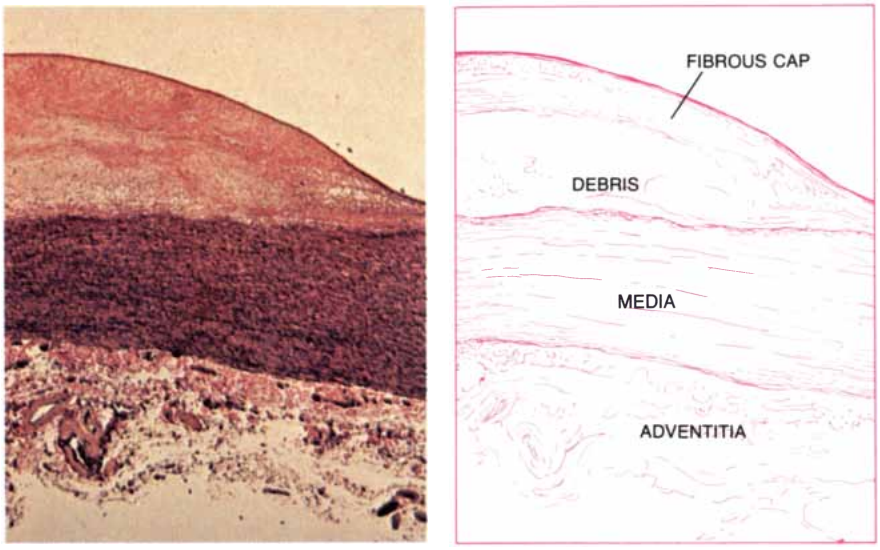


Energy for America's transportation needs—that's where our advanced battery research is driving.

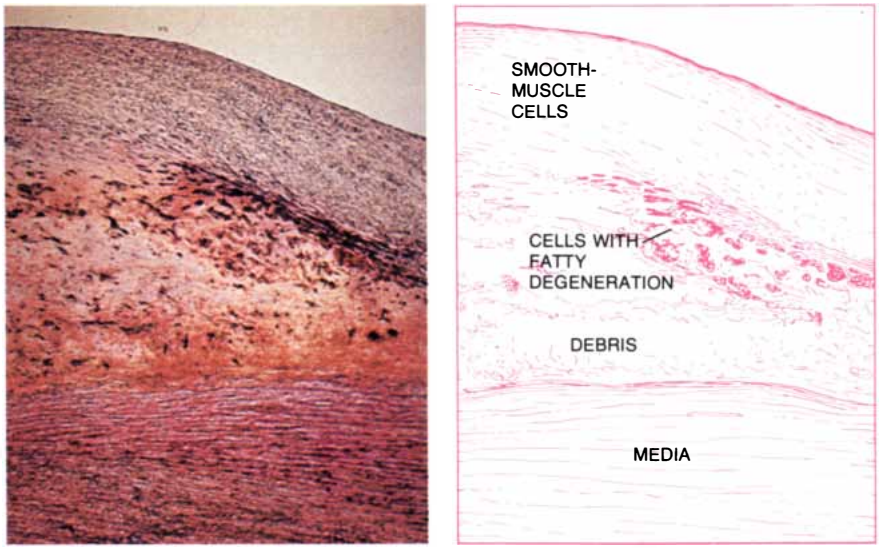
General Motors Research Laboratories
Warren, Michigan 48090



CROSS SECTION OF PLAQUE in a human coronary artery is enlarged 24 diameters in this photomicrograph, which is mapped at the right. The roughly oval atherosclerotic plaque, stained pink, is a thickening in the intima of the artery. The next layer is the media, stained brownish black. The outer layer, the adventitia, contains connective collagen and fatty tissue.



PORTION OF PLAQUE in the human aorta is enlarged 27 diameters. The fibrous cap of the plaque, a mass of cells embedded in a matrix of collagen and other extracellular material, is underlain by debris. The plaque is elevated above the adjacent intimal surface of the vessel.



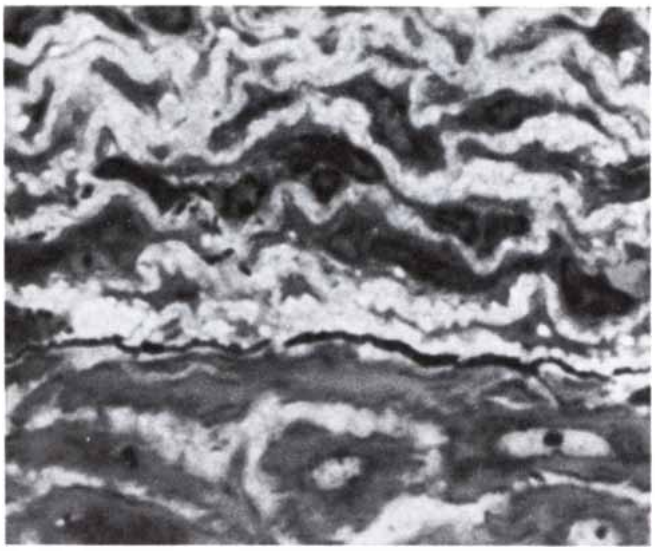
PLAQUE IN THE AORTA is further enlarged to 60 diameters and stained for cell nuclei (*blue*) and fat (*orange*). The cap is clearly composed of many cells embedded in an unstained fibrous matrix. The debris includes cells that contain fat and, below them, extracellular fat.

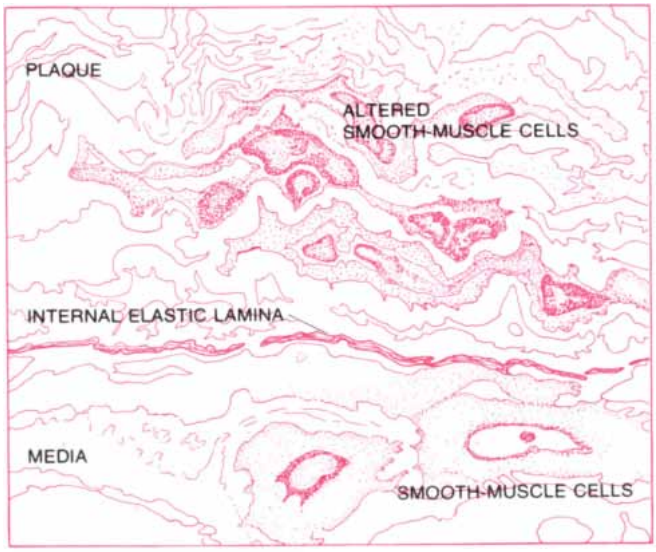
present to about the same extent in children of all populations, whereas adult atherosclerosis is rare in some populations and common in others.

The other basic concept of the origin of atherosclerosis, the encrustation theory, holds that the plaque begins with a small mural thrombus that is converted into a mass of tissue in the intima as arterial-wall cells migrate to it, multiply and then secrete the characteristic extracellular substances. Localized injuries to the arterial wall in experimental animals lead to a repair process of that kind, and substances that pass from the plasma into the wall, along with debris from dead and disintegrating elements of the thrombus, do cause such experimental lesions to resemble atherosclerotic plaques in many ways. It is postulated that in human atherosclerosis such lesions grow large enough to obstruct an artery as the result of repeated episodes of injury, each followed by the reparative clotting, migration and secretion.

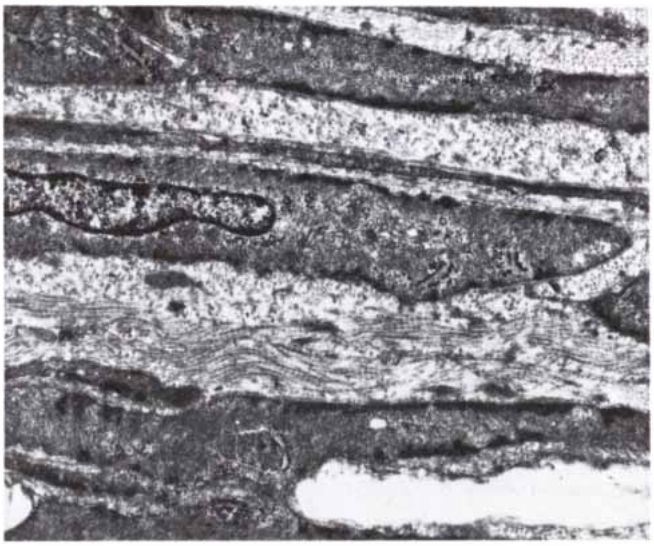
Ideas about the nature and origin of atherosclerosis began to change when the electron microscope revealed the cellular composition of the plaque. The fibrous, cellular cap covering the cholesterol-rich debris turned out not to contain ordinary fibroblasts, the cells that proliferate to heal a skin wound, but rather to contain smooth-muscle cells similar to those of the normal artery wall. Then it was discovered that in its early stages the human plaque does not contain much lipid, which implied that lipid insudation is not the primary initiating factor. By now the major current theories of the genesis of atherosclerosis share the belief that the lesions begin as localized excessive accumulations of smooth-muscle cells in the intima. The current debate is about what initiates those accumulations and what makes them grow.

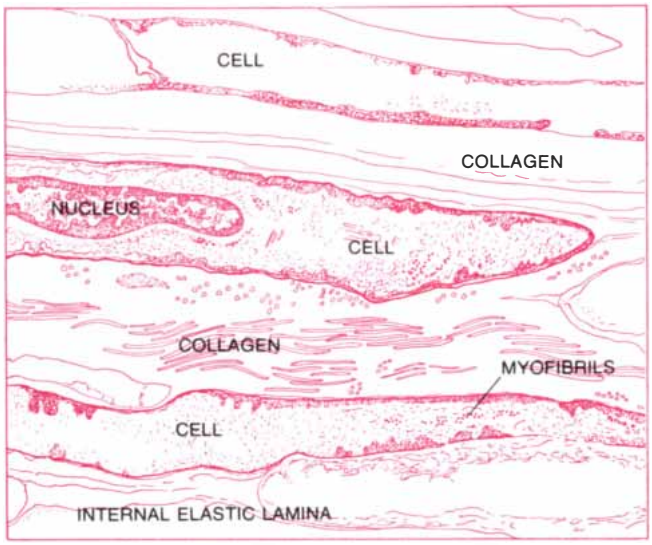
After having worked with various animal models of atherosclerosis in our laboratory at the University of Washington School of Medicine and having found them unsatisfactory, in 1967 I began, along with Ned S. Moss, to study atherosclerosis in chickens. That was the animal in which Ruth Pick, Jeremiah Stamler and Louis N. Katz of the Michael Reese Hospital had discovered that the development of fatty lesions in chicken blood vessels after cholesterol feeding could be prevented by treatment with a form of the female hormone estrogen; their finding had led to trials in which estrogen was administered to some male coronary patients in an effort to prevent a second occlusion. Moss and I fed cholesterol and administered estrogen to chickens and examined their vessels with the electron microscope. We found, first of all, that the lesions that cholesterol induced in the chickens did not resemble human atherosclerotic

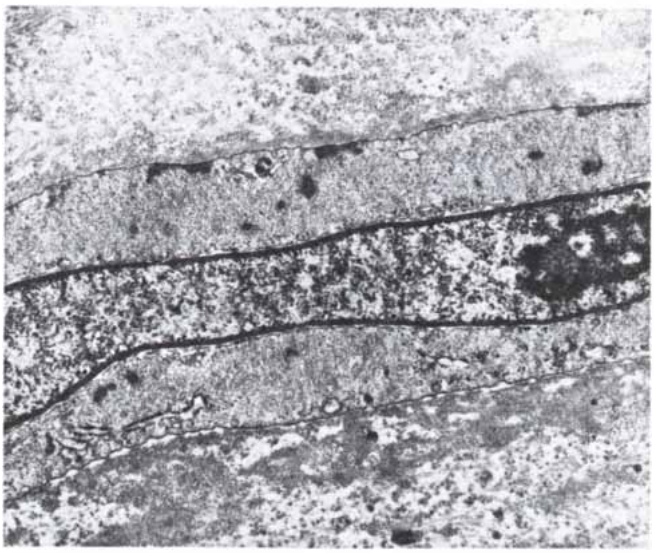


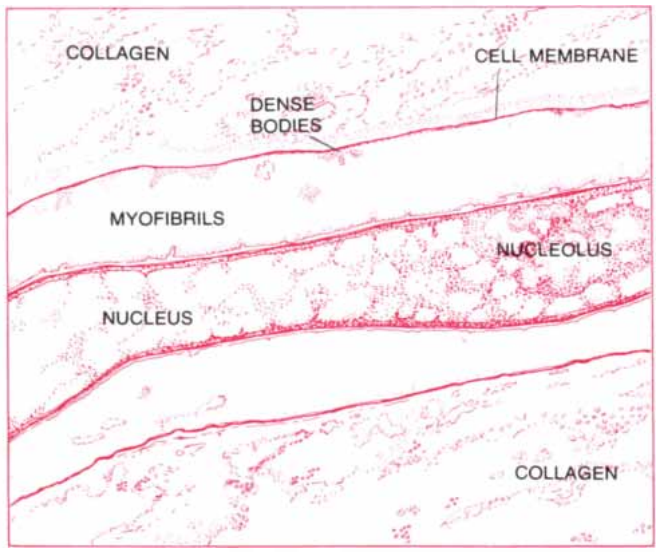


CELLULAR NATURE of an early atherosclerotic plaque is demonstrated in this photomicrograph. A section of the media and the base of an early plaque in the aorta of a chicken is enlarged 1,200 diameters. The cells of the plaque are altered smooth-muscle cells.

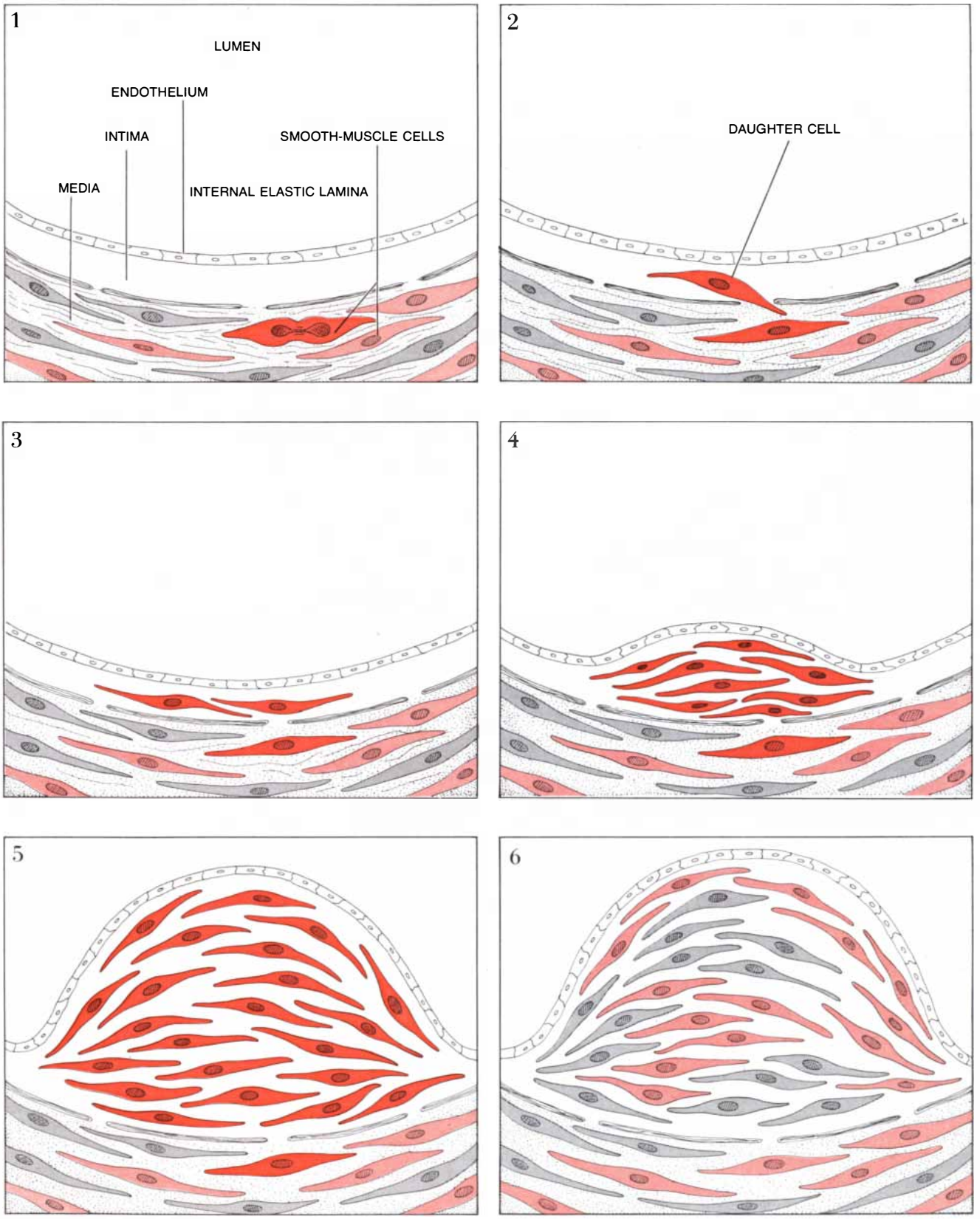








INDIVIDUAL CELLS of plaques appear in these electron micrographs made by Ned S. Moss. Cells from the base of an early lesion in a chicken artery are enlarged 15,000 diameters (*top*). Collagen fibers are seen head on and from the side, running between smooth-muscle cells. A single smooth-muscle cell is enlarged 40,000 diameters in a micrograph of a plaque from a human coronary artery (*bottom*).



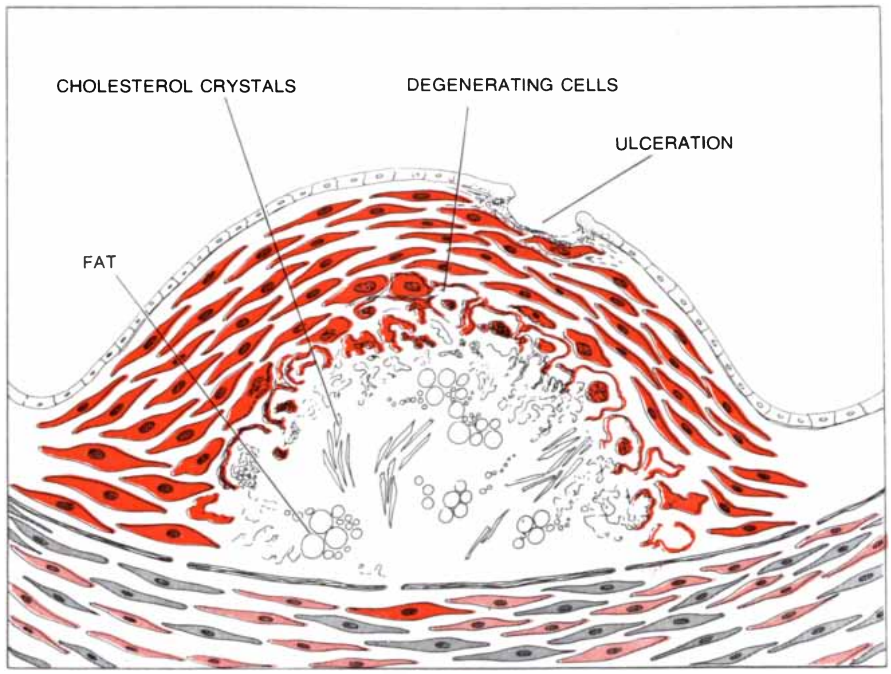
GENESIS OF A PLAQUE as proposed by the monoclonal hypothesis is traced in these highly schematic drawings. The process begins in the inner media. There are two cell types. A single cell (*dark color*) has undergone a mutation that gives it a selective advantage, and some stimulus causes the mutated cell to divide (*1*). Its daughter cell migrates into the intima (*2*). The progeny of the mutated cell, having a selective advantage and perhaps somehow freed of some curb on proliferation, continue to multiply, thickening the intima (*3, 4*) and eventually forming a lumpy plaque (*5*) all of whose cells are progeny of the original cell that mutated. The last drawing (*6*) shows, by way of contrast, a polyclonal plaque, which is the kind that would arise from the migration and proliferation of many cells of both cell types.

plaques. They appeared to be composed entirely of fat-filled cells derived from blood macrophages; there was no evidence of significant smooth-muscle-cell proliferation. And none of the lesions evolved into the raised plaques characteristic of the human disease. We found, on the other hand, that chickens that were not given cholesterol developed an arterial disease whose lesions did bear a striking resemblance to the plaques of human coronary atherosclerosis. Actually this naturally occurring disease of chickens had been well described in the literature of comparative pathology, but we had all tended to ignore it when our attention was focused on the experimental disease produced by cholesterol.

Now we were able to observe the earliest stages of plaque formation in young, untreated chickens. The first sign of a naturally occurring plaque was a small group of cells in the intima, which is normally populated by only an occasional cell. As we reconstructed the sequence of events, one cell or possibly a few cells migrated from the media, proliferated and slowly gave rise to a mass of cells in the intima. There was no evidence of cholesterol deposits in these early lesions. Degenerated and dead cells, intercellular debris and cholesterol deposits did, however, appear in the later stages. Why? What was the precise source and nature of the cells that populated the plaque? What initiated their proliferation and what caused the continued multiplication and degeneration that produced the fully developed fibrous plaque?

We noted that the cells of the early spontaneous plaque were subtly different from normal artery-wall cells. They were arrayed differently, they appeared to be smaller and to have few or no intercellular junctions, and in contrast to the normal cells of the media they manufactured larger amounts of collagen than of elastin. Moreover, the early lesions developed fatty vacuoles (cavities) when the chickens were on cholesterol; nearby normal artery-wall cells did not develop such vacuoles. Perhaps some metabolic change stemming from the movement of the cells to a new location was responsible for the various differences between artery-wall and plaque cells in chickens.

We decided next to see for ourselves just what the cells of a normal artery wall look like in the course of injury and repair. John Poole (who was visiting our laboratory from the University of Oxford), Stephen Cromwell and I simulated an injury by putting a fine suture in the artery wall. A thrombus formed around the part of the loop that was in the flowing bloodstream, and smooth-muscle cells migrated from the media into the thrombus, where they multiplied. These cells that populated the thrombus had all the characteristics (apart from some positional distortions) of the normal smooth-muscle cells of the media, including the formation of elastin and the development of intercellular junctions. In other words, they were in sharp contrast to the modified smooth-muscle cells we had seen in the spontaneous lesions in chickens.



ADVANCED MONOCLONAL PLAQUE is often ulcerated at the surface where endothelial and smooth-muscle cells have died. The interior is filled with fatty debris, the result of cell death and degeneration as well as of migration of cholesterol and lipoproteins into the plaque.

We realized then that various forms of the insudation-irritation theories had continued to dominate thinking about the cellular proliferation observed in plaques. At one time it had been assumed that the cells were wound-healing fibroblasts, and this fitted the idea of a response to irritation. Then electron microscopy had revealed that the cells were smooth-muscle cells, not fibroblasts, and yet no one had seriously questioned that the cells were there in response to some kind of irritation.

The study of the spontaneous lesions and the suture-induced lesions emphasized the unusual nature of the spontaneous-plaque cells and pointed to one of two origins for them: they could come from some small cell population that is present but not ordinarily observed in the normal media and is caused to proliferate by a stimulant of some kind, perhaps one connected with injury, or they could be smooth-muscle cells that have been altered by mutation. If they are genetically altered cells, then the cells of a given plaque would be expected to be monoclonal: to have been derived, like the cells of a benign tumor, from a single mutated cell. If, however, the plaque cells arise in response to injury or some other stimulus, the stimulus would presumably have its effect on many normal cells at many places, in which case the plaque cells should be polyclonal. The question—monoclonal or polyclonal—is susceptible to experimental testing in humans by a genetic technique.

The technique, originally applied by the geneticist A. H. Sturtevant to the study of tissue development in fruit flies, is based on the fact that an individual animal may be a "mosaic" composed of two distinguishable cell populations. As Mary F. Lyon of the Medical Research Council Radiobiology Unit at Harwell, England, first postulated, this is true of all human females. In female cells there are two *X* chromosomes, one derived from the father and one from the mother, only one of which is active in adult cells; the other is inactivated early in embryonic development and remains in the nucleus as a dense bit of chromatin known as the Barr body. The inactivation in any one cell is apparently random, so that either the maternal *X* chromosome or the paternal one may remain active in a given cell and in all the progeny of that cell. If there is a "marker" gene, such as one for a particular enzyme, in the maternal chromosome that is different from the corresponding gene in the paternal chromosome, one can distinguish between cell populations in which one or the other chromosome is active. There are several such polymorphic genes on the *X* chromosome. One of them codes for the enzyme glucose-6-phosphate dehydrogenase (G-6-

PD), and its two forms code for two major enzyme types that can be distinguished by electrophoresis: when subjected to an electric field, one type (*A*) moves faster than the other type (*B*).

As in the well-known case of the sickle-cell hemoglobin trait, a subset of the *A* type of G-6-PD confers resistance to malaria and is relatively common in the U.S. black population, which originated in malarious areas of Africa and continued to live for a long time in malarious areas of the U.S. About 40 percent of black females are heterozygous for the G-6-PD gene, that is, some of their cells carry each of the two enzyme types. R. G. Davidson, H. M. Nitowsky and Barton Childs of the Johns Hopkins University School of Medicine capitalized on the presence of the two enzyme types to establish the fact that once a particular *X* chromosome is inactivated in a human cell it remains inactivated. They cultured bits of skin from black women who had the two enzyme types. The fibroblast populations that grew in culture manufactured both enzymes, showing that the cells were of both types. When the investigators isolated single cells from the mixed population and cultured them, however, each clone (the progeny of a single cell) exhibited only one enzyme type, *A* or *B;* repeated subculturing of cells from a single clone continued to yield the same enzyme type. With the stability of the two cell populations' enzyme production thus established, it became possible to turn the process around: to analyze extracts of tissue samples for their G-6-PD composition by electrophoresis, and so to determine their cell mixture. For example, at the University of Washington School of Medicine, David Linder and Stanley M. Gartler examined tumors of uterine smooth muscle and found that each tumor was of one cell type; Philip J. Fialkow and others extended the studies to leukemia and other tumors.

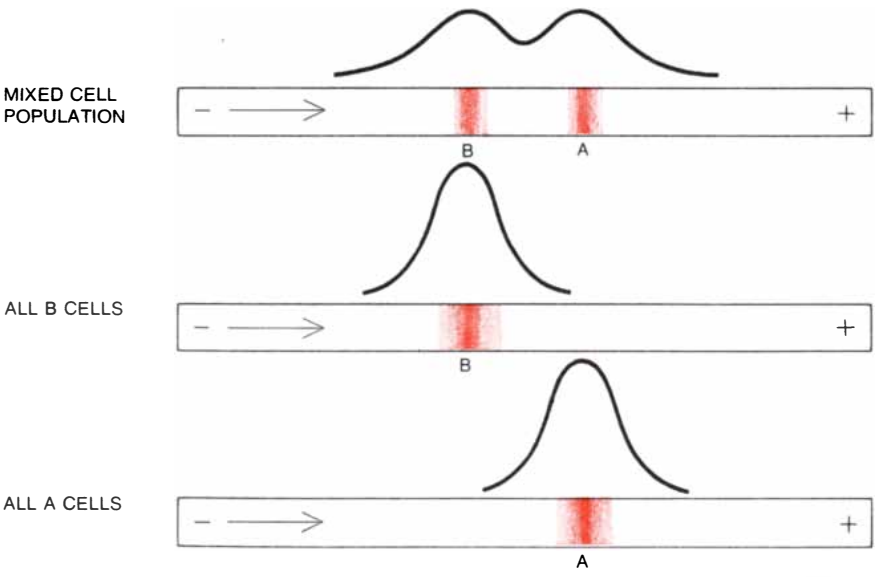
In 1973 we applied this analytic technique to atherosclerotic plaques and normal artery-wall tissue from vessels obtained at autopsy. The first case yielded 15 plaques that could be analyzed. Four produced only the *A* type of the enzyme and eight produced only the *B* type; three showed a mixed cell population. On the other hand, of 27 artery-wall samples that did not exhibit lesions, 25 had a rather even mixture of the two types of cells. (The two samples with a single enzyme pattern may have contained small plaques, but we could not be sure.) Analysis of more cases bore out those first exciting findings; it was clear that an atherosclerotic plaque frequently consists of cells of just one type. In 1975 nearly identical results were reported, based on a larger number of cases, by T. A. Pearson, A. Wang, Kim Solez and Robert H. Heptinstall of the Johns Hopkins School of Medicine. Similar results continue to be obtained as the observations are extended in these laboratories and in others. I should point out that it is not surprising that some atherosclerotic lesions appear not to be monoclonal, since several sources of normally mixed cell populations may be in or close to a plaque, for example contaminating blood cells or ingrowths of adjacent artery-wall connective tissue. Indeed, I had expected that blood-cell contamination might prevent our seeing any clear distinctions, and the data were therefore surprisingly unequivocal.

Before one can interpret the presence of only one cell type in a particular cell growth in a mosaic organism as being evidence of monoclonal origin, however, several issues need to be settled. First, one must establish that the size of the patches of cells of one type that can be found in normal tissue (patches that are presumably the result of accidents of cell growth and mixing during the formation of the embryo) is very small compared with the size of the putatively monoclonal growth. We did this by taking more than 1,000 samples of the smallest possible size from the inner portions of normal artery walls and analyzing the statistical variation in their cell populations. Our data suggest that the volume of a patch of cells of only one enzyme type in normal tissue is about a ten-thousandth of a cubic millimeter, which probably means it contains about 10 cells. A typical plaque, in contrast, has a volume of many cubic millimeters.

Second, one must exclude the possibility that the usual proliferative response seen in healing processes stems from a single cell. There are several indications that such is not the case. Wounds are quite generally observed to heal by the simultaneous proliferation of cells all around the periphery; more specifically, we found that many cells around a small injury to the aorta of experimental animals divided simultaneously. Moreover, examination of the thickened intima seen in middle-aged and elderly people, which is thought to be the result of repeated small injuries, reveals that the thickened areas are composed of mixed cell populations.

Some investigators have held that the presence of just one cell type in atherosclerotic plaques may be due to some process that favors the proliferation of one of the two cell types present in a mosaic individual. The fact that we regularly find both lesions composed of type-A cells and lesions composed of type-B cells in the same individual indicates, however, that neither enzyme type is producing a selective advantage or disadvantage.

It seems reasonable to consider the single-cell plaque as being monoclonal in origin and to propose that some event provides a single cell with an advantage over its neighbors, and that the progeny of that altered cell dominates an ensuing process of normal replacement multiplication or some kind of stimulated multiplication. The commonly accepted reason for the appearance of such a selective advantage in a body cell is an alteration in its genetic apparatus: a mutation. We have proposed that there are three stages in the pathogenesis of athero-



ELECTROPHORETIC PATTERN reveals the presence of two cell populations with two enzyme types. Enzyme solutions applied to a membrane migrate across it (*arrows*) under the influence of an electric current. After 50 minutes the position of the enzyme bands is visualized (*color*) by allowing the enzyme to react with its substrate, precipitating a dye. The presence of two separate bands shows there are two enzyme types; a photometric scan of the bands (*black curves*) allows one to estimate the proportions of the two enzyme types and thus of the cell types.

TR7. THE SHAPE OF THINGS TO COME AT A PRICE YOU CAN AFFORD TODAY

$4,995*

BRITISH LEYLAND

TRIUMPH

Besides an attractive price, there are other compelling reasons for owning a TR7. For example:

Consider its performance. TR7 won the Sports Car Club of America's Northeast Divisional Championship. An almost-unheard-of feat after only a few months of competition. And racing against such veterans as Lotus, Datsun and Porsche.

Consider its comfort. TR7 offers something most sports cars don't: Room. The cockpit is wider than the Corvette's or the Z-car's. And, since fabric doesn't retain heat or cold like vinyl, its seats are covered with fabric where you sit and vinyl where you don't. Motor Trend singled it out as: "One of the most comfortable two-seaters we've experienced."

Consider what you get. Two-liter overhead cam engine. Rack and pinion steering. Vacuum-assisted front disc brakes. Rear window defogger. MacPherson strut front suspension. Steel belted radial tires and full instrumentation.

TR7. At $4,995,* how can you afford not to own it. For the name of your nearest Triumph dealer call 800-447-4700. In Illinois call 800-322-4400.

British Leyland Motors Inc., Leonia, New Jersey 07605.

THE SHAPE OF THINGS TO COME

TR7

*Base P.O.E. sticker price, 1976 models. Transportation, local taxes and preparation extra.

Make your best deal on a Minolta electronic SLR before February 28, 1977. And we'll make it up to $75.00 better.

$75.00 cash back on the Minolta XK with Auto-Electro head and MC Rokkor-X f/1.7, f/1.4 or f/1.2 normal lens. $65.00 rebate on XK body with Auto-Electro head.

$40.00 cash back on the Minolta XE-5 with normal lens, $30.00 rebate on XE-5 body only.

Up to $75.00 cash rebate

Up to $40.00 cash rebate

Up to $60.00 cash rebate

$60.00 cash back on the Minolta XE-7 with normal lens, $50.00 rebate on XE-7 body only.

These limited-time cash rebates are your chance to own one of Minolta's finest electronic 35mm reflex models for close to what you'd pay for an ordinary mass-produced camera.

Make the best deal you can with your dealer. Then get a generous rebate besides, directly from Minolta.

The amount of the rebate you get depends on the camera you choose:

Up to $75.00 cash back on the Minolta XK. The only electronic 35mm SLR with interchangeable finders and focusing screens, plus virtually every convenience and creative feature you can imagine.

Up to $60.00 cash back on the XE-7. Quiet as a whisper, this camera's electronic shutter responds instantly and automatically to the most subtle changes in light.

Up to $40.00 cash back on the XE-5. An even more money-saving version of the XE-7, it has Minolta's remarkably quiet electronic shutter, easy handling, and a full complement of useful features.

The Minolta Rebate Plan. It gives you a great deal on a great deal of camera.

For illustrated literature on Minolta's electronic cameras, see your camera dealer or write Minolta Corporation, 101 Williams Drive, Ramsey, N.J. 07446.

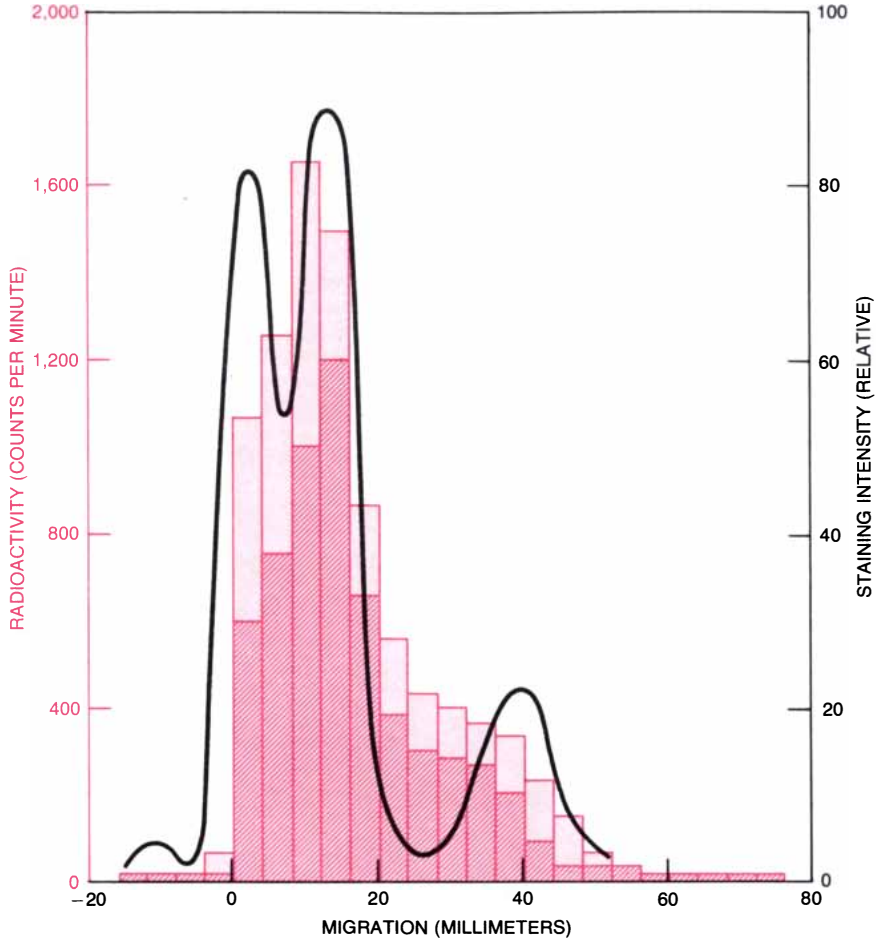
Minolta

This offer applies only to Minolta electronic 35mm SLR's purchased between November 1, 1976 and February 28, 1977 by a consumer for his or her own use or as a gift and not for resale. Claims must be postmarked no later than March 15, 1977. Offer good only in the United States, U.S. Virgin Islands and Puerto Rico; Minolta reserves the right to modify or discontinue it without notice.

sclerosis. First comes an initiation stage during which there is mutation in an artery-wall cell. Then some factors or conditions promote the expression of the selective proliferative advantage conferred by the mutation, enlarging the mass of cells; the mutation, in other words, may never be expressed as gross plaque formation unless something promotes cell multiplication and gives the altered cells an opportunity to express their altered capability for growth. Finally, there is the stage of complication; the tendency of cells to degenerate and of lesions composed of those cells to break down and ulcerate is compatible with the presence of an altered cell population.

If this general proposal is correct, one ought to consider as causes of atherosclerosis the conditions and factors that cause mutation or facilitate the expression of advantageous mutations. Among the possible initiating factors are intrinsic genetic ones that lead to excessive mutations and such extrinsic ones as chemical mutagens, viruses and possibly ionizing radiation. The factors that might promote the subsequent development of atherosclerotic plaques are those that promote cell multiplication, such as certain chemical or physical injuries. The possible causes of the third stage, plaque degeneration, are not at all clear yet.

The primary value of the monoclonal hypothesis is that it provides a new framework within which one can ask new questions about the role of various risk factors. Cigarette smoking, dietary habits, changes in blood lipids (of genetic or dietary origin) and hypertension (high blood pressure) have all been implicated as contributing to the rising incidence of coronary disease and strokes. How does cigarette smoking, for example, fit into the monoclonal hypothesis?



POTENTIAL MUTAGENS are carried in the blood by the same blood proteins that carry cholesterol. The black curve shows the electrophoretic pattern of lipoproteins in human blood serum; the peaks at the left represent the chylomicrons and the low-density lipoproteins. Radioactively labeled cholesterol dissolved in serum migrated mainly with those lipoproteins (*color bars*). A radioactive sample of the premutagen methylcholanthrene migrated in the same lipoproteins (*hatching in bars*) as cholesterol, lipoproteins known to move to cells of artery wall.

The burning of cigarettes manufactures chemical substances that are known to be precursors of mutagens; among them are the aryl hydrocarbons, such as benzpyrene and methylcholanthrene. The fact that the enzyme aryl hydrocarbon hydroxylase, which converts these premutagens into mutagens, is induced (produced in extra amounts) in the liver and other tissues when the substances are administered shows that they are taken up by the blood and carried through the body. In what blood elements are these noxious substances carried? We have shown by electrophoresis that they are carried in the low-density and very-low-density lipoproteins, the same fraction of the blood-protein spectrum in which cholesterol is carried. It has also been noted that the higher the concentration of lipoproteins in the blood is, the more aryl hydrocarbons the blood will carry. Where do the aryl hydrocarbons go? Workers in several laboratories have established that blood lipoproteins seem to be particularly good nutrients for culturing smooth-muscle cells from the human artery wall. Mont Juchau, James Bond and I have found that the aryl hydrocarbon hydroxylase enzyme system is present in the artery wall of rabbits, monkeys and human beings—and that the system in the wall is induced, or turned on, by aryl hydrocarbons.

What all of this means is that artery-wall cells are capable of converting into mutagens certain premutagenic substances that come from the environment and are transported to the cells by blood lipoproteins. Does that happen and does it cause atherosclerosis? Roy E. Albert and Martin Vanderlaan and their colleagues at the New York University School of Medicine administered two known mutagens, benzpyrene and dimethylbenzanthracene, to chickens. The mutagens gave rise to marked increases in the number of plaques in the aorta and in the rate at which the plaques developed, and they did so without there being any increase in the blood level of cholesterol. The mechanism of plaque formation in the chickens has not been reconstructed, but the results are consistent with the monoclonal hypothesis.

Cholesterol, the centerpiece of the insudation theory, may also be found to fit the monoclonal hypothesis. M. F. Gray, T. D. V. Lawrie and C. J. W. Brooks of the University of Glasgow noted the presence of an epoxide derivative of cholesterol in human blood serum and found that the epoxide's level was elevated in people with high blood cholesterol. Cholesterol epoxide is known to be able to produce connective-tissue tumors in mice and rats. Perhaps it is because epoxides or other substances formed in the body from cholesterol are mutagens that cholesterol levels correlate with the incidence of coronary disease. Clearly it would be interesting to look for evidence of mutagens in the blood serum of populations that have high and low risks of atherosclerosis. We have begun to do that, working with the bacterial mutagen-screening system developed by Bruce N. Ames of the University of California at Berkeley. There are also mammalian-cell-culture

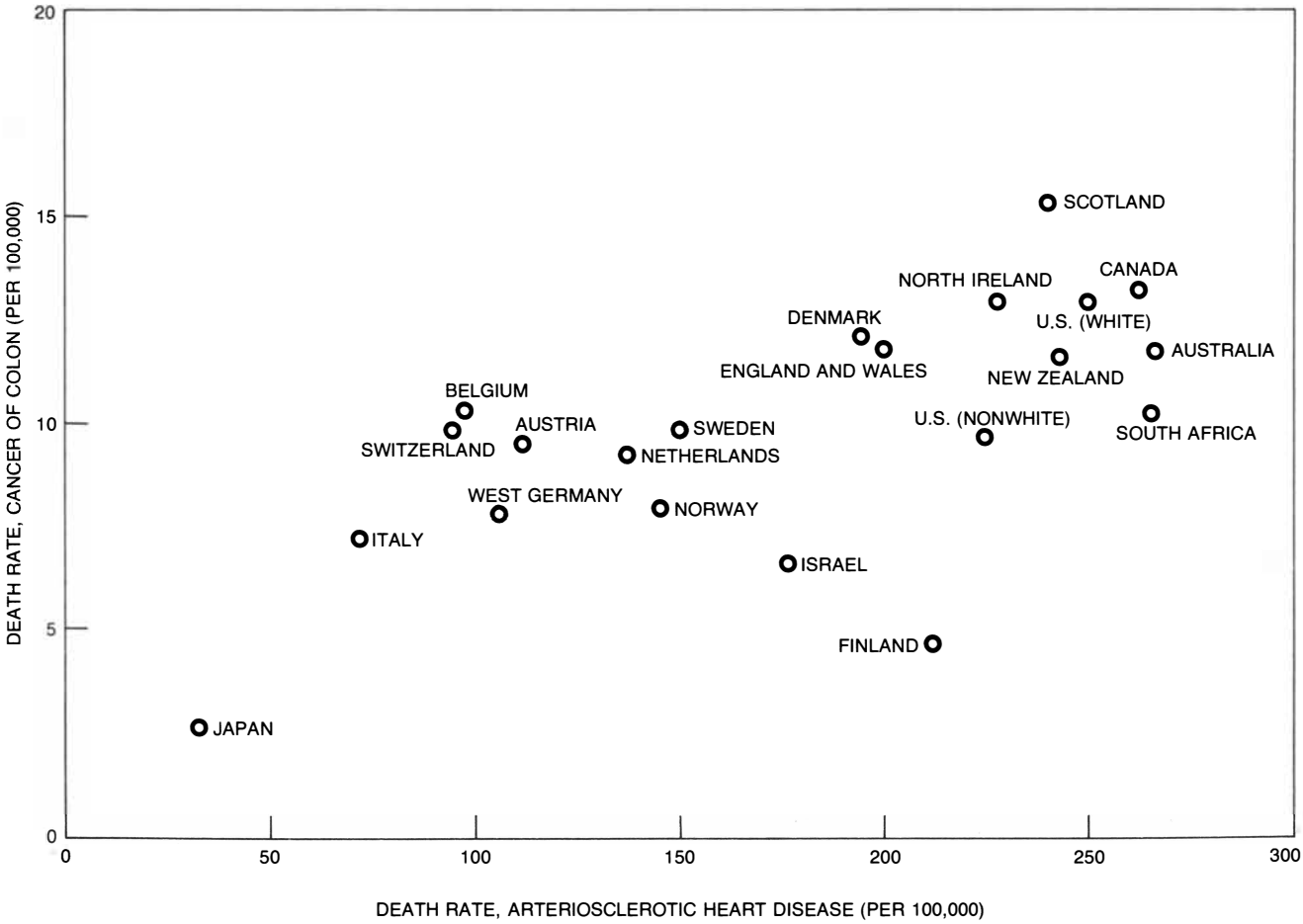
systems by means of which one can find substances that are injurious to DNA, the genetic material, and hence likely to be mutagenic for animal cells.

High blood pressure, which is known to increase the risk of atherosclerosis, may do so by exerting a chemical or even hydrodynamic effect that makes artery-wall cells multiply faster; in our laboratory Stephen Schwartz is trying to identify some such mechanism. Recently R. W. Pero and his colleagues at the University of Lund in Sweden found that the DNA of people with hypertension is more susceptible to breakage in cells by mutagens than the DNA of people with normal blood pressure. This finding seems to conform with evidence that the incidence of cancer is higher in individuals with hypertension. Is it possible that there are subsets of the human population with an increased propensity for mutation in particular tissues, such as the artery wall? An increased potential for mutation, if it is combined with exposure to substances in the environment that enhance the rate of mutation, could lead to a higher incidence of plaque formation.

The epidemiologist Ernest L. Wynder has pointed out an association on a geographical basis between the death rates for cancer of the colon and for arteriosclerotic heart disease [*see illustration above*]. Presumably there are either environmental or genetic factors, or both, that effect such an association. A connection has been established between at least one dietary factor and cancer as well as atherosclerosis: breast-cancer rates have been found to be closely correlated worldwide with dietary fat intake, a correlation not unlike that found for deaths from heart disease.

I have alluded to therapeutic trials of estrogens for preventing recurrent heart attacks in men. They were undertaken on the basis of experimental evidence in chickens and of the well-known observation that before menopause women have fewer heart attacks and less atherosclerosis than men, whereas after menopause the incidence in women of both coronary disease and atherosclerosis rises. When estrogen was tested in men in a large and carefully designed study, the Coronary Drug Project, no overall positive therapeutic effect of estrogen could be discerned. On the contrary, the overall death rate for the men given estrogen was somewhat higher than that for the control group, and so the treatment was discontinued. The estrogen group also showed an increased incidence of cancer. The monoclonal theory suggests a possible explanation for these effects of estrogen.

Some of the chickens to which Moss and I administered the potent synthetic estrogen diethylstilbestrol developed tumors of the lymphatic system, an effect that had been observed earlier. The atherosclerotic plaques also appeared to be worse in the diethylstilbestrol animals. And in the smooth-muscle cells of the plaques and artery wall of one of them we discovered virus particles, something we had not seen in a great many samples from many animals not treated with estrogen. In some of the earlier experiments at Michael Reese Hospital it had been noted that a combination of cholesterol feeding and estrogen administration caused the spontaneous plaques of chickens to ulcerate. It is well known that diethylstilbestrol can rapidly elicit the proliferation of latent tumor viruses in mice. These various observations suggest that the activation of latent



CORRELATION between the death rates for cancer of the colon and for arteriosclerotic heart disease, indicated by the roughly linear arrangement of points on this scatter chart, suggests that cancer and atherosclerosis are likely to have some causative factors in common.

viruses may be a possible mechanism by which some of the complications of human atherosclerosis are induced.

The idea that atherosclerotic plaques may be some form of neoplasm, or abnormally proliferating tissue, is quite startling if one's concept of a neoplasm is limited to malignant cancers, which spread. Many tumors, however, are benign: they remain localized, grow slowly and may even regress. As a matter of fact, a current concept of how cancers originate postulates that several successive mutational steps are required before extreme loss of control allows the tumor to spread [see "The Cancer Problem," by John Cairns; SCIENTIFIC AMERICAN, November, 1975]; it appears that many more cells may undergo the first changes toward neoplasia than have up to now been considered. And even a small potential of cells for enhanced growth would obviously have more serious consequences in the narrow confines of an artery than, say, in the skin.

New information is emerging about the biology of the artery wall and its cells that should make it possible to understand how such loss of control may come about. At the University of Washington School of Medicine, Russell Ross and John A. Glomset and their co-workers have found a protein in blood platelets that promotes the multiplication of arterial smooth-muscle cells and other cells in culture; it seems to have a role in stimulating cell proliferation to repair an injury. One can envision the possibility that a step in the evolution of an atherosclerotic plaque is the loss by a cell of the need for this protein, so that the cell and its progeny divide when they should not and thus produce the mass of the plaque. Pursuing a different line of research, George M. Martin in our department has been studying the aging in culture of cells from animal and human artery walls. Cells from different arteries age at different rates; cells from segments of the aorta that are more prone to atherosclerosis tend to age more rapidly. This may be an important clue to what determines the unequal distribution of atherosclerotic plaques throughout the arterial system.

The multifactorial nature of atherosclerosis and its complications is evident. The monoclonal hypothesis does not immediately simplify the problem of identifying the causes of heart attacks and strokes. What it does do, I believe, is to enrich the information and the ideas that are available to investigators. It thereby puts us in a much better position from which to consider, test and identify the multiple factors, genetic and environmental, that are responsible for the current epidemic of these diseases, which not only shorten human life but also impair its quality in our steadily aging population.

Laser Separation of Isotopes

The isotopes of an element, ordinarily indistinguishable, can be sorted out in the monochromatic light of a laser. The process may make isotopes plentiful for medicine, research and nuclear power

by Richard N. Zare

In nature most elements are mixtures of isotopes: they are made up of atoms that all have the same number of protons and electrons but that differ in number of neutrons. Ordinarily the fact that an element is a mixture of several kinds of atoms matters little because the various isotopes are all but indistinguishable in most of their properties. For that very reason, however, when we do want to separate the isotopes of an element, the task can be exceedingly difficult. Some recent investigations into the absorption of laser light by the isotopes of elements and by compounds containing those elements now promise to make the separation both easier and cheaper.

In isolating an element from a compound or a mixture of elements it is common to rely on differences in the chemical properties of atoms. These properties are determined almost entirely by the electron clouds that surround the nucleus; the atoms of each element, of course, have a characteristic number of electrons. The isotopes of a single element, on the other hand, have virtually identical electron clouds: the electrons are identical in number and differ only slightly in their geometric configuration. As a result the separation of isotopes by single-step chemical extraction has not proved practical.

For light elements isotope separation by repeated chemical extraction is possible, but for all those heavier than oxygen only physical methods have been developed. The physical methods all depend ultimately on the small discrepancies in mass per atom that result from variations in the number of neutrons in the nucleus. The best-known of these methods is gaseous diffusion, in which isotopes are distinguished by the slightly different rates at which they diffuse through a porous barrier; lighter atoms pass through the barrier somewhat faster than heavier ones. Gaseous centrifugation, multiple distillation and electromagnetic separation take advantage of other properties that depend on atomic mass. All these procedures are tedious and cumbersome, with the result that the products of separation—isotopically pure or enriched elements—are extremely costly. The enriched uranium that serves as the fuel for nuclear fission reactors is the most important of these products; other isotopes, employed in small quantities in research, in medicine and in other fields, are many times more expensive.

The separation of isotopes by laser light differs fundamentally from other methods. It distinguishes between atoms of different isotopes or between compounds containing different isotopes not on the basis of mass but through subtle differences in electronic structure. These differences, even though they are small, affect the wavelengths of light absorbed by a substance; each isotope absorbs light of a slightly different color. Because a laser emits light of very pure color it can be employed to "tag" the atoms or compounds of one isotope while leaving all others undisturbed.

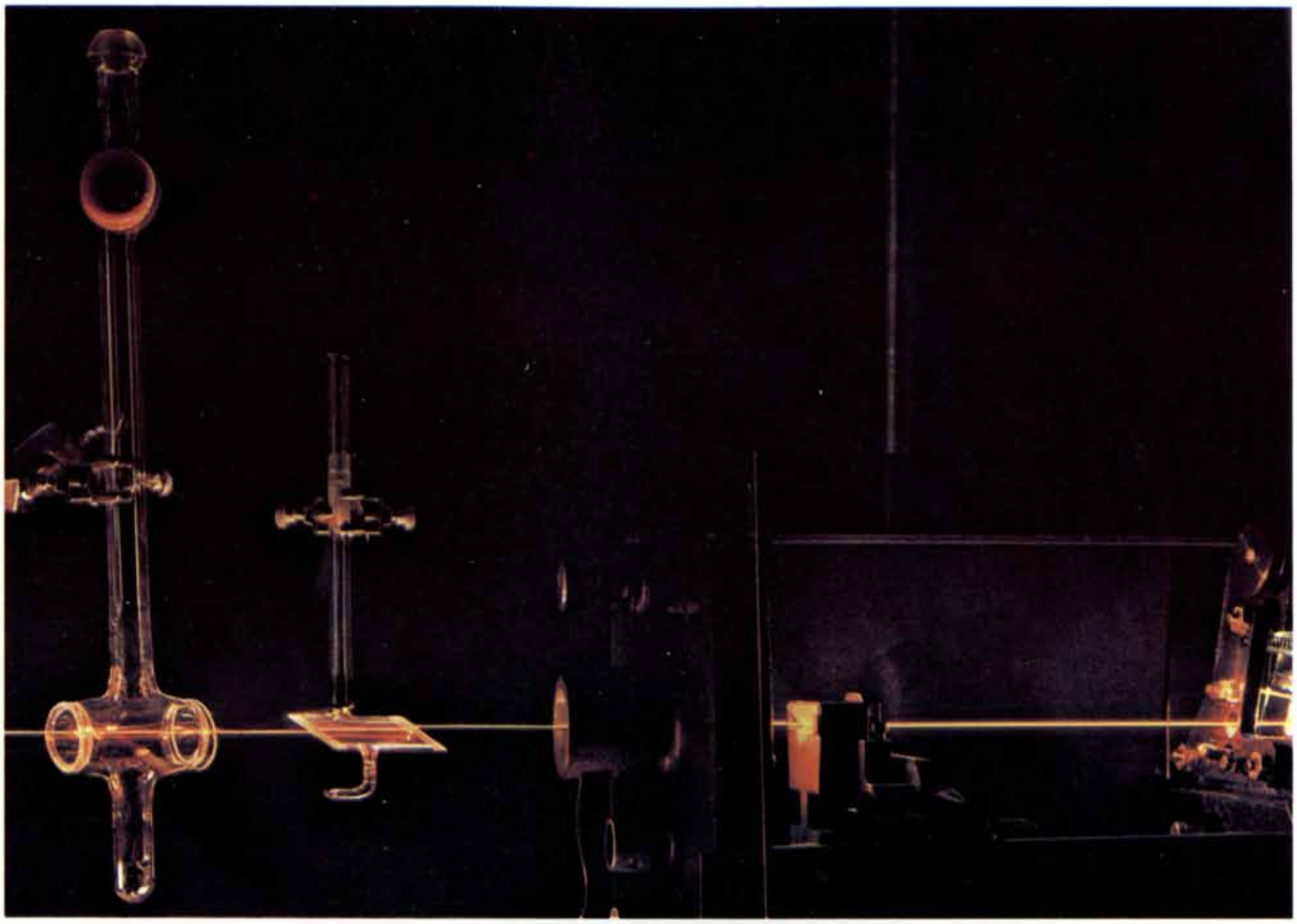
One of the first principles of quantum mechanics is that an atom or a molecule can absorb energy only in discrete units. That is because the atom has only a finite number of discrete energy states, each one representing a particular configuration of its electron clouds. By absorbing or radiating away energy the atom can move abruptly from one state to another, but intermediate energies are forbidden.

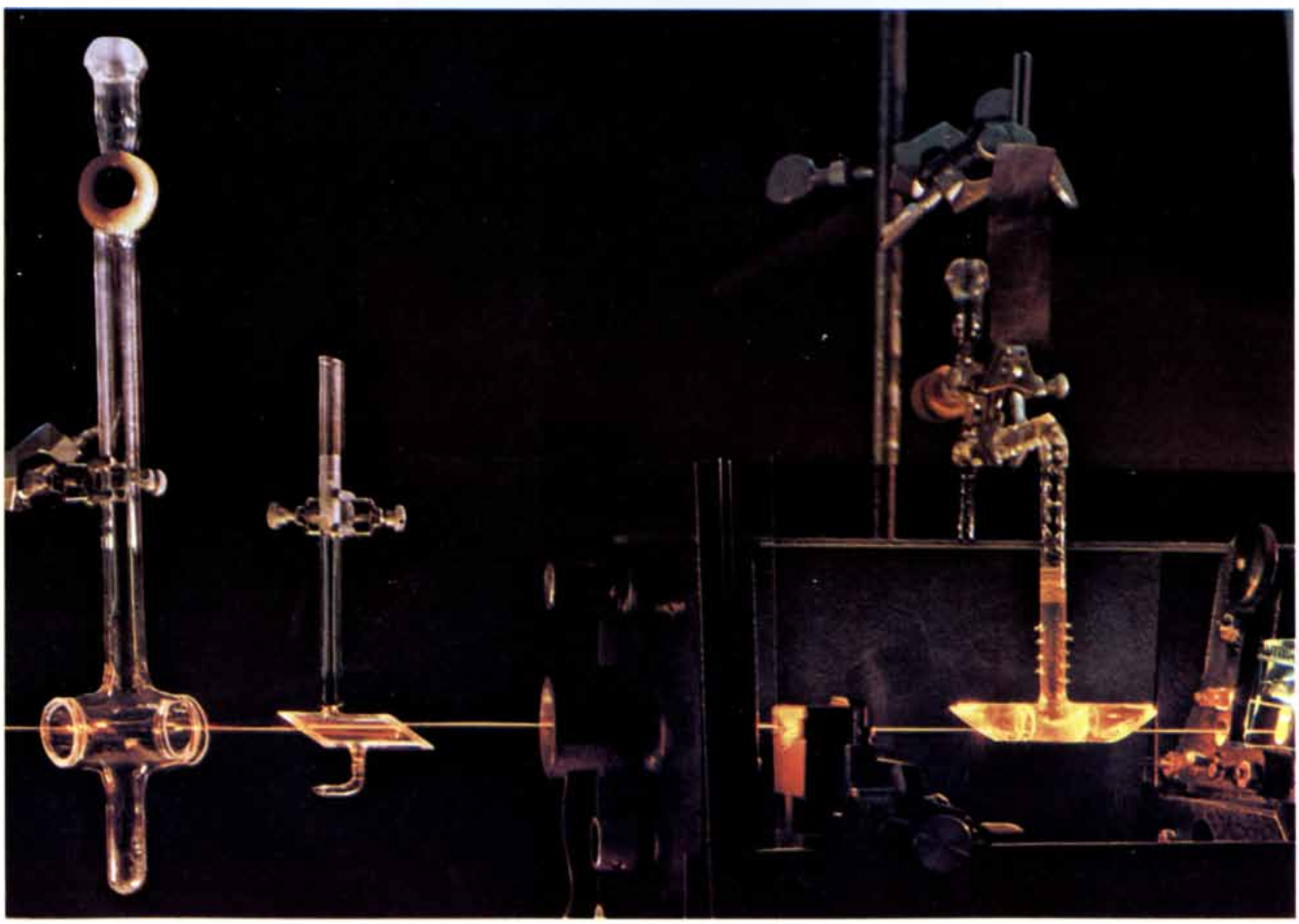
Atoms can make these abrupt transitions by absorbing or emitting light or other electromagnetic radiation. It is only a matter of convenience whether the radiation is regarded as a stream of particles or as a system of waves; the two expressions are formally equivalent. The particles, called photons, each have a definite energy, inversely proportional to the wavelength of the corresponding wave. Photon energy (and wavelength) is unaffected by the intensity of a light source; increasing the intensity simply increases the number of photons. Within the visible portion of the spectrum the energy or wavelength of a photon is perceived by the eye as color.

Light can be absorbed by matter only when the energy of a photon corresponds to the difference in energy between two of an atom's allowed states; photons of other energies simply fail to interact with the atoms and the light is transmitted. When a photon is absorbed, it induces a change in the atom's electronic structure: a single electron is promoted to a state of higher energy and the atom is said to have entered an excited state. On the average the excited electron is farther from the nucleus. Additional photons (of the appropriate energy or wavelength) can elevate the electron to still higher energy levels, and as the energy increases so does the density of the allowed states. The ultimate level is the ionization limit, where the electron is torn loose from the atom; ionization can be regarded as a continuum of allowed states.

After an atom has absorbed a photon

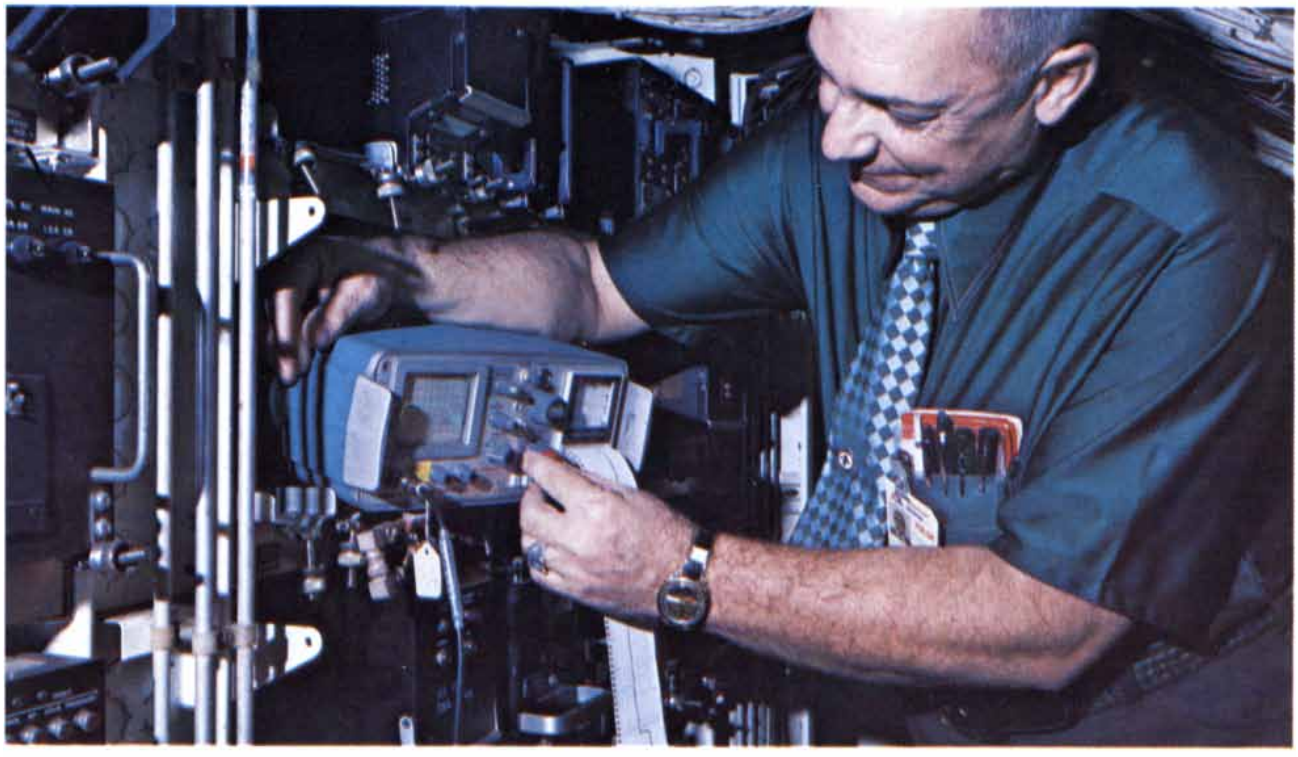
SELECTIVE LASER EXCITATION of two isotopes of molecular iodine (I_2) is demonstrated in an experiment conducted by Douglas M. Brenner and Saswati Datta in the author's laboratory at Columbia University. The laser, part of which is visible at the right, emits light in a narrow band of wavelengths, but its spectrum is broad enough for the light to be absorbed by both isotopes of iodine. The laser beam passes through two glass cells, one containing molecules in which both iodine atoms have an atomic mass of 127 (*left*), the other containing iodine molecules made up of atoms with a mass of 129 (*center*). In the top photograph the light is absorbed by the gases in both cells. Each molecule that absorbs a photon, or light quantum, is promoted to an excited state, then dissipates its energy by reemitting photons, which are observed as fluorescence, a streak of soft orange light through the middle of each cell. In the bottom photograph an additional cell (*right*) containing molecular iodine 127 has been inserted in the laser cavity, where it suppresses the output of the laser at just those wavelengths that are absorbed by iodine-127 molecules. As a result the iodine 127 in the external cell is not stimulated; only the iodine 129 absorbs the laser light and fluoresces. The photographs were made by Fritz Goro.





"With TDR* cable testing at American Airlines, we're finding cable disturbances long before they cause system failures."

Aubrey Thomas, American Airlines
Maintenance and Engineering Center, Tulsa, Oklahoma



Aubrey Thomas checks a cable and antenna by looking at their signatures on the screen of a TEKTRONIX TDR cable tester in a 747's electronic equipment bay, from which most routine avionics troubleshooting can now be done. Not only can he spot subtle changes in systems—if there is a problem, he quickly knows what it is and precisely where.

*Time Domain Reflectometer

Aubrey Thomas points out that "anybody who has had to pull panels throughout an airplane to find a cable fault will understand why we appreciate the TDR's* ability to quickly identify the nature of the problem and to tell where it is—often to the inch, or closer.

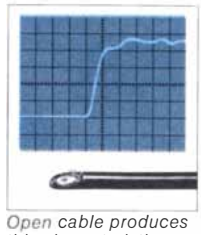
"But even more impressive is a situation where, let's say, you might have to figure out why a pilot was getting strong navigation signals close to a station, but not farther away. If you used a meter and it showed continuity in the system, you might waste hundreds of man-hours and change thousands of dollars worth of components, and still not be any better off.

"But by using the TDR in the equipment bay, you would know immediately that the problem was, let's say, six feet of corroded cable shield, starting at the vertical-fin disconnect and coming back toward the inside fuselage. That's the beauty of the TDR, it's not limited to identifying shorts or opens —it points out any disturbances."

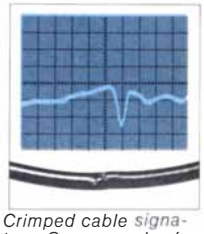
Back in 1971 Aubrey Thomas and two other people at American Airlines were looking for a better way to test the miles of cable that carry radio, navigation, and instrumentation information, as well as power for complex basic electrical systems. "I knew that the TV industry used time domain reflectometry a lot," Aubrey says, "and couldn't see why it wouldn't work on airplanes."

They started by using a TEKTRONIX oscilloscope and plug-in TDR unit, on a roll-around cart. But because work quarters on aircraft are often either cramped or relatively inaccessible, what they really needed was something much smaller and battery powered.

Recognizing these needs, Tektronix had been developing TDR units that were not only small, portable, and battery operated—but were also simple to use, had chart-recording capabilities, could be used in hostile environments (rain, snow, extremes in temperature and altitude), and on a wide variety of cable types.



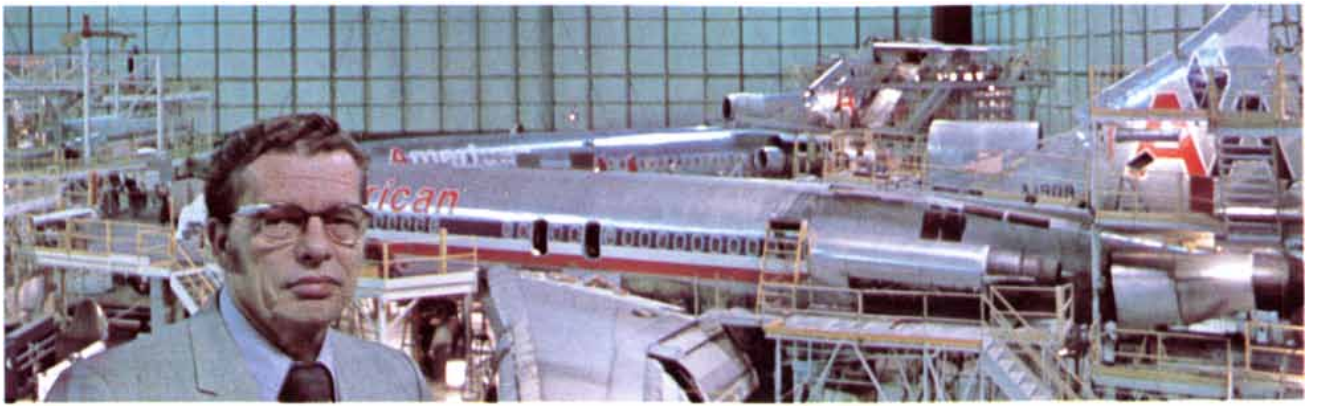
Open cable produces this characteristic signature. Detectable by other methods, but a TDR gives the precise location.



Crimped cable signature. One example of a potential problem virtually impossible to detect by conventional methods.

What an avionics tech sees

A time domain reflectometer (TDR) works in a manner similar to radar. It generates repetitive pulses of energy that are sent down a cable and displayed on a cathode-ray tube screen. Any cable faults (impedance changes) cause pulse reflections. The shape of the reflection (the signature) allows the type of problem to be identified. Distance to the fault is determined by measuring the elapsed time between the pulse and reflection. Entire lengths of cable



"Cost reductions are a major objective at American Airlines. One way we achieve this is through preventive maintenance programs that result in less down-time for airplanes."
John Hill, Supervisor, Aircraft Maintenance Support Group

can be examined, and when a disturbance is detected, that portion of the cable can be viewed in detail.

Conventional testing methods require access to a cable at both ends (a watt meter, for example, being used at one end and a signal source at the other). On aircraft, there is the sheer physical problem of getting to and removing an antenna, for example, which may be out on a wing, on top of the plane, or six stories up a tail fin. Additionally, conventional methods tell if a cable system is shorted or open, but they cannot locate the fault. Nor do they deal with the more difficult situations, such as gradual impedance changes caused by moisture and corrosion. TDR is also very useful where knowing precise cable length is critical.

American Airlines keeps Aubrey Thomas and George Beyl on 24-hour call, forming a two-man office that acts as a liaison between engineering, flight, and repair personnel—doing everything from identifying avionics problems to developing and evaluating test equipment and training maintenance personnel.

Their job is to come up with tools and procedures that solve problems quickly and eliminate guesswork. George recalls an incident that happened in the early days of TDR at American, involving another airline's plane on which American had contracted to do heavy maintenance work. "They'd been having a VHF problem, and I knew they'd been changing transceivers trying to solve it. The TDR told me that the problem was in the cable, in a relatively inaccessible place, 77 feet from the electronic equipment bay. Not a place you want to go into unless you're sure. It took a lot of convincing. And about four hours to get in there. But when the man from the other airline saw I was right, and had located the problem precisely, he looked straight at me and said, 'What is that machine? I want one of them.' "

Tektronix' 1502 TDR Cable Tester ($3,200) is recommended for cable lengths up to 2,000 feet. For longer lengths, such as telephone lines, the 1503 TDR Cable Tester ($2,985) is recommended. The optional, plug-in Y-T Chart Recorder is priced at $575.
U.S. sales price FOB, Beaverton, Oregon

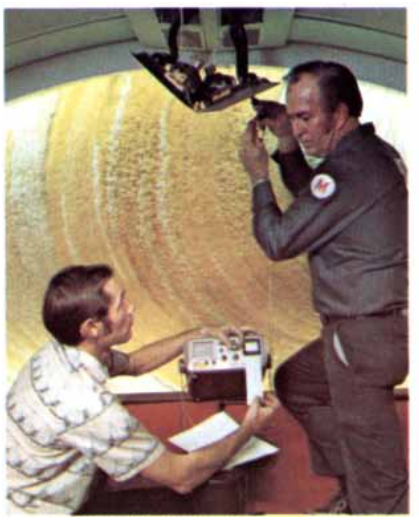
These are just three of more than 835 TEKTRONIX products that serve the test, measurement, and information display needs of thousands of customers worldwide, in transportation, science, education, health, communications, and industry.

For a copy of our annual report or product information, write to Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97077. By phone—call 503-644-0161.

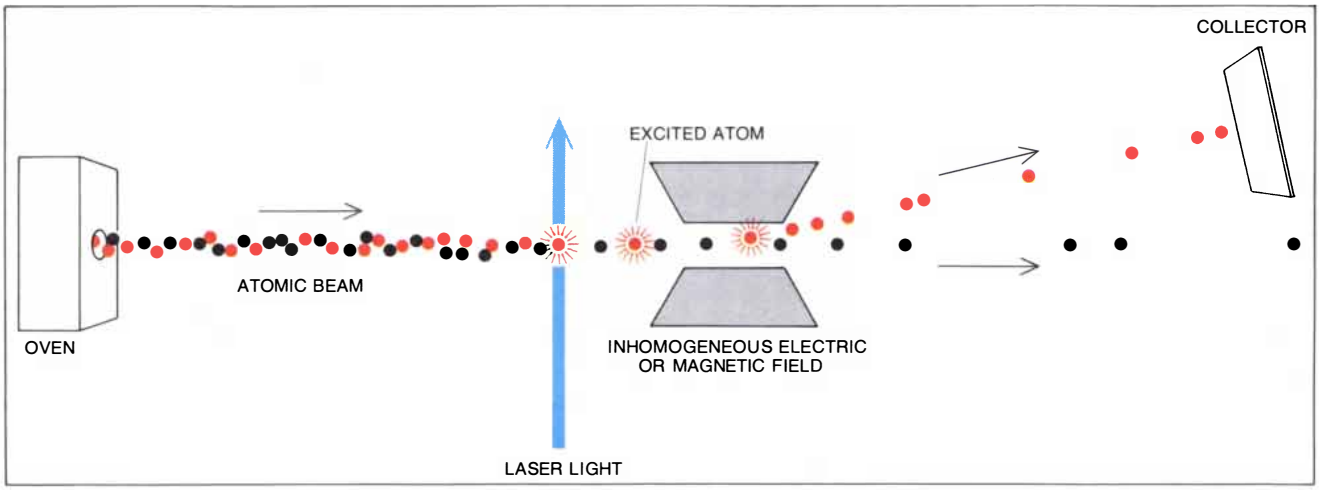
Tektronix
COMMITTED TO EXCELLENCE

Knowing the condition of cables is becoming even more important as avionics systems increase in complexity. Chart recordings provide useful system histories, records of unusual problems, and can be used as training aids.

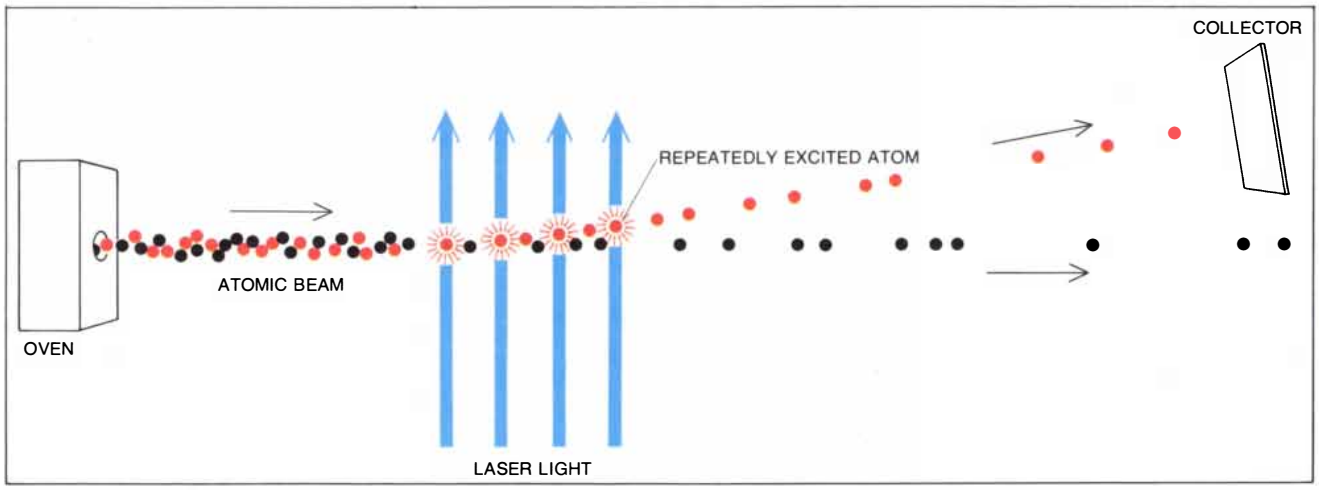
Within minutes, George Beyl (left) and Sterling Griffin tested the new Omega navigation system cable. "The thing about cables on aircraft, "George says, "is that they're buried. Even when you do uncover them, you can't always look at one and say it's good or bad."



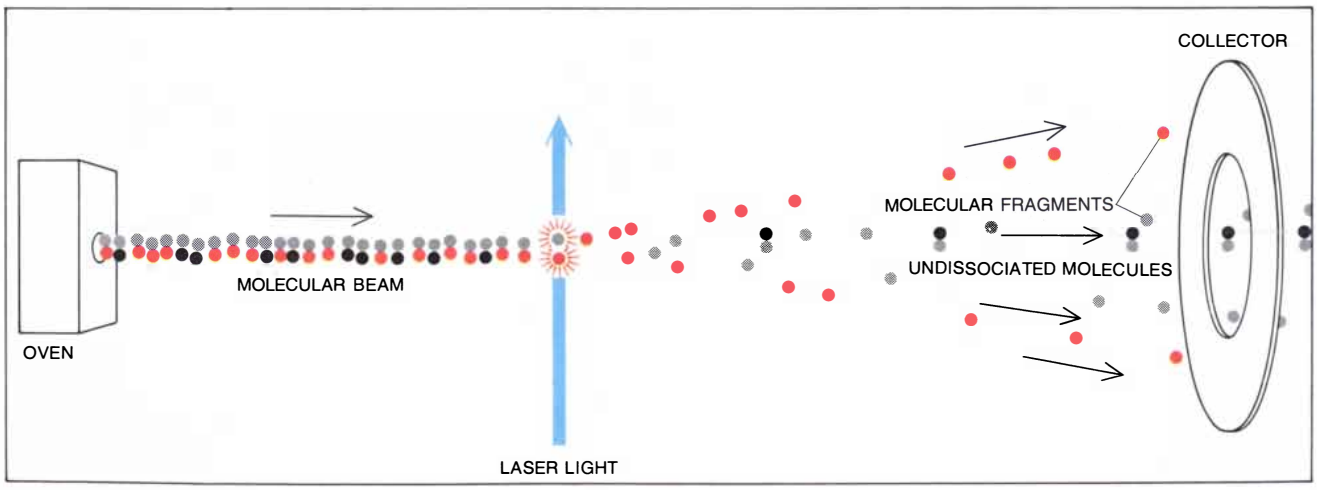
"One beauty of the TDR is its simplicity," says Aubrey Thomas. "I can train a mechanic to use it in about four hours. And since it's battery operated, we can take it anywhere we need it."



DEFLECTION OF EXCITED ATOMS is perhaps the most obvious method for the laser separation of isotopes. The atoms, a mixture of two isotopes (*black dots and colored dots*), issue from an oven to form an atomic beam. They are then irradiated by a laser tuned to excite the atoms of one isotope but not those of the other. Excited atoms often have electrical and magnetic properties different from those of atoms in the lowest energy state, and the excited atoms can be extracted from the beam by an inhomogeneous electric or magnetic field.



RADIATION PRESSURE of repeated photon absorptions can also be employed to deflect one isotopic species. Again the laser is tuned to excite one isotope, but in this case the excited state decays quickly (by fluorescence), so that many photons can be absorbed during the brief transit of the atoms through the laser beam. With each photon absorbed the atom acquires a small increment of momentum, and so it is gradually pushed out of the atomic beam; atoms of the other isotope, which do not absorb the laser photons, are not deflected.



RECOIL OF DISSOCIATING MOLECULES represents a third means of separating isotopes by deflection. The molecules, which are made up of one element that has two isotopes (*black and colored dots*) and another with only one isotope (*gray dots*), have absorption bands that depend on isotopic composition. The laser excites and dissociates only molecules that include one isotope (*color*). Part of the energy of the broken chemical bond pushes the fragments apart; the lighter fragment (*color*) is deflected through a larger angle and can be collected.

it can give up its energy of excitation in any one of several ways. The simplest route is for it simply to emit a photon of the same energy as the one it absorbed; this is the process of fluorescence. Some excited atoms can decay to a metastable state, which persists for a relatively long period before the energy is reemitted. The energy can also be dissipated through a series of small transitions and thereby be converted to random kinetic energy, or heat. Ultimately the atom returns to its lowest allowed energy state: the ground state. Since an atom can occupy only designated energy states, it absorbs and emits light only in narrow lines of precisely defined wavelength, each line corresponding to a particular atomic transition. The collection of all such lines is the spectrum of the atom.

Like atoms, molecules have electronically excited states. In addition, they have vibrational and rotational energy states, corresponding to various possible modes of oscillation and rotation of the constituent atoms around their common center of mass. Transitions between vibrational states are also associated with the absorption and emission of electromagnetic radiation, although the wavelengths involved are generally longer than those of atomic spectra. Most transitions between the electronic energy levels of atoms or molecules are in the visible and ultraviolet regions of the spectrum, whereas transitions between molecular vibrational states are in the infrared.

The characteristic spectra of both atoms and molecules are subtly influenced by the details of nuclear structure. Electrons are bound to an atom by the positive charge of the nucleus, and their motions are determined primarily by the number of protons in the nucleus. Neutrons do have an influence on the electron cloud, however; by changing the mass, volume and shape of the nucleus, changes in neutron number can subtly alter the trajectory of an electron. In a molecule differences in nuclear mass can have somewhat larger effects, by altering the frequency of the molecular vibrational states. All these effects are small and they play no part in most interactions of matter. They are nonetheless crucial for the laser separation of isotopes. They give each isotope of an element and each molecule composed of different isotopes a different set of energy levels, leading to small shifts in absorption and emission spectra.

Several mechanisms for the laser separation of isotopes have been proposed, but all of them have as their basis the same principle. A collection of atoms or molecules containing more than one isotope is irradiated by a laser whose wavelength has been adjusted so that it excites the atoms of one isotope but has no effect on the others. In this way the various species of atoms are distinguished from one another. Several methods are then available for actually sorting them into different "bins."

Laser light is essential to the technique; no other light source would do. Lasers themselves operate by exploiting the quantum-mechanical transitions between the energy levels of atoms and molecules. In a laser a substantial fraction of all the atoms in a population of atoms are promoted to the same excited state; the atoms return to a lower energy state by emitting light coherently, or in phase. The coherence is ensured by bouncing a portion of the light back and forth between two mirrors so that it passes through the laser medium repeatedly, stimulating atoms to radiate as it passes. The two mirrors form a resonant cavity, a kind of organ pipe for light. In some cases the cavity can be "tuned" in order to adjust the wavelength of the light emitted.

Two properties in particular recommend the laser for the work of isotope separation. First, it can produce a light of high intensity, that is, a beam with a large flux of photons; with dimmer sources separation would probably be too slow to be practical. Second, laser light can be made highly monochromatic, so that all the photons emitted have very nearly the same energy. Emission over a narrow range of wavelengths is essential for the excitation of one isotope to the exclusion of others, since the spectral lines of isotopes are generally close together.

The various proposals for laser isotope separation differ mainly in the method employed to extract the selected atoms or molecules after they have been excited by the laser. One of the most straightforward techniques simply exploits intrinsic physical properties that distinguish excited species from those in the ground state. For example, in the excited states of many atoms the electron cloud is more readily distorted in an electric field or it has a larger magnetic moment than it does in atoms in the ground state.

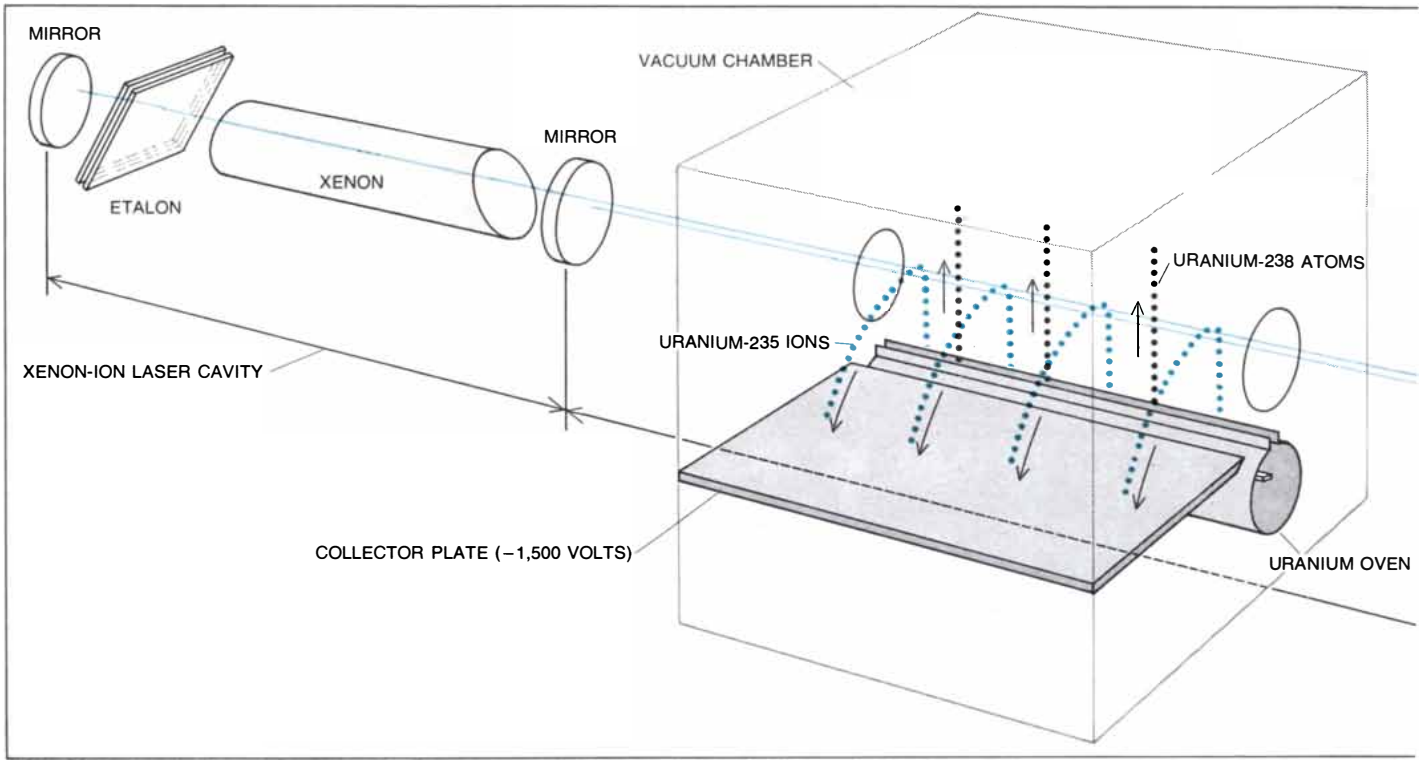
For experiments in isotope separation it is often convenient to employ an atomic beam: a stream of atoms that all move in the same direction and have a relatively narrow range of speeds. The beam is created by evaporating the substance in an oven inside an evacuated chamber; the resulting thermal motions of the atoms are random, with the average velocity determined by the temperature. Atoms that happen to be moving in a particular direction pass through a small opening in the oven, and the beam can be further collimated by passing it through a series of orifices, although only at the cost of reduced intensity. Because the beam travels in a vacuum, collisions that would disturb the straight-line motion of the atoms are minimized. The same technique can be employed to prepare a beam of molecules.

An experiment in the separation of isotopes by the deflection of excited atoms might begin with a beam of some arbitrary element A, which might consist of two isotopes, designated A_1 and A_2. The beam is irradiated by a laser tuned to some feature of the spectrum of the isotope A_1, so that many A_1 atoms make a transition to an excited state (denoted by A_1^*) whereas almost all the A_2 atoms remain in the ground state. The A_1^* atoms are thus conspicuously labeled and can be separated from the rest. The separation is accomplished by passing the atomic beam through an inhomogeneous electric or magnetic field, which deflects those atoms that are more readily polarized or have a larger magnetic moment. The deflected atoms are then collected, for example by condensation on a cooled surface. It should be emphasized that the selective step in this procedure is not the deflection in an inhomogeneous field; the field would deflect excited A_2^* atoms as well as A_1^* atoms. The isotopes are separated because of the selective laser excitation of the A_1 species.

For this process to be successful two conditions must be met: a substantial fraction of all the A_1 atoms must be "pumped" by the laser, and the excited state must survive long enough for the field to cause a measurable deflection. Unfortunately these two requirements are contradictory. A large proportion of the atoms can be made to undergo a particular transition only if that transition is a highly probable, or favored, one, but in that case the reverse transition to the ground state must also be favored. In other words, if an atom is likely to absorb a photon of a given wavelength, then it is also likely to emit such a photon. The excited atoms decay rapidly by fluorescence.

One possible way to resolve this dilemma might be to illuminate the atomic beam with a second laser (or some other source of energy) that would convert the excited A_1^* atoms into a longer-lived, metastable species that could be labeled A_1^{**}. The metastable atoms, which also commonly bear distinctive electrical and magnetic traits, could then be deflected.

Alternatively the short radiative lifetime of the excited species A_1^* might be turned to advantage. That could be achieved by actually pushing the atoms out of the beam with the radiation pressure of the laser light. For this purpose the laser must intersect the atomic beam at a right angle. Each atom that absorbs a photon then acquires from it a small increment of momentum that tends to propel it away from the laser source. The momentum is proportional to the energy of the laser photons, but it is always very small, so that for any appreciable deflection each atom must absorb many photons. The short lifetime of the



SELECTIVE IONIZATION of atoms was employed in the laser enrichment of uranium in a technique demonstrated at the Lawrence Livermore Laboratory. Two lasers, one operating with a medium of xenon ions, the other employing krypton ions, were arranged on a common axis and a beam of uranium atoms was introduced into the cavity of the krypton-ion laser. By means of an etalon, a device that narrows the bandwidth of a laser, the xenon laser was adjusted so that its wavelength corresponded to one of the absorption lines of the isotope uranium 235. In this way uranium-235 atoms were promoted to an excited state, whereas atoms of the commoner isotope uranium

excited atoms is essential so that they can quickly return to the ground state to absorb another laser photon. It should be noted that each time an excited atom returns to the ground state by emitting a photon the atom recoils with a momentum exactly equal to that gained when light is absorbed. The recoil momentum is randomly oriented, however, with the result that after many recoils the average momentum from the reemissions is zero. The momentum of the absorbed laser photons always pushes the atoms in the direction of the laser beam.

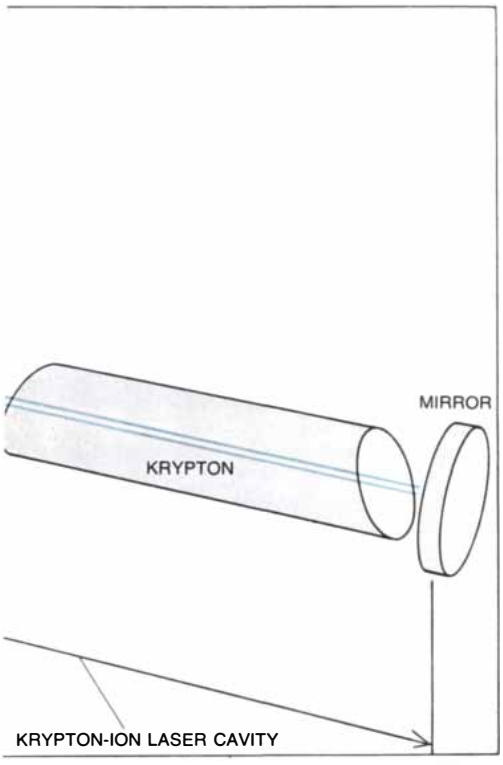
The first successful application of this technique was reported in 1974 by Anthony F. Bernhardt, Donald E. Duerre, Joe R. Simpson and Lowell L. Wood of the Lawrence Livermore Laboratory. They prepared an atomic beam of barium and tuned a laser to a line in the barium spectrum at a wavelength of 5,535 angstroms, which falls in the green part of the visible spectrum. The absorption of a single photon of this wavelength changes the transverse velocity of a barium atom by about .8 centimeter per second. That speed is about 50,000 times smaller than the longitudinal velocity of the atoms in the beam, so that repeated absorption and reemission is clearly essential. The number of photons that can be captured is limited by the transit time of the barium atoms in the laser beam, by the finite time required for the excited state to decay and by the loss of excited atoms that decay not to the ground state but to metastable states from which another photon cannot be absorbed. Even under the best conditions the angular deflection is small, and a highly collimated beam of atoms is necessary.

Barium has a number of stable isotopes, of which the most abundant one, making up about 72 percent of the natural element, is the isotope with an atomic mass number of 138. The atomic mass number is the sum of the number of protons (in this case 56) and the number of neutrons (82) in the nucleus. By selective excitation the Lawrence Livermore group was able to produce barium enriched in this isotope by a factor of two or three.

One disadvantage of the technique is that it requires many laser photons, each of relatively high energy, for each atom separated. A third proposed method of separation by deflection overcomes this difficulty by obtaining part of the energy required from another source: the laser-induced rupture of a chemical bond in a molecule.

The technique relies on choosing a molecule that is stable in the ground state but decomposes spontaneously when it is promoted to an excited state. For the sake of simplicity it can be assumed that the molecule is diatomic and can be represented by the arbitrary symbols *AB*, where *A* again has two isotopes A_1 and A_2. If a laser can be tuned so that it excites only those molecules that incorporate A_1 atoms, then only those molecules will be dissociated. The energy of the chemical bond is dissipated in both the internal excitation of the products and in their motion; the recoil motion, which is much larger than the recoil associated with photon absorption, deflects the atoms from the beam. There is the potential for a substantial deflection triggered by a single photon, but so far the technique has not been successfully demonstrated.

Instead of deflecting atoms that are excited but electrically neutral, another approach to isotope separation converts them into ions, which are much more easily manipulated. A strong electric field can efficiently sweep the charged particles from a beam of neutral atoms in the same way that an electron beam is swept across the face of a cathode-ray tube. The ionization can be accomplished in two steps: first one isotopic species is selectively excited with a finely tuned laser, then the excited atoms are ionized with another, less precise laser or even with some other source of energy. The method was demonstrated in 1974, when the isotopes of calcium were separated by investigators at the University of Cologne, and when the isotopes of uranium were separated by a group at the Lawrence Livermore Labo-



238 were not affected. Each excited atom could then be ionized by a photon from the krypton-ion laser; atoms that had not been excited could not be ionized. Ions were swept out of beam by an electrically charged plate.

ratory. The commercial application of the technique is now being considered.

In the experiments in Cologne and at Livermore only microscopic quantities of material were separated, but there is reason to believe the devices and techniques can be scaled up. In 1975 Sam A. Tuccio, Richard J. Foley, James W. Dubrin and Oscar H. Krikorian at Livermore reported the enrichment of milligram quantities of uranium, and it subsequently became apparent that similar work had been started earlier by Richard H. Levy and G. Sargent Janes at the Avco Everett Research Laboratory. Avco Everett and the Exxon Corporation are now building a pilot plant for the laser enrichment of uranium at Richland, Wash. Because of security considerations and proprietary secrecy many of the details of this process (as well as those of other uranium-isotope-separation methods) remain obscure, but a major portion of the work at Livermore has been made public.

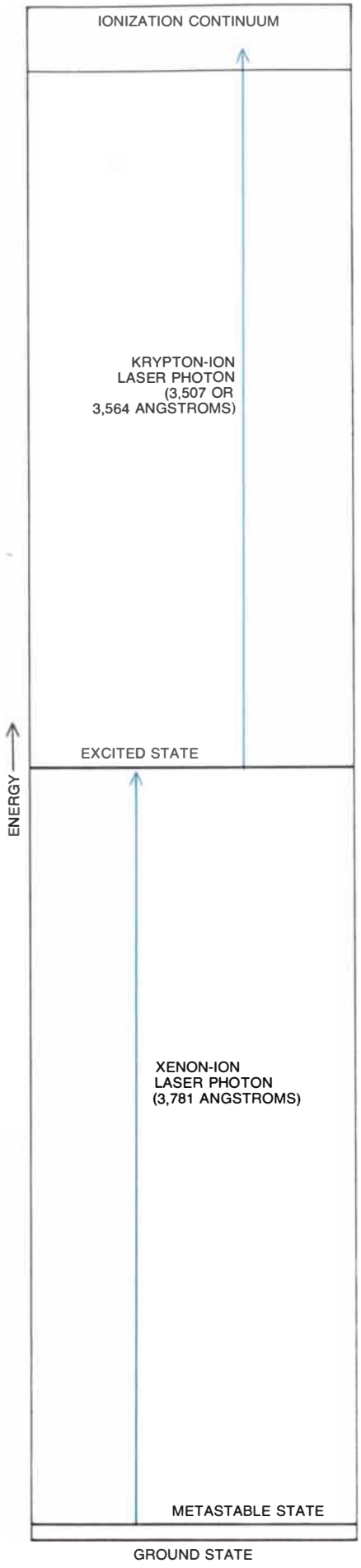
In the Livermore experiments a beam of uranium atoms emerges from an oven at a temperature of 2,600 degrees Kelvin. At this temperature 45 percent of the atoms are in the lowest possible energy state and 27 percent are in a metastable state of only slightly higher energy. (This metastable state is not an independent, excitational energy level, and it is not reached by radiative transitions; it is formed by the splitting of the ground state into sublevels, giving a "fine structure" to the atomic spectrum.) It is the atoms in the metastable state that are excited and ultimately ionized and isolated.

The excitation is provided by a laser whose operating medium is a gas of xenon ions; its radiation at a wavelength of 3,781 angstroms (in the ultraviolet region of the spectrum) excites only the lighter and easily fissionable uranium isotope of atomic mass number 235 and only those atoms of uranium 235 that happen to be in the low-lying metastable state. Atoms of the heavier isotope uranium 238 are not affected, whether they are in the ground state or in the metastable state.

To ionize an atom a specific wavelength is not needed; any photon with enough energy to overcome the ionization potential barrier will suffice. In this case the uranium atoms excited by the xenon laser have only to absorb another photon with a wavelength less than 4,400 angstroms in order to be ionized. The photons are supplied by a second laser, employing krypton ions rather than xenon, with two strong emission lines at 3,507 and 3,564 angstroms. The second laser is not isotopically selective; it would ionize excited states of either uranium 235 or uranium 238.

The excited state of uranium 235 has a brief lifetime (235 nanoseconds), and so it is important that the second photon be supplied immediately after the atom is excited. That is ensured by arranging the two lasers on a common optical axis, with the beam of uranium atoms inside the cavity of the krypton laser. The ionized atoms, which are stripped of one electron and hence have a positive charge, are attracted to and deposited on a collector plate with a negative charge of 1,500 volts.

The system was run continuously for about two hours, with the xenon-ion laser operating at a power of 70 milliwatts and the krypton-ion laser at 30 watts. The much higher power of the second laser was required to compensate for the small probability that a given excited atom would absorb a photon and be ionized. The yield is somewhat reduced by



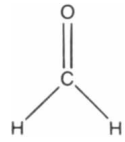
IONIZATION of uranium atoms in the Livermore experiment was accomplished in two steps, only one of which was isotopically selective. The atoms susceptible to laser excitation were those in a metastable state lying only slightly above the lowest possible energy level, the ground state. Atoms of uranium 235 in the metastable state were stimulated by the xenon laser to make a transition to an excited state, but uranium-238 atoms were not excited. Any atom in the excited state could then be ionized by absorbing a photon with a wavelength of less than 4,400 angstroms. The krypton-ion laser, emitting photons with wavelengths of 3,507 and 3,564 angstroms, was capable of ionizing excited atoms of either uranium isotope.

the fact that some uranium atoms are thermally ionized in the oven, a process that is not isotopically selective. Nevertheless, four milligrams of uranium were obtained with a uranium-235 content of about 3 percent. That is four times the abundance of uranium 235 in natural uranium and is approximately the level of enrichment required for nuclear power reactors.

Several variations on the method of selective ionization have been proposed. For example, instead of a two-stage process several or many photons could be employed. Another appealing idea is the creation of very highly excited states, lying just below the threshold of ionization, so that the final ionization step would require only a gentle electric field or collisions with charged particles. On the other hand, certain parasitic processes must be suppressed. Collisions between positively charged uranium-235 ions and neutral uranium-238 atoms can transfer the charge to the heavier isotope, thereby scrambling the isotopic content of the product. A more dramatic failure would be the creation of a population inversion among the excited uranium atoms; under some circumstances the atoms might be stimulated to emit radiation as they drop to a lower energy level. In other words, the uranium vapor could itself become the medium of a laser. Nevertheless, these experiments represent the first steps toward the commercial development of a new method of uranium isotope separation. It remains to be seen whether or not this particular method will turn out to be the most economical.

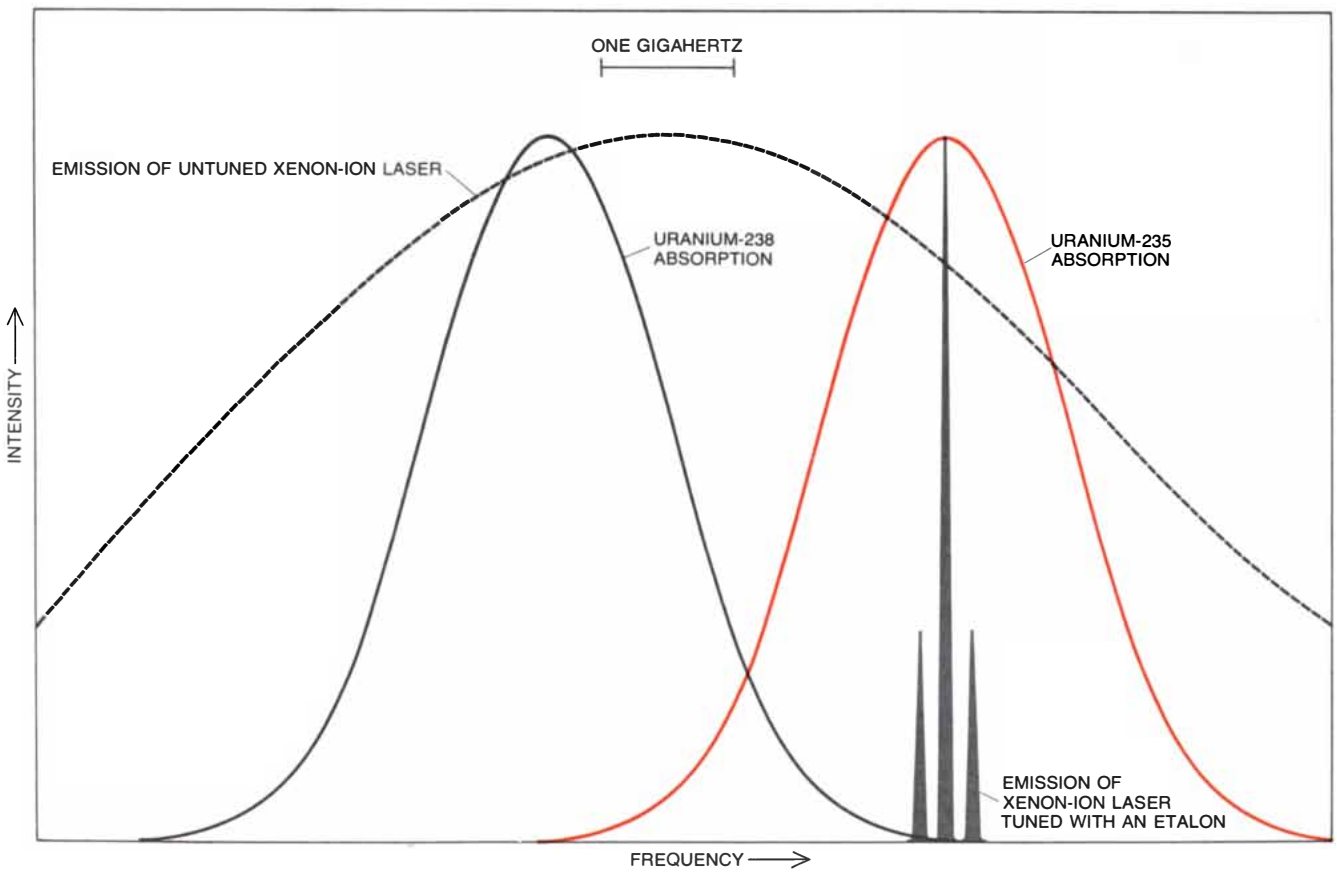
A class of isotope separation techniques that has the attraction of great simplicity is the decomposition of molecules into stable products that can then simply be removed from the mixture. A prerequisite, however, is a molecule that satisfies a rigorous list of specifications: it must be possible to excite the molecule with laser photons, the molecule must then dissociate spontaneously and the products of the dissociation must be stable, so that there are no further chemical reactions. The last requirement is a particularly difficult one to satisfy; many molecules that can be decomposed by electromagnetic radiation give rise to free radicals, fragmentary molecules that are highly reactive.

For the purposes of isotope separation the reaction that has probably been studied most extensively is the laser decomposition of gaseous formaldehyde, an organic molecule with the structure



When formaldehyde is decomposed by laser irradiation, it can yield two distinct sets of products, molecular hydrogen (H_2) and carbon monoxide (CO), or the free radicals H and HCO. The free radicals are unstable and react promptly with one another or with other substances present. The molecular products, on the other hand, are stable and could easily be separated by chemical means, with the result that any isotopic composition they might be given by selective excitation would be preserved.

The photochemistry of formaldehyde decomposition is quite complex, but the relative yield of molecules and free radicals apparently depends on the wavelength of the light absorbed, so that the



ABSORPTION SPECTRUM of uranium isotopes can be closely matched by the emission spectrum of the xenon-ion laser. The absorption spectrum includes two adjacent peaks, the one at higher frequency (or shorter wavelength) representing the absorption of uranium 235. The natural emission spectrum of the laser is comparatively broad and encompasses the absorption peaks of both isotopes, so that it would not be suitable for discriminating between them. The emission of the laser is narrowed by inserting an etalon into the laser cavity; the etalon confines the laser to only a few modes of resonance, giving rise to a spectrum of distinct spikes. The sharpened emission can be tuned so that it coincides with the maximum uranium-235 absorption and lies outside the range of uranium-238 absorption.

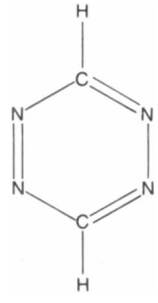
process may be amenable to experimental manipulation. Three groups of investigators have already reported the successful application of this procedure to the separation of hydrogen isotopes.

Hydrogen has two stable isotopes, the common one with a mass number of 1 (^1H or merely H), which has a solitary proton as its nucleus, and the much rarer deuterium (^2H or D), with a mass number of 2 and a nucleus that consists of one proton and one neutron. Formaldehyde can be prepared with pure hydrogen (H_2CO) or with pure deuterium (D_2CO). Employing a mixture of equal quantities of these gases, Edward S. Yeung and C. Bradley Moore of the University of California at Berkeley achieved a deuterium-enrichment ratio of six to one in 1972, and with the same starting materials other workers later reached a ratio of nine to one. In 1975 John B. Marling of Livermore succeeded in selectively exciting HDCO, the form of formaldehyde in which both hydrogen isotopes are present; the deuterium content of the products, in the form of HD, was 14 times that of the starting materials.

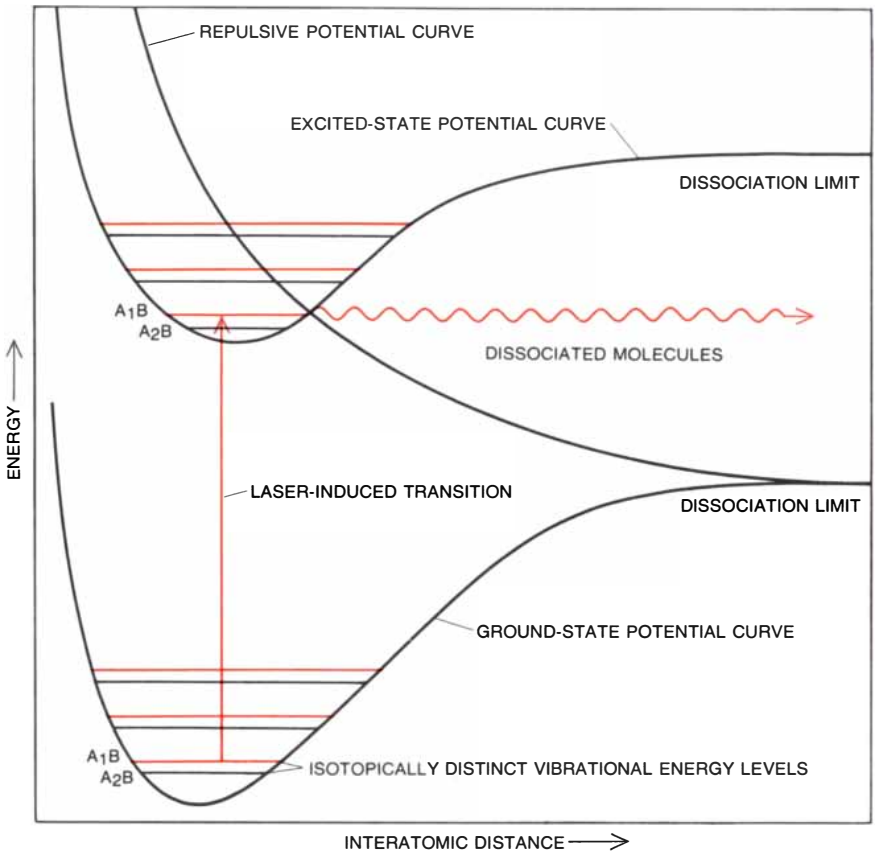
Dissociation of the formaldehyde molecules does not come about through excitation all the way to the dissociation continuum. If photons with sufficient energy to achieve that result were supplied, they would be absorbed by all formaldehyde molecules, without isotopic selectivity. Instead the molecule is disassembled at a lower energy through a phenomenon called predissociation. It is raised to a precise energy level where the force between the constituent atoms can change from attractive to repulsive; even though the energy supplied is less than that ordinarily required to break the chemical bond of the molecule in that electronic energy state, the molecule comes apart.

The separation of deuterium from hydrogen is facilitated by the comparatively large differences between the spectra of these isotopes, which can be attributed to the large ratio of the atomic masses. The isotopes of carbon and oxygen display much smaller spectral shifts, but recently they too have been separated by the photodecomposition of formaldehyde. John H. Clark, Yehuda B. Haas, Paul L. Houston and Moore of the University of California at Berkeley, working with the carbon isotopes of atomic mass 12 and 13, have increased the abundance of carbon 12 in carbon monoxide to 81 times its normal value, thereby enriching the undecomposed formaldehyde in carbon 13. Their experiment employed laser light with a wavelength of 3,032 angstroms, where the creation of free radicals predominates. Nitric oxide, which combines with free radicals, was added to the reaction mixture in order to achieve these enrichment factors. More recently Marling has shown that wavelengths greater than 3,300 angstroms suppress the creation of free radicals; 80 percent or more of the yield is in the form of molecular products. He has been able to enrich oxygen 17 and oxygen 18, both of which are rare, as well as carbon 13 and deuterium. Of particular importance, he was able to achieve enrichments by a factor of three or four with formaldehyde made up of elements in their natural isotopic abundances. When rare isotopes are being separated, most of the effort required in conventional methods is often exerted in reaching the enrichment level of a few percent. Marling's results illustrate one of the potential benefits of laser technology: large single-step separation factors for the very rare isotopes.

Studies of separation by photodecomposition have centered on, in addition to formaldehyde, symmetric tetrazine, an unstable organic molecule with the structure



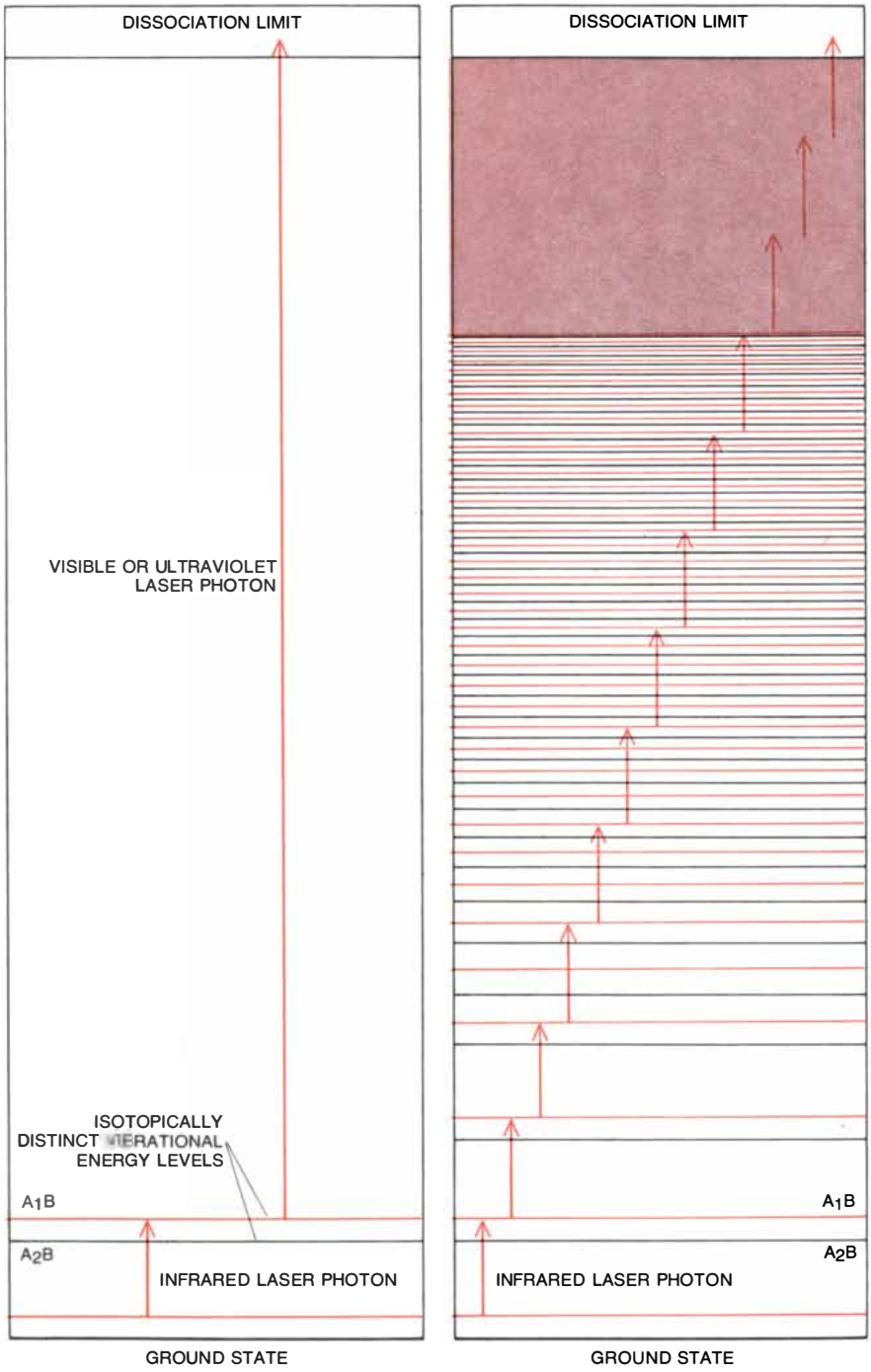
When tetrazine is irradiated, it decomposes into two molecules of molecular nitrogen (N_2) and two molecules of hydrogen cyanide (HCN). Robert R. Karl and K. Keith Innes of the State University of New York at Binghamton



PREDISSOCIATION OF MOLECULES into chemically stable fragments offers another approach to laser isotope separation. The energy of the chemical bond in a molecule is a function of the distance between the atoms, and the curve describing this relation is called a potential curve; in a stable molecule the curve has an energy minimum where the forces of attraction and repulsion are in balance. Actually a molecule can have a number of potential curves, each curve associated with an electronic energy state, and some of them may not have a stable minimum; on such a curve the force between the atoms is always repulsive. The absorption of a laser photon can induce a transition from one potential curve to another. If this excited-state curve is intersected by a repulsive potential, the molecule may then dissociate. The process is called predissociation because it takes place at an energy below the usual threshold for dissociation on that potential curve. It can be made isotopically selective by tuning the laser so that only one isotopic species is promoted to the excited-state potential curve. Within a bound potential there are a finite number of molecular vibrational states (*horizontal lines*), and the positions of these energy levels are slightly different for each isotopically distinguished molecule.

have shown that each photon absorbed by tetrazine leads to the decomposition of one molecule. The process has been employed to separate the isotopes of hydrogen, carbon and nitrogen.

Robin M. Hochstrasser and David S. King of the University of Pennsylvania have also demonstrated isotopic enrichment through the photolysis of tetrazine, but their method differed in an important respect from that of most other experiments. Instead of exciting molecules in the gas phase they irradiated a crystal of symmetric tetrazine cooled to 1.6 degrees K. (1.6 degrees Celsius above absolute zero). When the laser was tuned to spectral features of molecules with a particular isotopic composition, the selected molecules completely decomposed. Irradiation for a few minutes enriched the crystal in nitrogen 15 and carbon 13 by a factor of 1,000 or more.



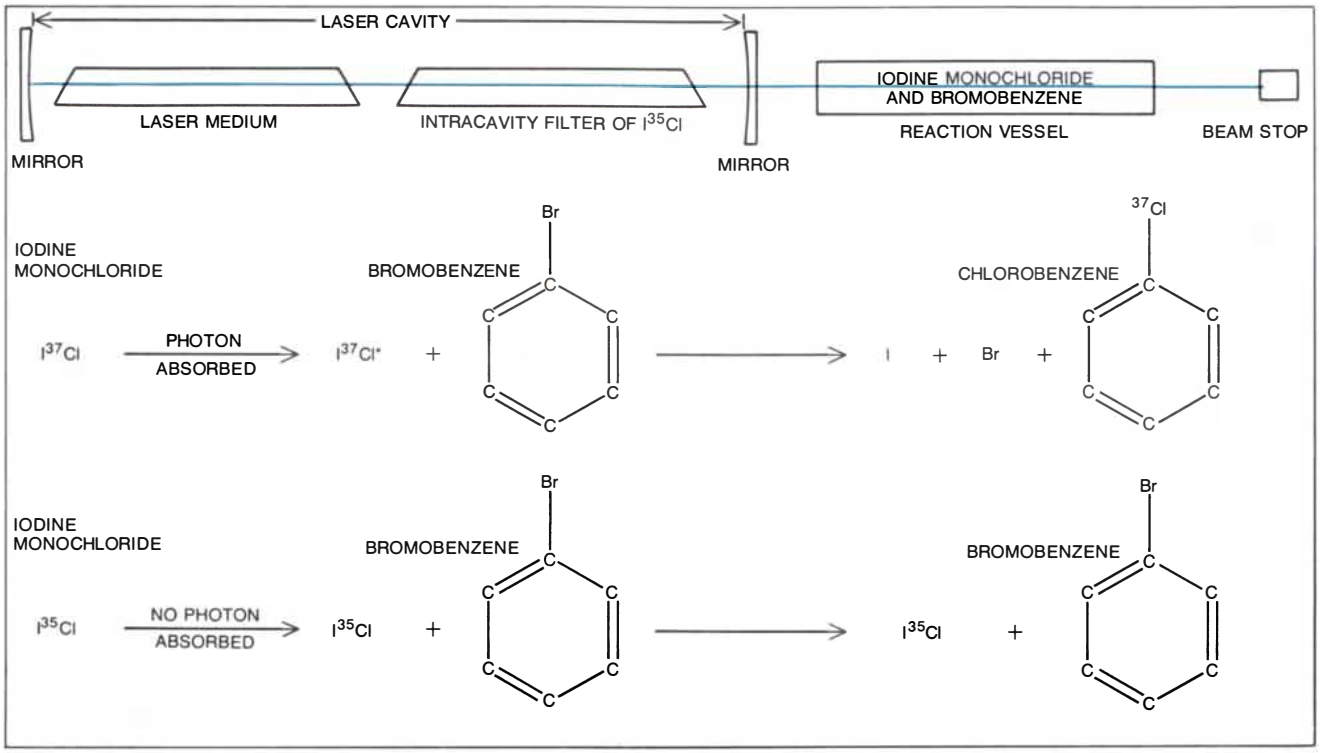
MULTIPLE PHOTON ABSORPTION is another method for separating isotopes by the dissociation of molecules. In a two-stage process (*left*) one photon selectively excites molecules containing a particular isotope; a second photon then dissociates the excited molecules. The first photon is usually an infrared one, causing a transition between vibrational states, whereas the second photon is in the visible or ultraviolet region of the spectrum. In an alternative procedure (*right*) a molecule absorbs many infrared photons in rapid succession, increasing its vibrational energy until a chemical bond breaks. This method has been applied successfully only with comparatively large molecules made up of several atoms; such molecules have many closely spaced vibrational states. Only the first few infrared transitions are isotopically selective.

Not all molecules can be made to predissociate into stable fragments; it is often necessary to work with substances whose properties are not so convenient for the chemist. In many cases dissociation requires a two-photon process, in which a molecule is first excited, then induced to make a second transition either to the dissociation continuum or to another excited or metastable state that decomposes. Such a two-step process for the separation of uranium isotopes is being investigated at the Los Alamos Scientific Laboratory. An infrared photon selectively excites molecules of uranium hexafluoride gas that contain an atom of uranium 235 but not those with the heavier isotope. An ultraviolet photon then decomposes the excited $^{235}UF_6$ but not the unexcited feedstock. The products of the decomposition are $^{235}UF_5$ and atomic fluorine; the $^{235}UF_5$ subsequently precipitates from the gas. To aid in the selective excitation of $^{235}UF_6$, the absorption spectrum of the molecule is simplified by expanding the gas through a nozzle, causing it to cool but not to condense.

In still another technique dissociation is induced by the absorption of many low-energy infrared photons, rather than just one or two of rather high energy. Indeed, the discovery of this process is one of the most exciting to emerge from research into laser separation. An example of its application is the separation of the isotopes of sulfur, sulfur 32 and sulfur 34, by the decomposition of sulfur hexafluoride (SF_6).

In an experiment conducted by R. V. Ambartzumian and V. S. Letokhov of the Institute of Spectroscopy in Moscow sulfur hexafluoride was irradiated with a pulsed carbon dioxide laser supplying a power of between one and two billion watts per square centimeter. The laser was tuned to an infrared wavelength coinciding with a vibrational excitation of $^{32}SF_6$. Virtually all the $^{32}SF_6$ was decomposed, and the residual gas was enriched in $^{34}SF_6$ almost 3,000-fold. When the laser was adjusted to another wavelength, which excited $^{34}SF_6$, that molecule was decomposed. Essentially the same results were obtained independently by John L. Lyman, Reed J. Jensen, John P. Rink, C. Paul Robinson and Stephen D. Rockwood at Los Alamos.

Subsequent molecular-beam studies have confirmed an early conclusion that the sulfur hexafluoride molecule decomposes without collisions after it has climbed a "ladder" of successive vibrationally excited states up to the dissociation continuum. The process is not yet well understood, but it has already been employed in the enrichment of isotopes



CHEMICAL SCAVENGER was employed in the separation of isotopes of chlorine at Columbia University. Natural chlorine, which has stable isotopes with atomic weights of 35 and 37, was combined with iodine to form the compound iodine monochloride (ICl). The compound was then mixed with bromobenzene, the scavenger molecule, and the mixture of gases was irradiated. The laser was tuned to excite only those molecules of iodine monochloride that contained an atom of chlorine 37. (The compound in its excited state is written $I^{37}Cl^*$.) Bromobenzene has the property that it reacts with excited states of iodine monochloride but not with the ground state. As a result chlorine 37 was extracted from the $I^{37}Cl^*$ molecules (ultimately forming chlorobenzene) but not from $I^{35}Cl$. The laser was tuned with an intracavity filter of $I^{35}Cl$ gas, which quenched the laser's output at precisely those wavelengths that would excite that molecule.

of hydrogen, boron, carbon, silicon, chlorine, titanium, molybdenum, tungsten and osmium as well as sulfur. So far it has been observed only in molecules made up of more than three atoms, suggesting that the high density of excited states characteristic of these molecules may be needed for the chain of photon absorptions to continue unbroken all the way to dissociation.

As a rule excited states of atoms are chemically more reactive than the ground state, and this distinguishing trait suggests still another method for isotope separation. The method consists in mixing with the feedstock a scavenger molecule, one that does not react with the atom or molecule to be separated when that atom or molecule is in the ground state but combines irreversibly with it when it is in an excited state. Finding such an ideal scavenger is not a trivial undertaking, but when one is available, it offers a significant benefit. No additional photons, and thus no additional energy, are required to ionize or dissociate the excited states.

Chemical scavenging has been employed by Douglas M. Brenner and Saswati Datta at Columbia University in separating the isotopes of chlorine. In their experiment a mixture of iodine monochloride (ICl) and bromobenzene (C_6H_5Br) was irradiated with a dye laser operating at a wavelength of 6,050 angstroms (in the orange-red). At this wavelength the laser excited molecules of iodine monochloride containing chlorine 37 but not those containing the other stable isotope, chlorine 35. In subsequent collisions of the excited $I^{37}Cl^*$ molecules with bromobenzene the bromobenzene abstracted the chlorine-37 atom to form an unstable radical intermediate, $^{37}ClC_6H_5Br$, that rapidly expelled bromine to yield the stable product chlorobenzene ($C_6H_5{}^{37}Cl$). After irradiation for about two hours several milligrams of C_6H_5Cl was produced; it was enriched sixfold in chlorine 37.

A special feature of the Columbia work is the use of an isotope to tune the laser for the selective excitation of another isotope. A sample of $I^{35}Cl$ was placed in the cavity of the dye laser, where by its absorption spectrum it quenched the output of the laser at precisely those frequencies that would excite $I^{35}Cl$. By the use of this intracavity filter $I^{37}Cl$ molecules were selectively excited without taking extraordinary measures for narrowing the emission line of the laser and locking it onto a particular $I^{37}Cl$ transition. The method offers the selective excitation of an isotopic species without detailed knowledge of its spectrum.

The Columbia work has also shown that an understanding of the scavenger mechanism may make possible the direct preparation of isotopically labeled compounds. Since many isotopes are employed not as pure elements but as compounds, the technique could increase the utility of laser isotope separation. Indeed, research on isotopically selective photochemistry not only promises to yield practical methods for isotope separation and isotope labeling but also may provide a means for following and understanding the chemistry of excited-state reactions.

Widespread interest in the laser separation of isotopes derives largely from its possible application to the nuclear power industry. At present the dominant technology for the enrichment of uranium is gaseous diffusion. A brief review of this process suggests incentives for developing alternatives.

In a gaseous-diffusion plant vapors of uranium hexafluoride (UF_6) are pumped through a porous barrier, the lighter $^{235}UF_6$ diffusing more rapidly than the heavier $^{238}UF_6$, so that the transmitted vapor becomes slightly enriched in uranium 235. The enrichment in passing through a single stage is small, and so hundreds of stages must be linked together in a cascade, where the

feed to each stage consists of the enriched stream from the stage below combined with the depleted stream from the stage above. In order to separate a quantity of UF_6 containing one kilogram of uranium enriched to 3 percent uranium 235, with waste UF_6 at .2 percent uranium 235 discarded, almost 1,500 kilograms of natural uranium must enter the cascade at the first stage and more than two million kilograms of uranium must be pumped and recirculated through the cascade. An energy of about five million electron volts is expended for each atom of uranium 235 that is separated.

The present cost of obtaining uranium 235 of 90 percent purity by gaseous diffusion is about 2.3 cents per milligram. This compares favorably with the cost of from $1 to $10 per milligram of most other isotopes at the 90 percent enrichment level, but a more familiar standard of economic value shows immediately that all purified isotopes are quite precious. The present price of gold is about .3 cent per milligram.

The U.S. has three gaseous-diffusion plants capable of separating 3,960 metric tons of 3 percent uranium 235. The capital cost of a new plant with an annual capacity of about 2,050 metric tons of 3 percent uranium 235 is estimated to be about $3 billion with an annual operating cost of about $500 million. Estimates of the demand for enriched uranium are uncertain, but domestic consumption could require a capacity equivalent to between four and eight new plants by the end of the century, and foreign demand could double or triple that number. The adoption of other physical separation techniques, such as gaseous centrifugation, might reduce the cost of uranium-isotope separation by from 10 to 30 percent. If large-scale laser separation proves feasible, it offers the potential of much greater savings.

The energy required to generate visible photons or infrared photons for laser separation might be from one to 10 electron volts per uranium-235 atom separated. Even if the efficiency of the laser in converting electrical energy into light is no greater than .002, the energy cost of the process is between 500 and 5,000 electron volts per uranium-235 atom. That is at least 1,000 times less than the energy cost of gaseous diffusion. Because the laser is also expected to make possible a high separation factor in each stage, the potential exists for removing almost all the uranium 235 in the ore. Gaseous diffusion can economically extract only 60 to 70 percent of the uranium 235 in the feedstock, leaving uranium containing .2 to .3 percent uranium 235 as "tails," or waste. Higher extraction efficiency would effectively increase useful uranium reserves. Indeed, a laser separation plant might be able to reprocess the stored wastes from gaseous diffusion plants; these wastes represent between 30 and 40 percent of all the uranium 235 that has ever been mined! Although a more sophisticated economic analysis might be less optimistic, it would seem that a savings of several hundred billion dollars could be realized by the end of the century if the laser technology works.

These calculations assume the continued use of light-water reactors like those now operating in the U.S. Another type of reactor eliminates the need for uranium isotope separation by "burning" a fuel of natural uranium. These heavy-water (D_2O) reactors, however, require large quantities of deuterium: about one ton of D_2O per megawatt of electrical capacity. The widespread adoption of heavy-water reactors would therefore motivate another kind of laser isotope separation program.

Uses of isotopes in fields other than nuclear power generation are diverse, but much smaller amounts are consumed. Isotopes are important as tracers in research, medicine and agriculture, but because they are so costly there is little incentive for finding new applications. This may change dramatically if laser isotope separation techniques can reduce the present cost by a factor of 100 or 1,000. For example, in chemistry an abundant supply of low-cost isotopes might lead to the widespread adoption of isotopically labeled compounds for structural analysis, for analytical detection and for kinetic studies.

The separation of isotopes is an important process, which the intense, monochromatic light of the laser may soon make cheaper and therefore commoner. It is possible that the application of the laser to chemistry may ultimately have even greater significance, a possibility made plain when the laser itself is viewed in the light of history.

The origins of chemistry are customarily traced to the alchemists, whose work was funded by royal patrons eager to transform lead into gold. The alchemists of course failed to achieve that transformation, but in their efforts they assembled a body of knowledge that provided a factual basis for much of modern chemistry. Today the royal patrons of the sciences are government agencies, which urge the development of new methods for separating isotopes, again with the prospect of economic rewards. This time the goal will probably be achieved. As before, however, the ultimate reward may prove to be of far greater value than the immediate object being sought. By understanding the mechanism of laser isotope separation we may be laying the foundation for a new chemistry, one in which compounds are made not by supplying the random energy of heat but by exciting only those internal motions of molecules that facilitate the transformation of reactants into products.

Waveform fidelity. If you don't understand it, you could be making a $350 mistake.

Today a good amp and tuner can easily cost you $350, $500, $700 or even more. But no matter how much a component costs, if it doesn't have waveform fidelity, the music that's put into it won't be the music that comes out. And that's an expensive mistake to make.

It's also a mistake Technics won't let you make. Because Technics' two new integrated amps, the SU-7600 and the SU-8600, as well as our two new tuners, the ST-7600 and the ST-8600, have superb waveform fidelity.

With both tuners, the waveform being broadcast will be the waveform you'll receive, with virtually no distortion or cross modulation. Because both have flat group delay filters in the IF sections. So the time delay is constant for all frequencies.

There's also a Phase Locked Loop IC in the MPX sections. That's why, for example, with the top of our line, the ST-8600, you'll get stereo separation of 45dB at 1kHz and 35dB at 10kHz. And a frequency response that's as flat as it is wide, 20Hz to 18kHz (+0.2dB −0.8dB).

And with an 8-ganged tuning capacitor (5 for FM and 3 for AM) and a Technics developed 4-pole MOS FET, broadcasts with the ST-8600 will sound more like master tapes than FM.

You'll also find waveform fidelity in both amps. Including our most powerful one, the SU-8600. *With 73 watts per channel, minimum RMS, both channels driven into 8 ohms from 20Hz to 20kHz, with no more than 0.08% total harmonic distortion.*

And the SU-8600 will stay 73 watts regardless of the power-hungry transient bursts found in many musical waveforms. The reasons: Sixfold independent power supplies for the control voltage and power amplifiers. The results: Virtually no transient cross-talk distortion. And optimum waveform fidelity.

So before you make a $350 mistake, or an even more expensive one, listen to our new amps and tuners. Your Technics dealer has them. Along with Technics waveform fidelity.

Cabinetry is simulated wood.

Technics
by Panasonic

Social and Nonsocial Speech

In order to communicate effectively with others children must learn not only the language itself but also the use of social speech, which takes into account the knowledge and perspective of another person

by Robert M. Krauss and Sam Glucksberg

As Bertrand Russell put it, "No matter how eloquent a dog may be, he cannot tell me that his father was poor but honest." All organisms communicate with members of their own species in one way or another, and some of the nonhuman signaling systems can be impressively complex and efficient, but they are limited in a fundamental sense: each species has a repertory that is pretty much restricted to a fixed set of messages with a fixed set of meanings. It cannot construct novel messages in order to communicate new concepts—or even clichés about honest poverty.

Unlike other species, human beings seem to be capable of communicating about virtually anything, whether or not they have the precise words available for doing so. If our vocabulary happens not to contain the standard term for denoting a particular concept, we are usually able to invent some way of expressing our meaning, perhaps by the use of metaphor or circumlocution. Scholars, pedants and bureaucrats, among others, devise terms for new inventions, discoveries or concepts, assigning meanings in a deliberate and explicit fashion. Young children also frequently find themselves forced to invent ways to talk about things whose names are not yet part of their repertory. Although the terms children invent lack the explicit definitions that characterize technical terminology, they are often perversely accurate and considerably more entertaining—as when the daughter of one of us communicated her discovery of her father's bald spot by proclaiming: "Daddy has a hole in his hair."

All of us are under continuous pressure to invent new ways of communicating with others. The necessity comes in part from the nature of language itself. Although it is not obvious until one thinks about it, the nature of language is not such that for each word there is one and only one thing (or class of things) to which it can be applied. It is also not such that each thing can be referred to by one and only one word. For example, the word "line" can be used, given the appropriate context, to refer to a straight line or a curved line, a telephone line or a power line, an ideological line, a salesman's line of merchandise or his sales talk, a queue of people or a line of type. Similarly, any given thing can be referred to by any number of different words or phrases. Even a 10-cent piece can be called just that or "dime," "money," "change," "that coin" and so on.

The point is that the relation between the reference, or verbal expression, and the referent, or the thing referred to, is not in the nature of an unequivocal code. In the Morse code, for example, three dots followed by a momentary pause and then by three dashes invariably denotes the letter sequence *SO*. No word, let alone a phrase or sentence, in any natural language bears any such invariant relation to a thing or concept it may denote.

We learn at least two rather different kinds of things when we learn our language. We learn the language itself, which means learning its sound system, its syntax and its vocabulary. We must also learn how to manipulate the language for communicating concepts effectively and efficiently, and that is not quite the same thing as having learned the language. One way to appreciate this distinction is to contrast social messages with nonsocial ones. Nonsocial messages are messages that are not intended to communicate information to another person; they can be expressed in the abbreviated, idiosyncratic, private language one uses in writing a reminder to oneself. Since nonsocial speech is not directed to another person, the knowledge and perspective of a particular recipient need not be considered in its formulation. People who speak nonsocial speech would be likely to address young children in precisely the same way they speak to adults, or to address laymen in the same way they speak to colleagues in their profession. An ornithologist speaking social speech directs a child's attention to a nearby "robin redbreast"; he does not ask, "Do you see that *Turdus migratorius?*" Social messages are characterized by variability because they take into account both the nature of the audience and the context of the conversation.

That people do take the characteristics of their audience into account is not difficult to demonstrate. Douglas Kingsbury, who was then an undergraduate at Harvard University, casually approached randomly selected passersby on the streets of Cambridge and asked them the way to Central Square. To some he addressed the question, "Can you tell me how to get to Central Square?" in a nondescript local accent. The typical response was brief and direct, containing neither more nor less information than the situation seemed to require. Does this reflect the brusqueness and impersonality of modern urban

GIVING DIRECTIONS on a busy city street, passersby communicate socially. Asked for

life? Not at all. When Kingsbury prefaced his question with the statement "I'm from out of town," the same busy Cantabrigians gave him involved and explicit instructions, describing landmarks he would encounter en route and telling him how he could be sure he was in Central Square when he reached it. Interestingly, Kingsbury found he could achieve the same effect if he signaled his ignorance of local geography implicitly by adopting a rural Missouri accent, which is exotic enough in Cambridge to indicate quite clearly: "I'm from out of town."

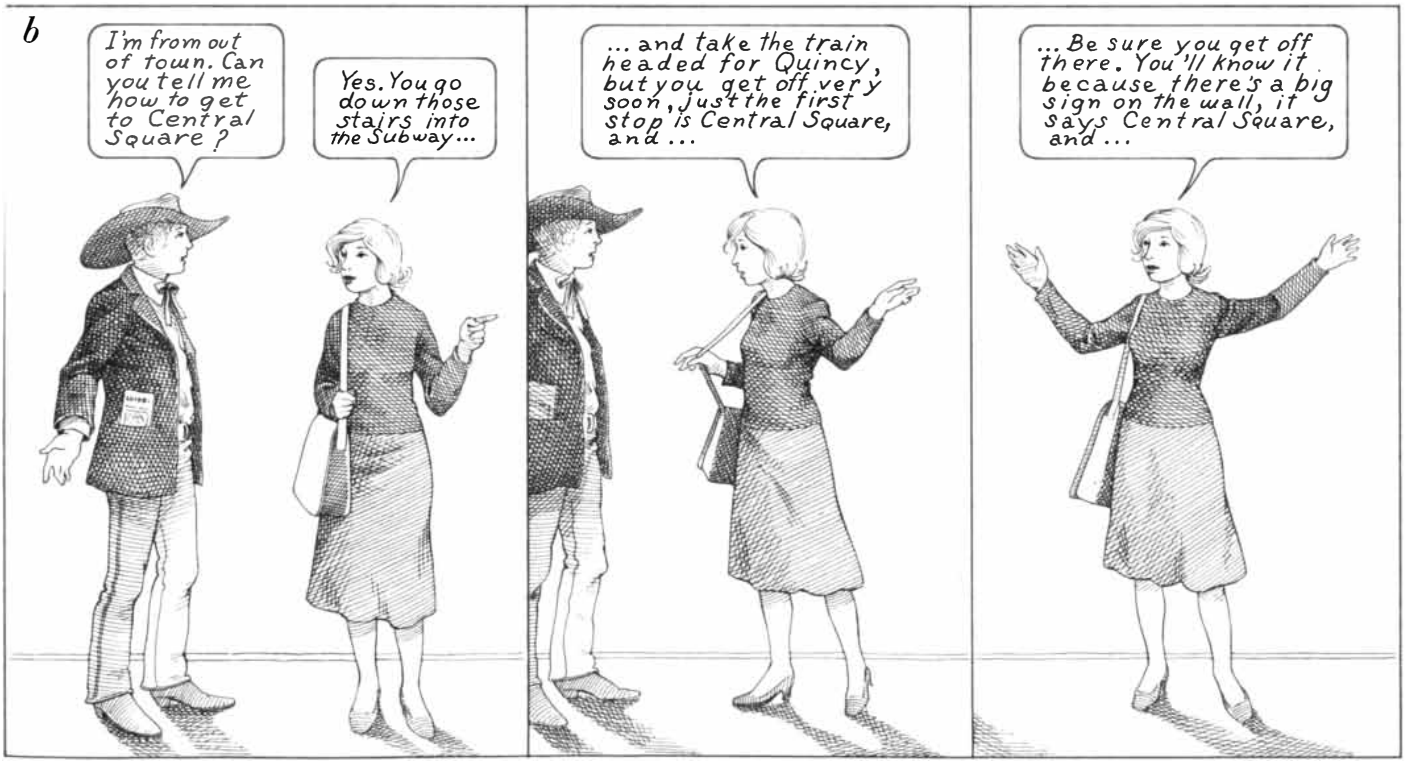
What those Cambridge pedestrians were demonstrating was their implicit knowledge of how to use language communicatively. They did not say the same thing even when they were talking about the same thing—how to get from point *x* to point *y*. They tailored what they said and how they said it to suit what they understood to be the knowledge and perspective of their listener. In the same way adults tailor what they say in accordance with whether they are talking to children or to other adults. Noam Chomsky of the Massachusetts Institute of Technology and others have held that language skills must be acquired by means of some "innate language-acquisition device," because, among other reasons, children surely could not learn a language by exposure to the kind of speech adults typically inflict on one another, which is syntactically complex, fragmented and virtually incomprehensible out of context. Catherine E. Snow of McGill University, pondering the Chomsky view, decided to compare the ways adult women talk to older children and to younger ones. When they were talking to younger children, the women she studied, whether or not they were experienced mothers, spoke in short and syntactically simple sentences. As a result a two-year-old was likely to hear—and understand, and learn language skills from—this kind of talk: "That's a lion. And the lion's name is Leo. Leo lives in a big house. Leo goes for a walk every morning. And he always takes his cane along." The women knew quite well that it would be pointless to express the same ideas to a two-year-old in the form: "That's a lion named Leo, who lives in a spacious house and makes it a practice to take a constitutional every morning, invariably accompanied by his cane."

How and when do children learn to employ language so as to suit the demands of a particular listener and the particular circumstances of a conversation? We decided to investigate the question by means of a communication task one of us (Krauss) had designed some years before. The object of the original research had been to assess the efficiency of communication between adults over a noisy or otherwise degraded communication channel. Along with the findings on that question the research revealed certain patterns to which adult communications tend to conform, and those patterns became our prototypical model for assessing children's communication skills.

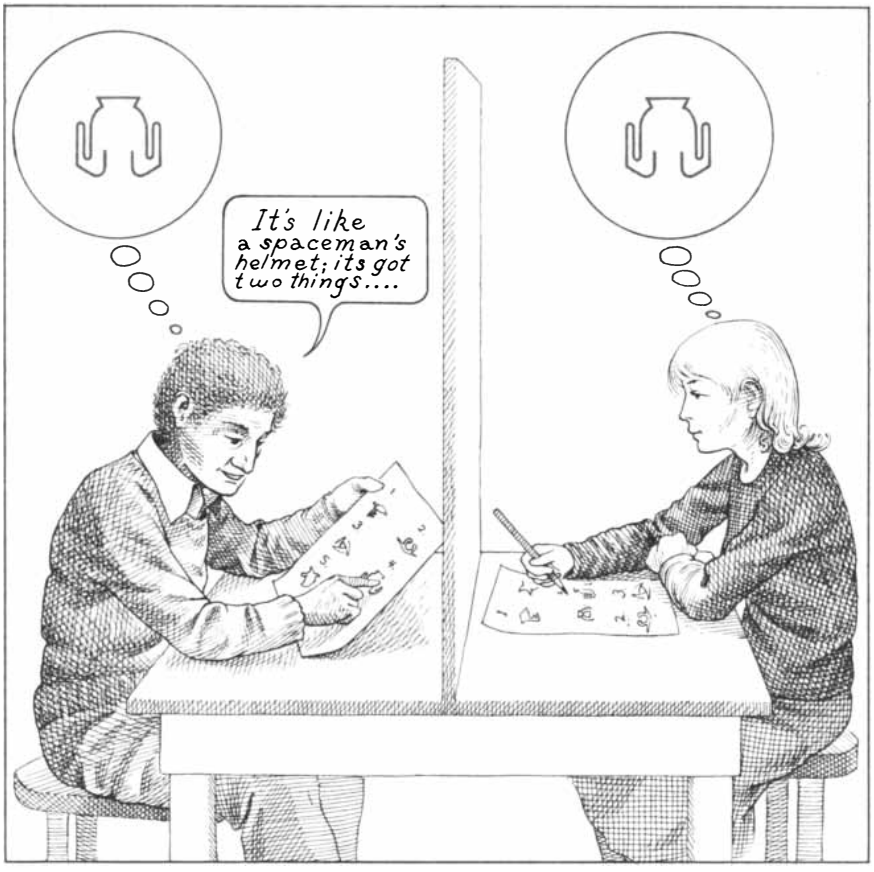
The communication task involved a speaker and a listener separated by an opaque barrier. In the adult version the speaker had in front of him a page showing a set of designs numbered in order from one through six. The listener had in front of him the same designs, arranged differently on the page and not numbered. The task called for the speaker to describe each design and give its number so that the listener could identify his copies and number them correspondingly. The measure of the accuracy of communication was the extent to which the listener's set was correctly numbered; one measure of the efficiency of the communication was the number of words required by the speaker and listener to accomplish the task.

What made the task more than trivial was that the designs were deliberately constructed so as not to have either short or familiar "names." The six forms are easy to distinguish from one another, but they do not evoke simple and unequivocal descriptions. Adults nonetheless found the task trivially easy, whether they were college sophomores practiced in the ways of psychological experiments or raw Army recruits. Even with no feedback, or knowledge of the results, provided by the experimenter, pairs of adults made virtually no errors on their very first try.

In addition to accuracy the adult performance was characterized by the development of an efficient social (in con-



directions in an offhand manner by a person who appears to be a native, people answer briefly and directly (*a*). When the questioner announces himself as being—or when he appears to be—from out of town, however, people answer at length and give explicit detail (*b*).



ADULT COMMUNICATION TASK required a speaker (*left*) to describe six odd designs on a sheet of paper in front of him and give the number associated with each; a listener (*right*) on the other side of an opaque barrier had to assign the correct number to copies of same designs.

FORM	INITIAL DESCRIPTION	SHORTER VERSION	SHORTEST VERSION
1	Looks like a motor from a motorboat. It has a thing hanging down with two teeth.	Motorboat with teeth.	Motorboat.
2	It looks like two worms or snakes looking at each other. The bottom part looks like the rocker from a rocking chair.	Two worms looking at each other.	Two worms.
3	It's a zigzag with lines going in all different directions.	The zigzag with lines.	Zigzag.
4	It's like a spaceman's helmet; it's got two things going up the sides.	The spaceman's helmet.	Helmet.
5	This one looks something like a horse's head.	The horse's head.	The horse.
6	It's an upside-down cup. It's got two triangles, one on top of the other.	An upside-down cup.	The cup.

ADULT SPEAKERS communicated successfully by giving detailed descriptions the first time a design was encountered, taking into consideration the listener's difficulty in identifying the unfamiliar forms. When the same form appeared in successive trials, speakers shortened their descriptions, as shown by these examples, and continued to be well understood by listerners.

trast to a linguistic) code, much as rock musicians or molecular biologists develop their own specialized jargon. At the beginning of the communicative interaction the speaker's language was detailed, redundant, even prolix. For example, the first time one adult speaker talked about a certain form he described it in nine words; he required fewer words when the same pattern showed up in a subsequent trial, and by the fourth trial he had settled on one word to get his message across. The original descriptive phrase was always an effective reference: on hearing it other people could accurately select the intended referent. The short final message, on the other hand, was adequate only for those listeners who had earlier heard the redundant original message; it did not usually communicate much to someone who had not participated in the social interaction from the beginning.

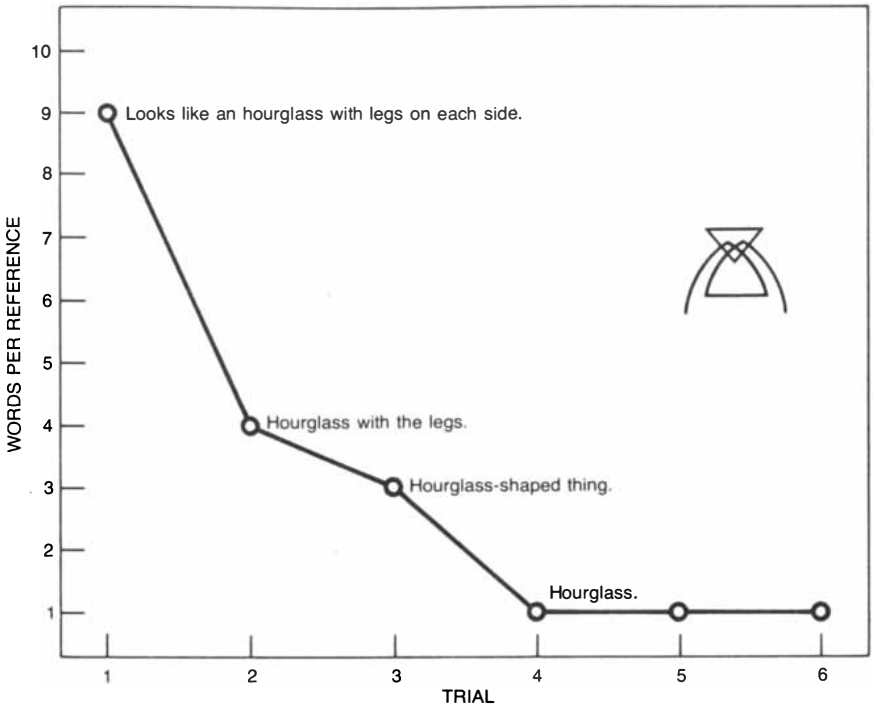
With these two characteristics—the accuracy and the social-language development—of adult pair communication in mind we set out to see what young children would do in a comparable task in the form of a stack-the-blocks game. The speaker has before him a peg and a dispenser, with a transparent front, holding six blocks; each block has a hole through it and is labeled with an identifying design. The listener has another peg and has duplicates of the six blocks placed randomly on his table. The speaker must take one block at a time from the base of his dispenser, put it on the peg and tell his partner which block to stack on his own peg. This continues until all six blocks have been stacked on both the speaker's and the listener's pegs.

We began with nursery-school children. First we made sure that they could play the game when each block depicted a familiar animal or household object instead of the strange, hard-to-describe designs that had been presented to the adults. Then we substituted blocks with the strange designs on them. An experimenter acted as the speaker and described the designs as they had been described by an adult in the original experiment. When one typical set of initial descriptions [*see bottom illustration at left*] was read off to children from 52 to 63 months old, none of the children made any errors. They continued to perform accurately even when, in subsequent trials, the messages were shortened systematically as they had been in the adult interactions from which they were taken.

When young children played the game with each other, however, not one of the six pairs of children we tested could complete a single errorless trial, even when we pointed out the errors they had made after each trial. Unlike adults, these young speakers used short and idiosyncratic messages at the out-

set; rarely if ever did they begin with an elaborate and redundant message. There was a notable lack of communality of description among the various speakers as well as a lack of obvious relation between reference and referent. Given such meager and idiosyncratic descriptions it is not surprising that the young listeners could not select the right blocks. Indeed, we wondered whether or not the speakers themselves knew what they were talking about. Did they assign those names blindly and randomly or did they do so in ways that were somehow meaningful, if only to themselves?

One indication that the messages were not random was the very consistency of the naming. Once a child had assigned a name to a referent, he virtually never changed it during the course of the game. Would a young speaker understand his own names, however, if he were put in the role of a listener? We looked into that by reversing roles, putting the erstwhile speaker in the role of the listener, with an experimenter in the role of the speaker. The experimenter-speaker instructed the child, identifying each form with the same name the child had previously provided. To our surprise none of the five children we tested made any errors, either during the first session in which they had generated the name or after a three-week period during which there was no intervening practice or study. Clearly a speaker's own descriptions were meaningful to him—but not to anyone else, because these young children had not yet learned how to use their language to develop a socially shared and mutually comprehensible code.



PROCESS OF SHORTENING referred to in the preceding illustration, in effect the tacit development of a two-person social code, is illustrated for one speaker's description of one form.

How long does it take before children reach adult levels of competence in this task? In our first attempt to trace development toward adult competence Hugh O'Brien, who was then an undergraduate at Princeton University, tested matched-age pairs of children from kindergarten through fifth grade on the same problem we had given the nursery-school children. Each pair of children played the game for eight successive blocks of two trials each.

The results were somewhat surprising. Kindergartners performed no better than nursery-school children and displayed the same lack of improvement with practice. Considering that adults make virtually no errors on the very first trial, the performance of children in the first, third and fifth grades is even more surprising: they were no better than kindergartners on the first trial. The older children did show marked improvement with practice, but it seemed clear that even the fifth-graders (who were about 10 years old) did not approach the adult level. This finding is all the more striking because the children were given full information about their performance after each trial, whereas the adults had been given none at all. How well would older children do under the no-feedback conditions?

We proceeded to test children from grades three through nine in the Princeton school system on the block-stacking version of the task, but without giving them any information about how they were doing. We were again surprised at the generally low level of performance. Ten pairs of children in each of the four grades were tested. The proportion of pairs performing perfectly on the first three trials ranged from about 25 to 42 percent [*see bottom illustration on page 105*]. The third-graders did not improve at all over the course of 15 trials, and the fifth- and seventh-graders improved very little. Ninth-graders, although they showed dramatic improvement in successive trials, still did not attain the virtually perfect accuracy that adults display from the very first trial.

What factors might account for the remarkably inept performance of our youngest subjects and for the older children's surprisingly slow attainment of adult competence? When we first began working with very young children, we concluded somewhat naïvely that the primary factor accounting for communicative failures in our experimental situation was "childhood egocentrism," a term coined by the Swiss developmental psychologist Jean Piaget to describe the thought and speech typical of an early stage of cognitive development. In its simplest terms egocentric behavior is characterized by the inability to detach oneself from one's own point of view and take into account the perspective of someone else. It is as though the egocentric child thought that others know precisely what he himself knows and believe what he himself believes—in short, that others are just like himself. Clearly egocentrism must be a matter of degree; by the age of two most children are aware that adults are more knowledgeable, more skillful and unquestionably more powerful. We thought, however, that young children may fail to appreciate that someone else may not be more knowledgeable, may indeed not know something they themselves know, and that what is apparent and perceptible to themselves may not be so obvious to someone else.

In this sense the messages generated by our youngest subjects could aptly be described as egocentric. They are meaningful to the speaker who generated them but cannot be understood by anyone who does not share the particular perspective of the speaker. We observed a particularly striking example of this kind of interaction in a session with a pair of four-year-olds:

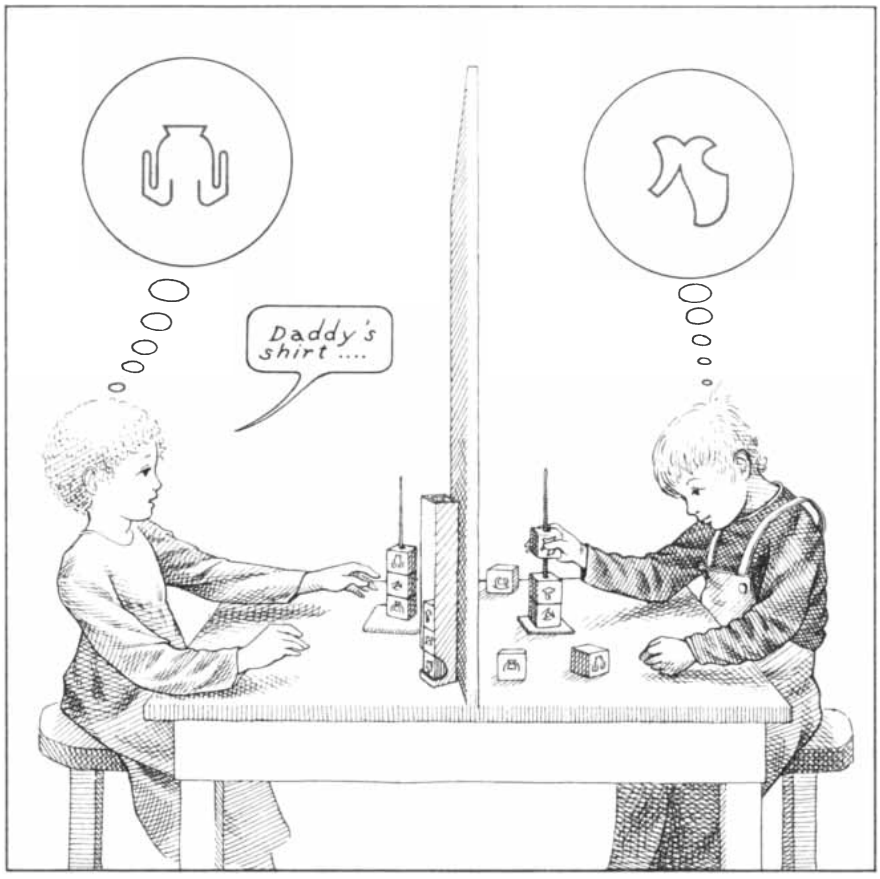
Speaker (referring to one of the geometric figures): "It's a bird."

Listener: "Is this it?"

Speaker: "No."

Neither child could actually see the other child or the other child's stimulus materials, but their interaction gives no evidence of that fact.

Tempting as such an explanation for the poor performance of young children may be, it is unsatisfactory for a number of reasons. First, numerous attempts to find correlations between standard mea-



CHILDREN'S VERSION required the speaker to describe the design on blocks appearing at the base of a dispenser and then to stack the blocks on a peg. The listener's task was to select the correct blocks from a randomly ordered collection and stack them in the same order. The youngest speakers gave noncommunicative descriptions that were usually misunderstood.

FORM	CHILD				
	1	2	3	4	5
1	Man's legs	Airplane	Drapeholder	Zebra	Flying saucer
2	Mother's hat	Ring	Keyhold	Lion	Snake
3	Somebody running	Eagle	Throwing sticks	Strip-stripe	Wire
4	Daddy's shirt	Milk jug	Shoe hold	Coffeepot	Dog
5	Another Daddy's shirt	Bird	Dress hold	Dress	Knife
6	Mother's dress	Ideal	Digger hold	Caterpillar	Ghost

TYPICAL INITIAL DESCRIPTIONS offered by five nursery-school speakers for each of the forms are shown here. Unlike adult descriptions, they were brief and highly idiosyncratic.

sures of egocentrism and performance in communication tasks have failed to produce convincing results. Second, by the age of eight most children should be beyond the point where egocentrism is an important factor in their behavior, and yet 13- and 14-year-olds did not perform with adult competence in our task. Although egocentrism may contribute to the poor performance of younger children, it cannot account for the overall pattern of performance we have observed. And in any case egocentrism is essentially a descriptive notion: it characterizes certain kinds of behavior but does not tell why they are displayed.

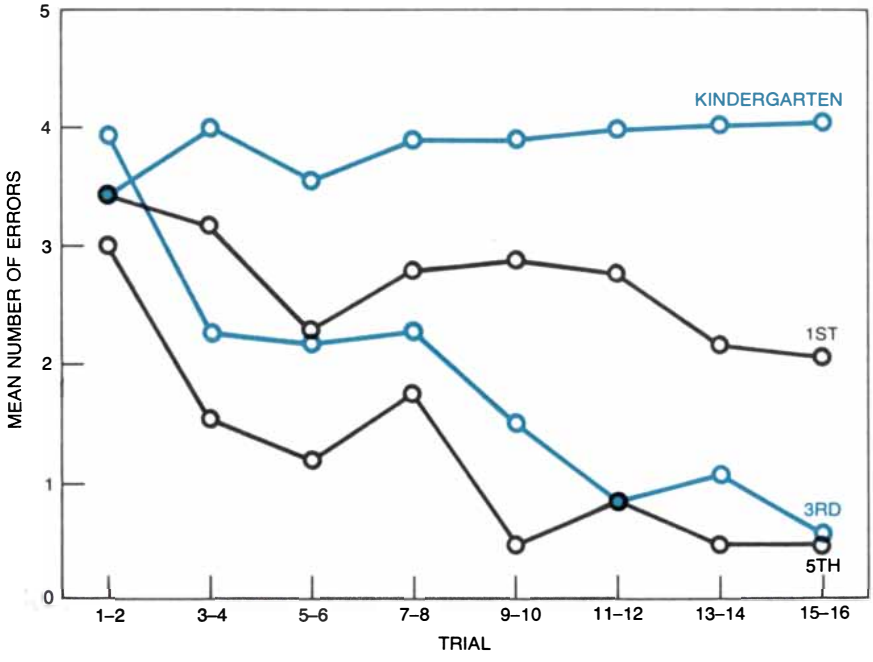
How, then, is one to explain the differences in communication performance that we find among children of different ages and between children and adults? Do children truly lack the capacity to role-play (to temporarily assume another person's perspective), which seems to be required for effective performance in any but the most routine and stereotyped communication situations? Or is it rather that children—even four-year-olds—have the ability to role-play but for one reason or another do not deploy the ability in certain experimental contexts? Perhaps these children have yet to learn under what circumstances role-playing is particularly important for effective communication. Or perhaps they fail to do so when the task is overly demanding cognitively, that is, when it overloads their information-processing capacity.

Recent work in our own laboratories and in those of other investigators seems to strongly implicate the latter possibility. As we simplify the communication task, and thereby reduce the sheer cognitive load the child must deal with, the performance of even very young children begins to approach the adult level of competence. This suggests that the poor performance of children in particular communication situations may stem from something other than a generalized inability to take into account the perspective of another person. When the demands of the task are relatively light, children do engage in social, nonegocentric speech, and they communicate rather successfully. As the demands become heavier children may still attempt to employ social-communication strategies, but they do so less effectively than adults. Finally, when the demands of the task become heavy enough, children may not have the opportunity to bring into play the social-communication skills they possess.

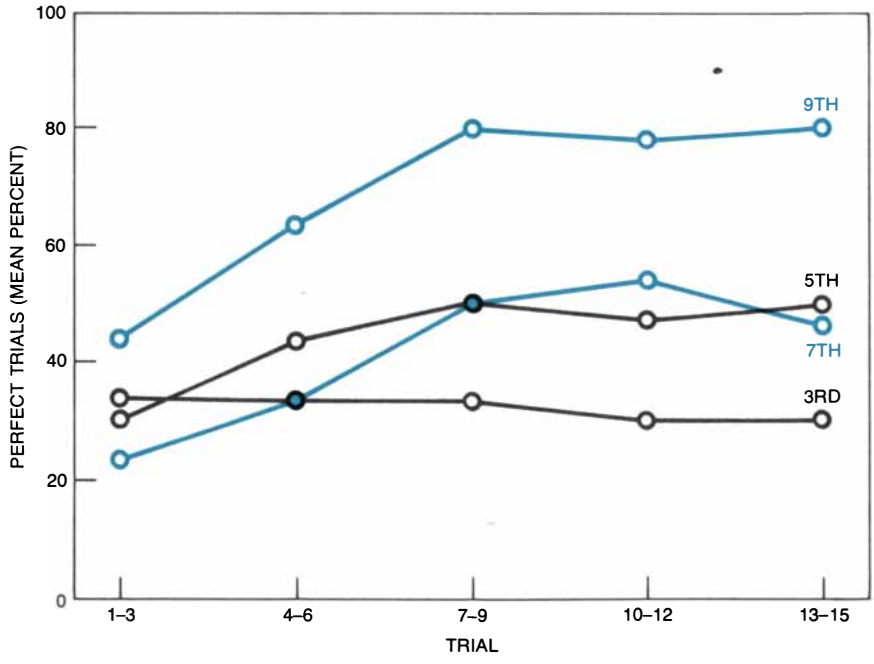
If this seems strange, it is well to keep in mind that even mature and articulate adults can find themselves in situations where they fail to take another person's knowledge and perspective into account. Consider the American tourist in a foreign country who asks, "Where is

the men's room?" and, on receiving no answer because his informant speaks no English, proceeds to shout, "Men's room, toilet, where?" Such an adult is not very different from the child who tries to communicate an unfamiliar geometric form by calling it "Daddy's shirt." Both the tourist and the child are ordinarily able to distinguish social from nonsocial speech and to communicate socially, and yet both may find themselves so overwhelmed by the demands of the particular situation that they do not bring that ability into play.

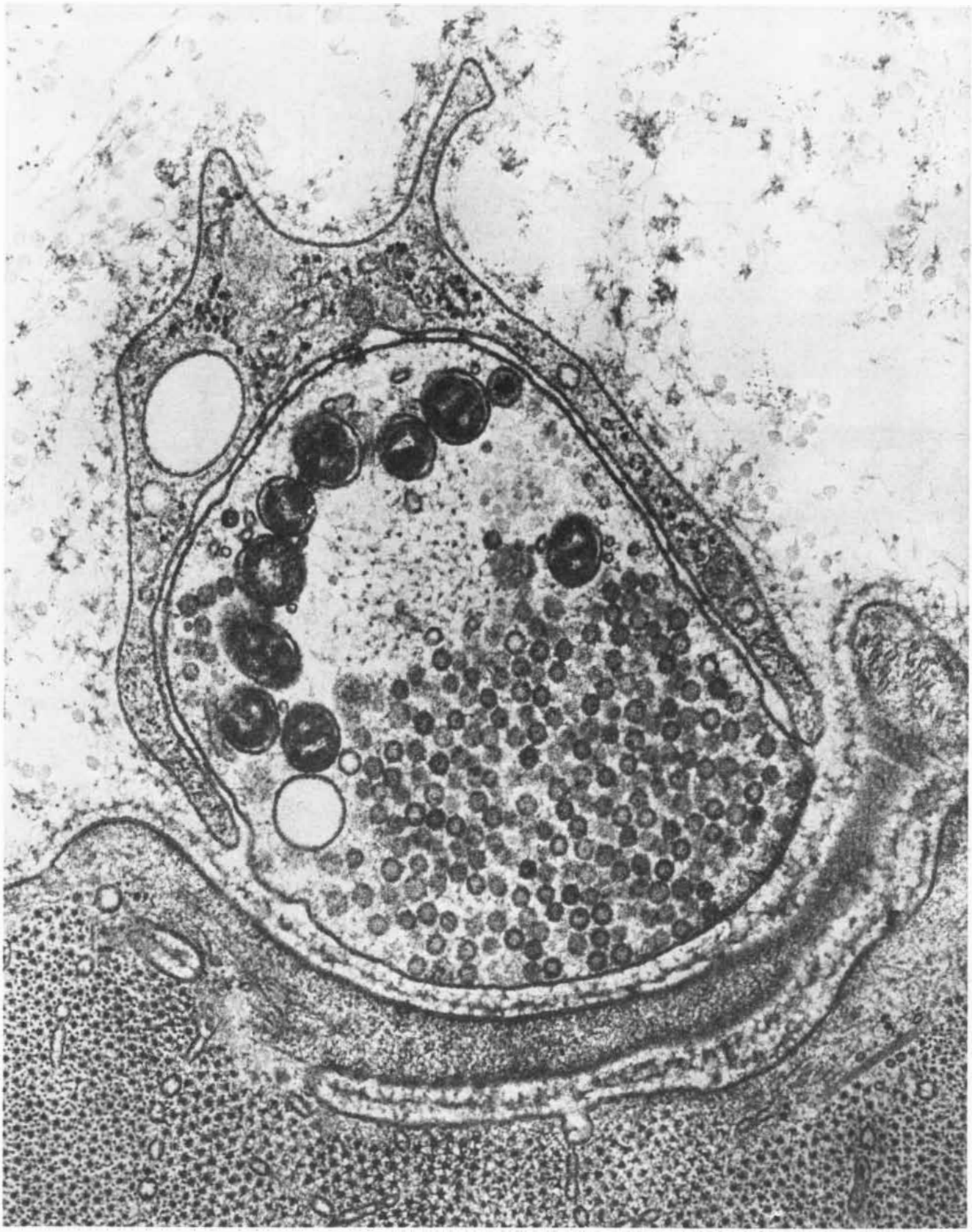
What we see developing so slowly in our studies of children's communication is a constellation of knowledge and skills that reflects the child's interaction with the world and with other people and cultures. The social use of language depends as much on that knowledge as it does on knowledge of language itself.



ELEMENTARY-SCHOOL CHILDREN performed badly on their initial trials. Kindergartners did not improve with practice. Children in the first, third and fifth grades did improve, with the help of comments from the experimenter pointing out the mistakes they had been making.



OLDER CHILDREN, tested on the block version but without feedback from experimenters, did not match adult performance. Only the ninth-graders showed significant improvement.



SITE OF ACETYLCHOLINE RELEASE from a motor-nerve terminal is magnified 71,400 diameters in this electron micrograph made by John E. Heuser of the University of California Medical Center in San Francisco. The terminal is stocked with saclike synaptic vesicles containing molecules of acetylcholine; the larger dark structures are mitochondria, which generate the energy required for the activities of the nerve ending. On the arrival of an impulse the synaptic vesicles fuse with the membrane, releasing acetylcholine into the fluid-filled cleft between the terminal and the muscle cell. The molecules of acetylcholine then bind to receptors embedded in the muscle-cell membrane. Below the cleft a deep invagination in the muscle membrane, or junctional fold, is shown in partial section.

The Response to Acetylcholine

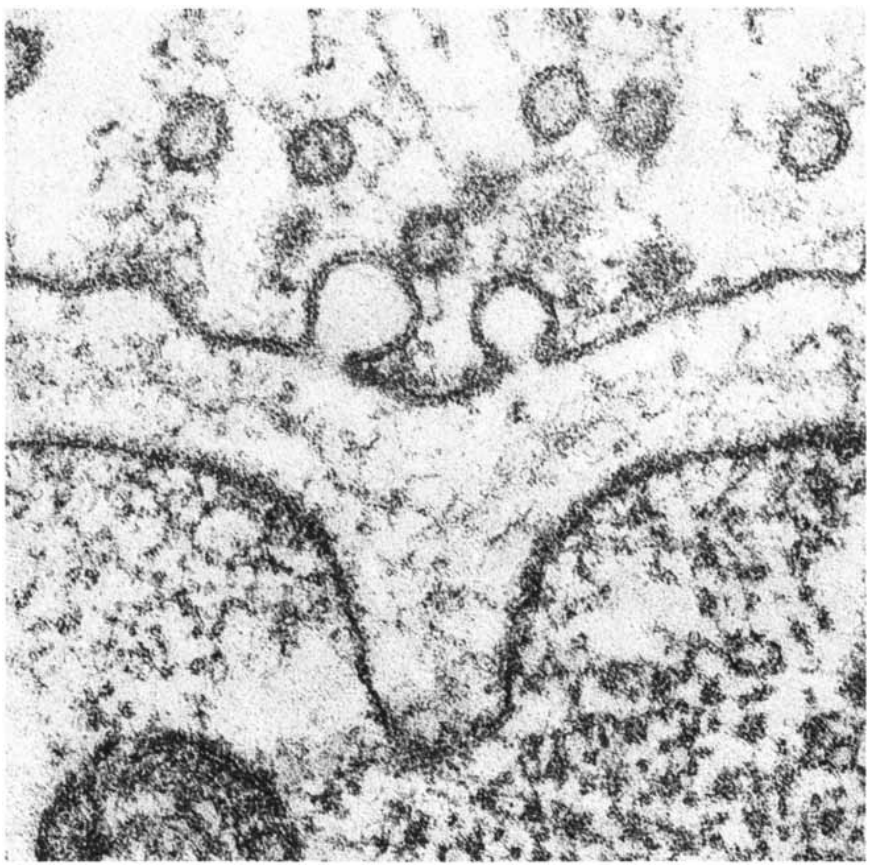
When a nerve makes a muscle cell contract, it gives the cell a tiny squirt of acetylcholine. Receptors on the cell respond by opening so that ions can travel through the cell membrane

by Henry A. Lester

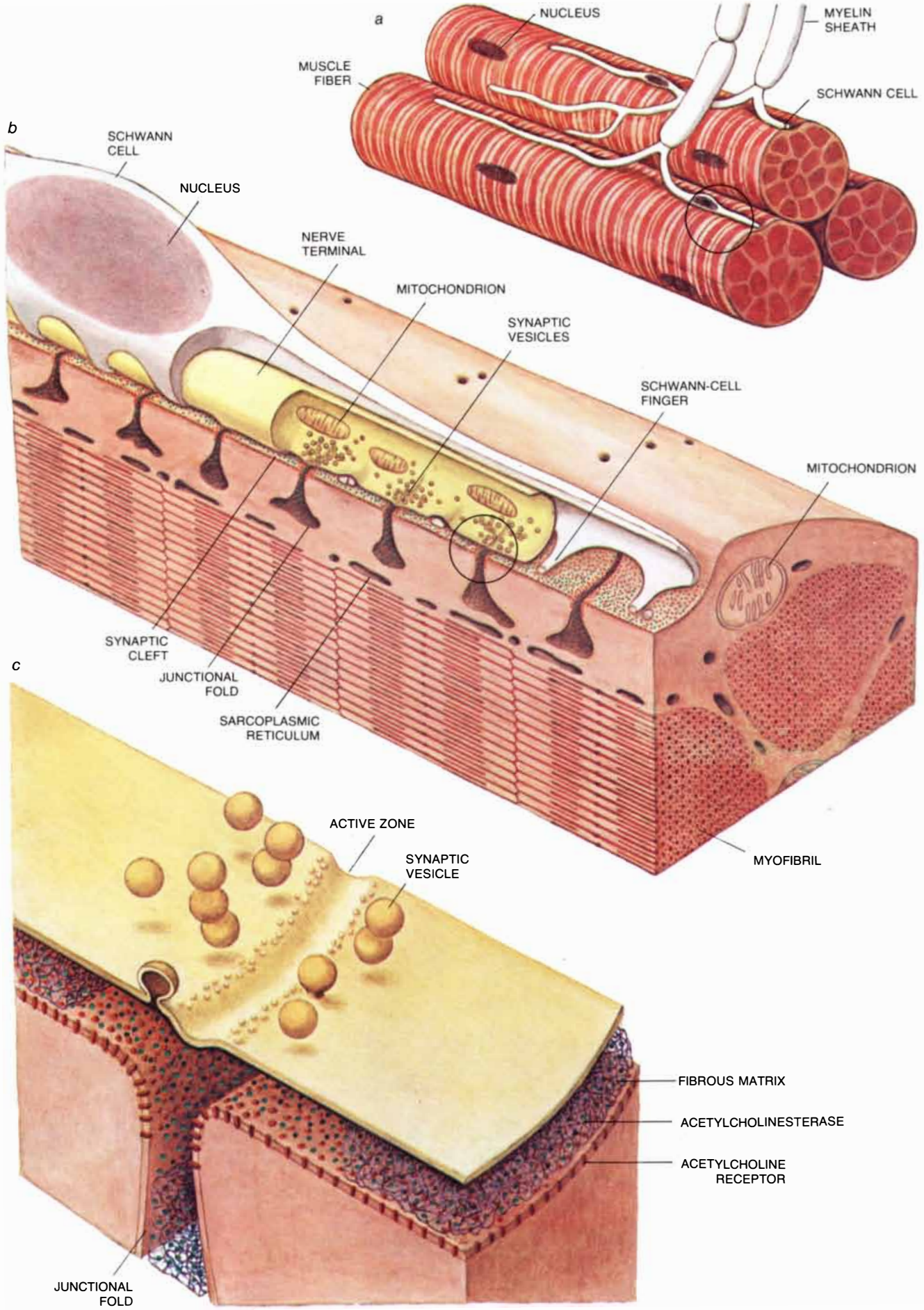
The transmission of impulses from one living cell to another is so fast that it was long thought to be a purely electrical phenomenon. This impression was enhanced by investigations with the light microscope, which revealed that cells with such connections are joined by the intimate contacts called synapses. Then in 1921 Otto Loewi, working at the University of Graz in Austria, showed in an elegant experiment that synaptic transmission in at least one system is mediated by chemical transmitter substances. According to Loewi, the idea for the experiment came to him in a dream. It had been known that the isolated heart of a frog could be kept beating in a vessel of saline fluid, and that stimulation of the vagus nerve leading to the heart would reduce its rate. Loewi set two frog hearts beating in separate vessels and allowed fluid from the vessel containing one heart to run through the other heart. When he stimulated the first heart's vagus nerve, its rate was reduced, and after a brief interval the second heart's rate was reduced as well. Some substance had clearly been liberated by the stimulated vagus nerve and transported in the fluid to influence the second heart. Loewi named the unknown transmitter substance *Vagusstoff,* and subsequent analysis in his laboratory demonstrated it to be acetylcholine, a relatively small molecule.

Since then acetylcholine has been identified as the transmitter at a variety of synapses in vertebrate and invertebrate animals. In the human body it slows the heart, constricts involuntary muscle, controls the contraction of the voluntary muscles and participates in the integrative functions of the brain and the spinal cord. The diverse physiological effects attributable to this small molecule can be explained by the presence of specific receptors on the membrane of the postsynaptic, or target, cells. Several classes of acetylcholine receptors are known. Nearly all appear to work by translating the binding of acetylcholine into the opening of channels in the cell membrane that pass ions such as those of sodium and potassium. Depending on the particular ions that move through the channels, the electric charge they carry and the direction of their movement, acetylcholine produces its characteristic excitatory or inhibitory effect. In recent years new information has been obtained about the response to acetylcholine at the synapse between nerve and voluntary muscle and at the very similar synapse between nerve and the electric organs of fishes such as the electric eel. Such studies deepen our appreciation of the chemical synapse as a minute but highly sophisticated biophysical machine, specialized to function on a time scale of milliseconds and a distance scale of micrometers.

At the nerve-muscle synapse the motor-nerve fiber lacks its fatty myelin sheath and branches into fine terminals. Each terminal lies in a shallow gutter-



SYNAPTIC VESICLES merge with the nerve-cell membrane, discharging their contents into the synaptic cleft in this electron micrograph, also made by Heuser. Image, magnified 230,000 diameters, was obtained by freezing tissue within a millisecond after stimulating it electrically.



like depression on the surface of the muscle cell. The electron microscope reveals what the light microscope could not: at the nerve-muscle synapse the membranes of the nerve terminal and the muscle cell are separated by a fluid-filled cleft some 500 angstroms wide. About every micrometer (10,000 angstroms) along the nerve terminal there are specialized areas associated with clusters of tiny vesicles, or sacs, each containing on the order of 10,000 molecules of acetylcholine. In the muscle membrane, precisely juxtaposed across the synaptic cleft from the clusters of vesicles, are deep invaginations called junctional folds. At the crests of these folds and part of the way down into them are the acetylcholine receptors: molecules of protein embedded in the membrane. The receptor molecules are tightly packed in these regions; if they were uniformly arranged in the plane of the membrane, they would be only 50 to 100 angstroms apart. Their density falls off by a factor of at least 100, however, just a few micrometers from the crest of the fold.

An impulse arriving at the presynaptic nerve terminal causes an influx of calcium ions across its membrane. This induces several hundred synaptic vesicles to fuse with the presynaptic membrane at specialized regions called active zones, liberating the vesicles' content of acetylcholine molecules into the synaptic cleft. The transmitter diffuses rapidly across the cleft to the muscle-cell membrane, where it combines with the receptor molecules.

Within .3 millisecond after each packet, or vesicle load, of acetylcholine is released it causes some 2,000 channels in the muscle-cell membrane to open. Each channel passes both sodium and potassium ions. The flow of these ions (sodium into the cell, potassium out) gives rise to a net electric current that short-circuits the normal potential of −90 millivolts across the resting cell membrane; this brief depolarization is known as the end-plate potential or the excitatory postsynaptic potential. Under normal circumstances the end-plate potential exceeds the threshold value for initiating an impulse that spreads through the entire muscle-cell membrane and causes the muscle cell to contract.

Transmitter molecules would linger in the synaptic cleft, hopping from one receptor to another on the muscle-cell membrane and opening additional channels, if it were not for the enzyme acetylcholinesterase, which breaks acetylcholine down into acetate and choline. The molecules of the enzyme are not embedded in the muscle-cell membrane as the acetylcholine receptors are; they appear to be associated with a loose matrix of collagen and mucopolysaccharide fibers that wind their way through the synaptic cleft and deep into the junctional folds. According to a recent estimate by Bernard Katz and Ricardo Miledi of University College London, acetylcholinesterase destroys about a third of the acetylcholine molecules before they even reach receptors and then rapidly disposes of the rest as they leave the receptors a millisecond or so after having been bound to them. The speed with which acetylcholine is bound and inactivated makes it possible for the entire process of neuromuscular transmission to be repeated up to several hundred times a second.

Attempts have been made in recent years to correlate information about the actual structure of the acetylcholine receptor, its ability to bind acetylcholine and related compounds and the properties of ion channels. Such investigations call for ways to identify the receptor protein in solution and in fragments of cell membrane, where electrophysiological measurements are not possible. This task has been simplified by the discovery of molecular labels that bind specifically and almost irreversibly to the receptor.

Such labels were obtained from an exotic source: the venom of elapid snakes, such as the cobra and the krait, that kill their prey by paralyzing the respiratory muscles. In the late 1950's Chen-Yuan Lee and his colleagues at National Taiwan University explained this action by showing that proteins such as the alpha-bungarotoxin in the venom of the banded krait (*Bungarus multicinctus*) block neuromuscular transmission. In succeeding years experiments by Lee's group, by me at Rockefeller University (with a cobra toxin purified by David Eaker and his colleagues at the University of Uppsala) and by several other investigators showed that those toxins block the acetylcholine receptor by binding to it in a highly specific way. They do not interact with acetylcholinesterase or interfere with any of the other processes of normal neuromuscular activity; they bind tightly and almost irreversibly to the receptor. The additional fact that elapid toxins can easily be tagged with radioactive atoms of iodine or hydrogen makes them ideal chemical labels for the acetylcholine receptor.

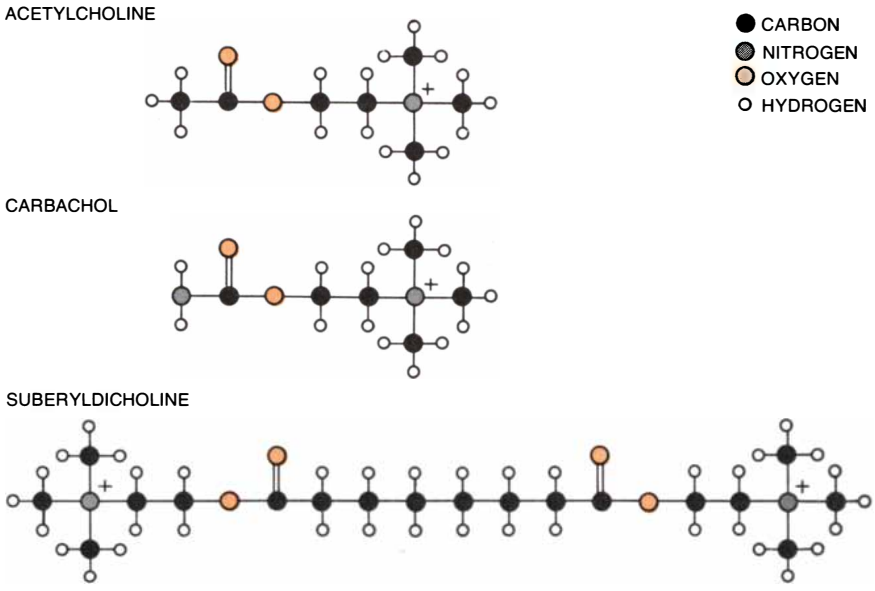
The snake-venom toxins have been useful in several ways. First, a number of convenient test-tube assays for the receptor protein are based on its binding to toxin. Second, autoradiography of tissue to which radioactive toxin has been bound has made it possible to examine the density and distribution of the receptor in intact cell membranes. Third, the toxins have been used to purify the receptor by means of a technique known as affinity chromatography. In this procedure toxin molecules are affixed to granules of the synthetic substance dextran, which are then packed in a column. When a mixture containing the receptor is passed through the column, the receptor binds to the toxin and therefore to the granules, but other compounds pass through unhindered. The toxin-receptor complex is then dissociated by passing a high concentration of acetylcholine or a similar compound through the column, and the receptor is collected for further study.

The next requirement for biochemical experiments, an abundant source of receptor, was satisfied by the electric organs of electric fishes. In many such fishes the electric organ develops in the embryo from the same type of tissue that gives rise to muscle, but instead of muscle cells the electric organs consist of large flat cells called electroplaques. These cells contain few or none of the contractile filaments that characterize muscle, but they share with muscle cells a sensitivity to acetylcholine. One side of the electroplaque (termed the innervated face) receives a large number of nerve terminals that form synapses. Electroplaque synapses function quite similarly to those of muscle: their acetylcholine receptors are activated by the

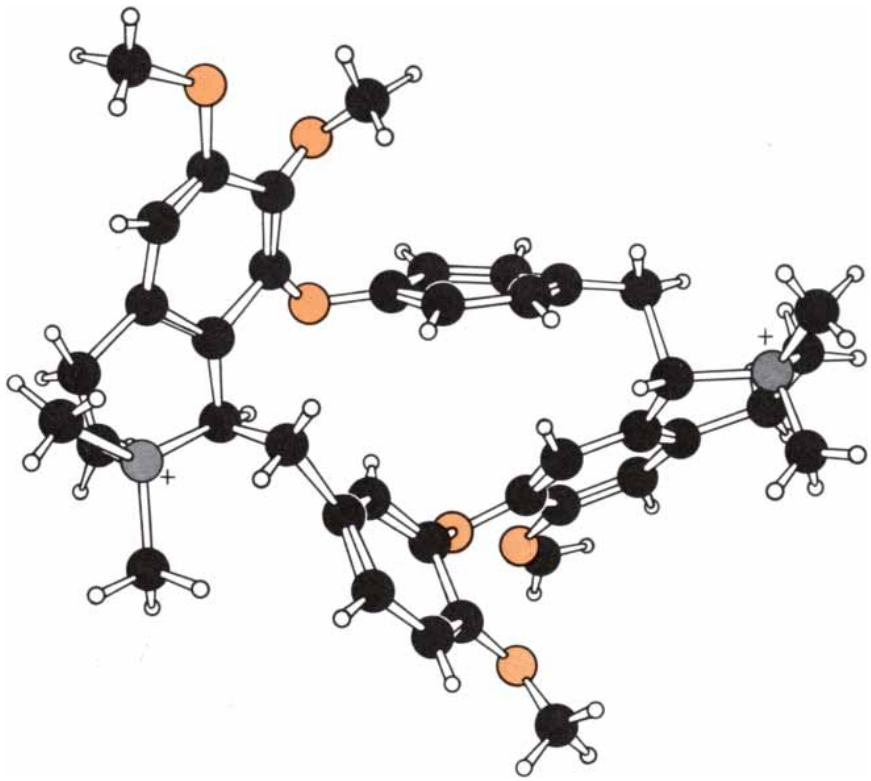
NERVE-MUSCLE SYNAPSE of the frog is diagrammed in this illustration. The slender terminal branches of a motor-nerve axon, lacking the fatty myelin sheath of the rest of the fiber, lie in gutterlike depressions in the membrane of a muscle cell (*a*). Each terminal region is covered by a Schwann cell that embraces it with fingerlike processes, subdividing it into 300 to 1,000 regularly spaced compartments (*b*). Within the nerve terminal are clusters of synaptic vesicles, or sacs, each of which contains on the order of 10,000 molecules of acetylcholine. When an impulse arrives at the nerve terminal, the vesicles fuse with the membrane along a double row of particles designated an active zone, releasing their contents into the synaptic cleft. One such fused vesicle is shown in *c*. The transmitter molecules then diffuse across the cleft and bind to specific receptors (*red ovoids*) embedded in the muscle-cell membrane at the crests of the junctional folds. The binding of acetylcholine to the receptors opens channels in the muscle-cell membrane, allowing both sodium and potassium ions to flow through the membrane. The inward sodium flux exceeds the outward potassium flux, resulting in a net inward current that short-circuits the membrane's electrically polarized resting state. This depolarization triggers a larger impulse that causes the muscle fibers to contract. Acetylcholine is subsequently destroyed by molecules of the enzyme acetylcholinesterase (*green balls*), which are distributed throughout the fibrous matrix that fills the synaptic cleft and lines the junctional folds. Here the matrix has been cut away near the active zone to reveal the receptors.

same agonists (acetylcholine and a few related compounds) and inhibited by the same antagonists (such as the snake toxins and curare), and the same kind of ion channel is thought to be involved.

Like a muscle cell, the innervated face of an electroplaque responds to acetylcholine with a large influx of sodium ions and a smaller efflux of potassium ions, resulting in a net flux of electric current across the cell membrane. In a typical marine electric fish this current completes its circuit by flowing out through the highly folded noninnervated face of the electroplaque (which receives no synapses) and around the fish. Electroplaques are arranged in columns, so that their voltage is summed as it is in the stacked plates of a storage battery; the columns in turn are arranged in parallel, so that their current is summed.



AGONISTS such as acetylcholine and a few related compounds activate the neuromuscular receptor, allowing a net flow of positively charged ions across the muscle-cell membrane. All agonists have at least one positively charged nitrogen atom that binds to the receptor.



ANTAGONISTS, or blockers of neuromuscular transmission, such as curare (shown here), apparently work by binding to an inactive, or closed, form of the acetylcholine receptor. Like many agonists the curare molecule has two positively charged nitrogen atoms. A potent paralytic agent, curare is used by some South American Indians as a poison on hunting arrows.

This proliferation of electroplaques attains extraordinary proportions in fishes that use their electric organs to shock their prey. The electric organs of the giant electric ray *Torpedo* and its close relative *Narcine* are kidney-shaped and occupy most of the ray's wings. The electroplaques, each of which generates about .1 volt, are arranged in columns of 500 cells and sum to produce a total of 50 volts at 20 amperes. Since 50 percent of the innervated face of each *Torpedo* electroplaque may consist of acetylcholine receptors, these cells are the richest known source of the receptor protein for biochemical experiments. (Electrophysiological experiments on this material have so far been precluded by technical difficulties.)

Another family of electric fishes includes *Electrophorus electricus,* the giant freshwater eel of tropical South America. This animal has 4,000 rows of electroplaques, representing about 70 percent of its mass, and it can generate more than 600 volts at one ampere. In *Electrophorus,* however, the postsynaptic response to acetylcholine merely constitutes the trigger for an impulse produced by channels in the nonsynaptic regions of the membrane, much as it does in muscle cells. *Electrophorus* electroplaques accordingly have fewer acetylcholine receptors than do *Torpedo* electroplaques, in which all the current generated by the fish flows through the receptor channels themselves. Nevertheless, *Electrophorus* electroplaques have more receptors than muscle tissue does, and they often serve both as a source of acetylcholine receptor in biochemical experiments and for electrophysiological investigations of the response to acetylcholine in intact cells.

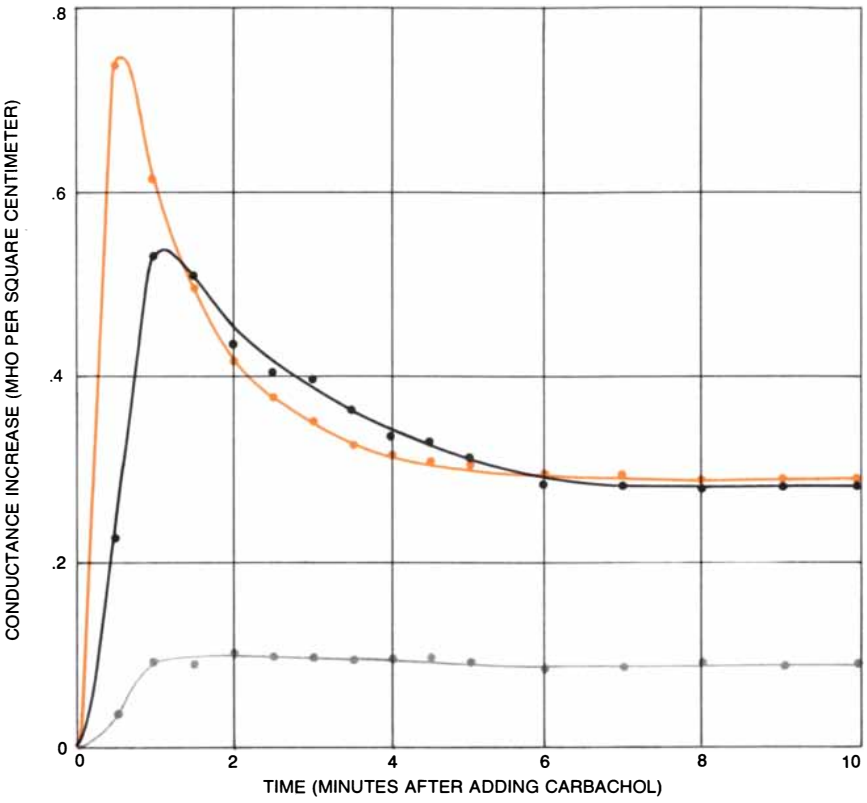
In 1971 and 1972 workers in several laboratories succeeded in removing the toxin-binding molecule (the putative receptor) from electroplaque membranes with detergents. The receptor was subsequently purified several thousandfold with affinity and conventional chromatography. It is a large protein molecule presumably with hydrophobic ("water-hating") regions where it traverses the double layer of lipid (fatty) molecules in the cell membrane. A small number of sugar molecules are also attached to it. Interest is now focused on the questions of how agonists open the channel in the postsynaptic membrane and how antagonists block the process.

At present one can only give a progress report on these problems. Some 10 years ago Arthur Karlin of the Columbia University College of Physicians and Surgeons and Jean-Pierre Changeux and his colleagues at the University of California at Berkeley pointed out a possible analogy between the acetylcholine receptor and regulatory enzymes, a class of the proteins that catalyze biochemical reactions. The rate of the reaction catalyzed by such an enzyme can be altered by a substance called an effector. The effector molecule may be structurally quite different from the molecule on which the enzyme acts, and it binds to the enzyme at a site distinct from the site involved in catalysis, altering the catalytic activity of the enzyme by changing the enzyme molecule's conformation, or three-dimensional folding pattern.

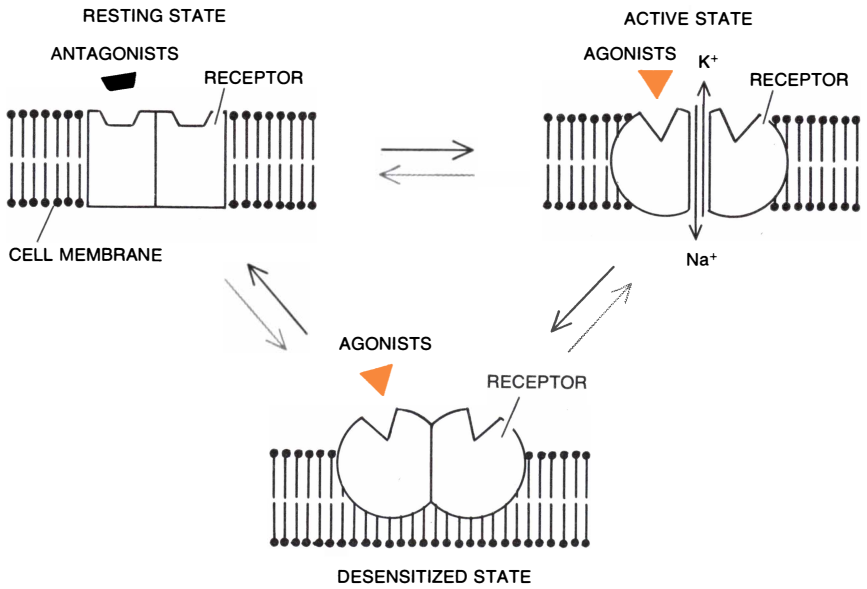
Acetylcholine bears little chemical resemblance to the sodium and potassium ions that flow through the channel in the postsynaptic membrane. Perhaps, it was suggested, acetylcholine could be considered an effector of the receptor molecule in the membrane. The opening and closing of the ion channel would then be analogous to the altered catalytic activity of regulatory enzymes. If the analogy was valid, the binding site for acetylcholine and the ion channel would be functionally distinct parts of the receptor and perhaps structurally distinct parts as well; furthermore, conformational changes in the receptor molecule would mediate the response to acetylcholine.

More specifically, Karlin and Changeux independently proposed that the acetylcholine receptor in the postsynaptic membrane can shift between two conformations: an active form associated with an open channel and an inactive closed form. In the absence of agonists the equilibrium state of the population of receptor molecules strongly favors the closed form. Agonists bind preferentially to the active form and so shift the equilibrium toward the open-channel conformation; antagonists bind preferentially to the inactive form, shifting the equilibrium toward the closed-channel conformation.

Such hypotheses are best tested with fragments of intact postsynaptic membrane containing the receptor; presumably such an environment is more natural than that of receptor molecules in a solution of detergent. In one investigation at the Pasteur Institute in Paris, Changeux and Jonathan B. Cohen made use of a fluorescent compound that binds reversibly to the receptor both at the agonist binding site and at "secondary" sites in order to monitor conformational changes in the receptor protein. They found that agonists altered the spectrum of the light emitted by probe molecules bound to secondary sites and



TIME-DEPENDENT RESPONSE of the receptor to three different concentrations of the agonist carbachol shows that when agonist is applied for short periods, the number of open ion channels increases with concentration. After prolonged exposure to high agonist concentration the response of receptors is dramatically reduced, a phenomenon termed desensitization. Agonist concentrations (per liter) are 300 micromoles (*color*), 100 micromoles (*black*) and 30 micromoles (*gray*). The conductance in mhos is equal to the reciprocal of resistance in ohms.



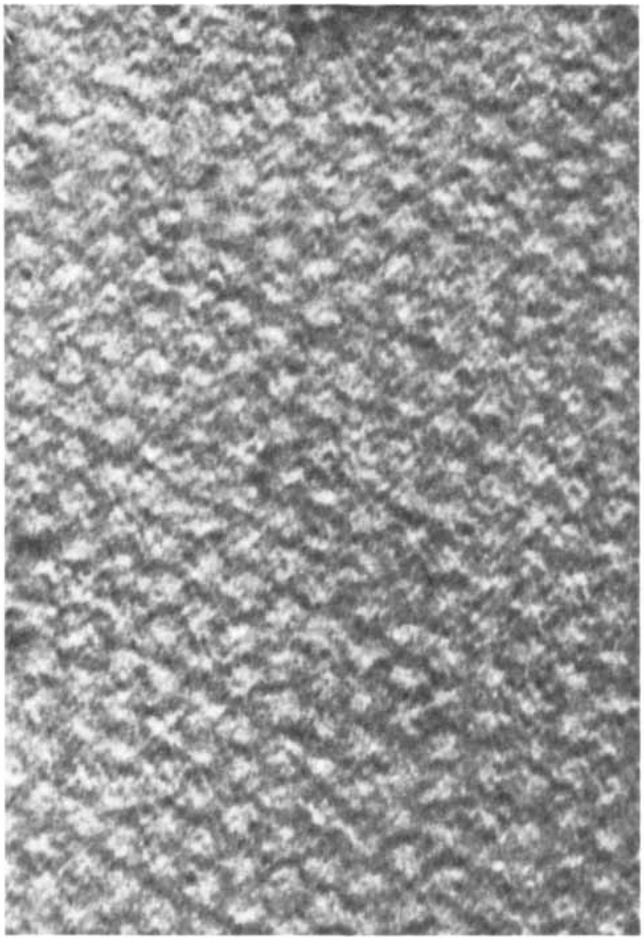
THEORETICAL MODEL proposed by Jean-Pierre Changeux of the Pasteur Institute explains the three functional states of the acetylcholine receptor—resting, active (open to ions) and desensitized—by correlating them with three separate conformational states of the receptor protein. In the absence of acetylcholine the large majority of receptors are in the resting (closed) conformation. When acetylcholine is released into the synaptic cleft, it binds preferentially to the active conformation, rapidly shifting the receptor population toward the state with an open channel. With prolonged exposure to agonist the receptor shifts at a lower rate to an inactive, or desensitized, conformation with an even higher affinity for agonist. Antagonists tend to stabilize either the resting or the desensitized state but not the active one.

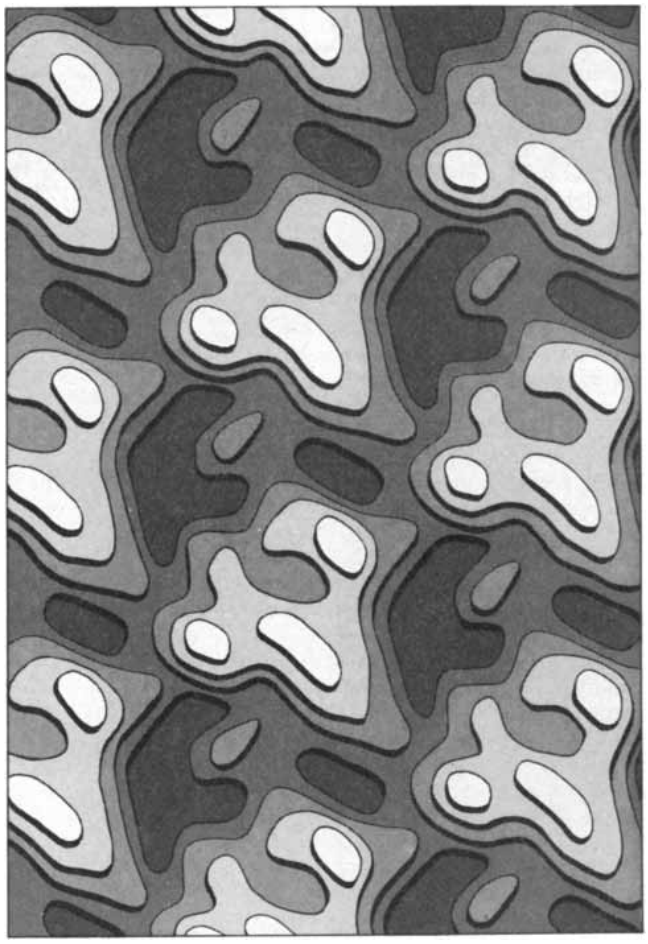
that antagonists did not. Since such spectra are quite sensitive to the physicochemical characteristics of the probe's immediate environment, Changeux and Cohen concluded that the receptor protein's conformation does indeed depend on whether an agonist or an antagonist is bound to it.

A complication in the receptor model was preoccupying Changeux when I arrived at his laboratory at the Pasteur Institute in 1971 as a postdoctoral student. It had been known for some time that regulatory enzymes can be made unresponsive to their effectors. It had also been known that when receptors are subjected to a prolonged exposure to a high concentration of agonist, the receptor channels open less frequently. This phenomenon, termed desensitization, may not be significant on the millisecond time scale of the functioning synapse, but it does have clinical applications: decamethonium is normally an agonist, but when it is injected into the bloodstream, it desensitizes the muscle-cell receptors and relaxes the muscles. Katz and Stephen Thesleff suggested in 1957 that desensitization might involve a binding of an agonist to the receptor that was much tighter, but much slower, than the binding that led to the opening of the channel. Several recent results are in agreement with this hypothesis. For example, Changeux and I found that if the agonist carbachol was applied to *Electrophorus* electroplaques quickly enough to avoid desensitization, a concentration of 300 micromoles of carbachol per liter was required to open half of the channels. In "slow" binding experiments with membrane fragments and with receptors in solution, however, half of the receptors have agonist bound to them when the carbachol concentration is only 10 micromoles per liter.

These and other observations led to the postulation of a third conformation of the receptor molecule corresponding to the desensitized state. According to this model, short bursts of agonist, lasting a millisecond or so, rapidly shift the equilibrium of the population of receptor molecules toward the open-channel conformation, whereas longer exposures result in the much slower shift of the receptors toward a tightly binding desensitized conformation in which the channel is closed. This revised regulatory-enzyme model of the receptor also accounts for the various effects of antagonists if one assumes that they bind preferentially to the resting or the desensitized conformations but not to the active conformation.

Another analogy with regulatory enzymes arose from an observation made by Katz and Thesleff when they measured the response of receptors to small concentrations of agonists. The



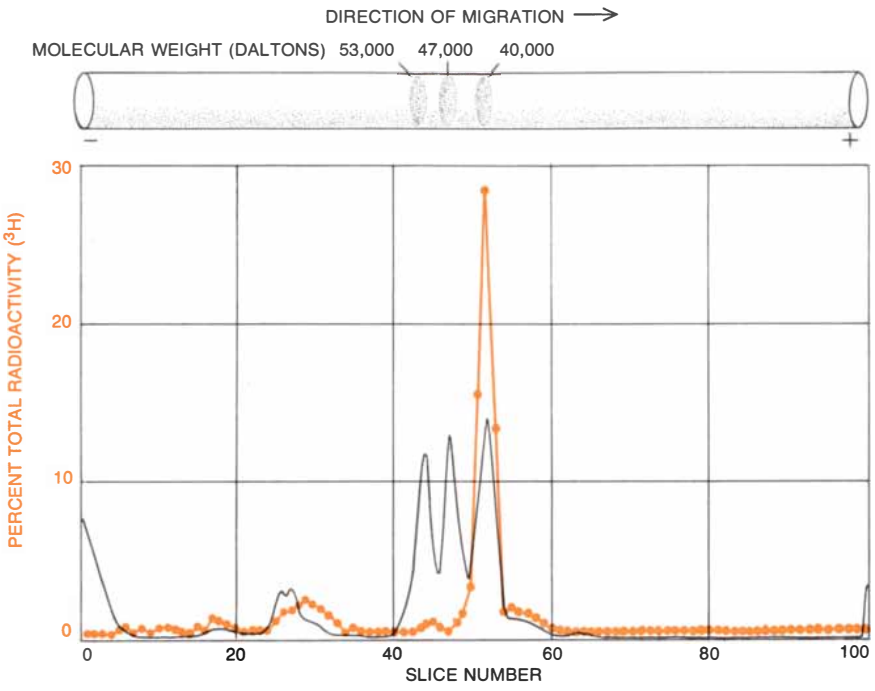


HEXAGONAL ARRAY of acetylcholine receptors, magnified 750,000 diameters, is shown in this electron micrograph of a negatively stained membrane fragment from the innervated face of an electroplaque of the electric ray *Torpedo californica*. Density map at the right is a reconstructed image of the receptor array at a resolution of 20 angstroms, obtained by electron diffraction analysis, a process analogous to cutting out many images of the receptor and superposing them to average them out. Each repeating pattern in the reconstructed image is believed to be a receptor molecule. The molecules are so tightly packed that there is virtually no space between them in the membrane. The receptor protein is strikingly asymmetrical, and the depression in its surface could conceivably be the opening of the ion channel. Micrograph was made by Michael W. Klymkowsky, Michael J. Ross, Robert M. Stroud and Michael A. Raftery of the California Institute of Technology; electron diffraction analysis was done by Ross, Klymkowsky, David A. Agard and Stroud.

plot describing this relation is not linear but concave upward: if the concentration of the agonist is doubled, the number of open channels nearly quadruples. It seems that the presence of agonist near the receptors not only activates some channels but also renders other receptors more responsive to additional agonist. Regulatory enzymes too show such "cooperative" behavior; it arises from the presence of several catalytic sites on the enzyme molecule, each on one of the molecule's component subunits. The entire enzyme molecule functions most efficiently when all the sites are active. It may be that the open state of the receptor channel is more likely to be associated with the binding of two agonist molecules than with the binding of just one molecule.

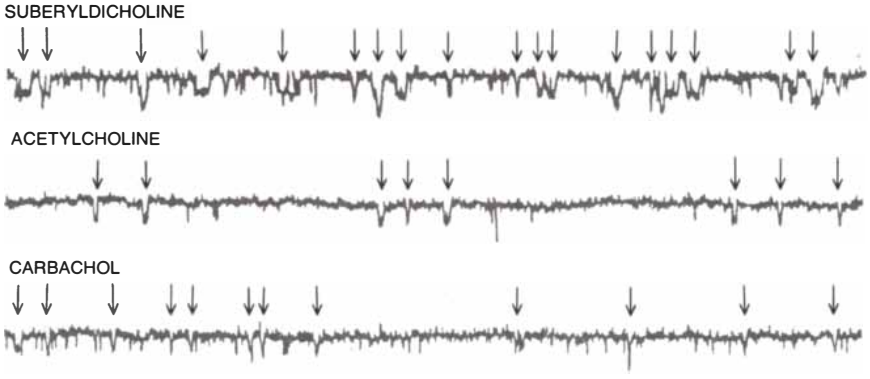
When purified receptor proteins from *Electrophorus* and *Torpedo* are subjected to conditions that would dissociate them into their component subunits, smaller protein molecules are found with molecular weights between 39,000 and 67,000 daltons. There appear to be three types of subunit in the purified *Electrophorus* receptor and four types in the *Torpedo* receptor; the number of copies of each subunit per molecule is still not known. Examination of purified electroplaque receptors in the electron microscope by Jean Cartaud of the University of Paris and André Sobel and Changeux of the Pasteur Institute has shown that they have a "rosette" structure consisting of five or six subunits with a central hole or pit.

The functions of the respective subunits are not known, with one exception. Karlin and his associates have synthesized a radioactively labeled compound that binds irreversibly to the purified receptor by means of an attached reactive chemical group. (The binding is blocked by some agonists and antagonists, possibly because all the compounds are binding at the same site.) When the labeled receptor is then dissociated into its component subunits, only one subunit, the smallest, is found to be radioactive. Hence this subunit might be involved in the binding of acetylcholine. In addition Michael A. Raftery and his colleagues at the California Institute of Technology have identified two types of binding site that are present in equal numbers on the same receptor molecule but that differ in their affinity for agonist. This observation would argue for an even number of binding sites per receptor molecule, probably two or four. The challenge that now remains is to correlate the complex functional states of the receptor with changes in the interactions of its component subunits and to identify the molecular nature of the gate mechanism that opens or exposes the ion channel.



ACETYLCHOLINE-BINDING SUBUNIT of the receptor protein was identified by Arthur Karlin and his colleagues at the Columbia University College of Physicians and Surgeons. The quaternary ammonium compound MBTA binds irreversibly to the receptor at a site thought to be the same as the agonist binding site. Receptors purified from *Electrophorus* electroplaques were exposed to radioactively labeled MBTA, and the protein was then decomposed into its three component types of subunit. When the subunits were subjected to gel electrophoresis, they separated into three bands according to their molecular weight. The cylindrical gel (*top*) was stained, scanned on a densitometer (*black curve*) and sliced into thin sections, which were individually assayed for radioactivity (*colored curve*). The peak of radioactivity correlated precisely with the third band, indicating that acetylcholine binds to only one type of subunit.

In 1970 Katz and Miledi opened the way for new electrophysiological approaches to the study of acetylcholine-receptor activation when they showed how to estimate the electrical conductance contributed by a single open channel in the postsynaptic membrane. Recording from frog muscle cells with micropipette electrodes, they found that continued application of acetylcholine produces a "noisy" depolarization in the muscle-cell membrane rather than a perfectly steady one. For example, in one experiment with enough acetylcho-

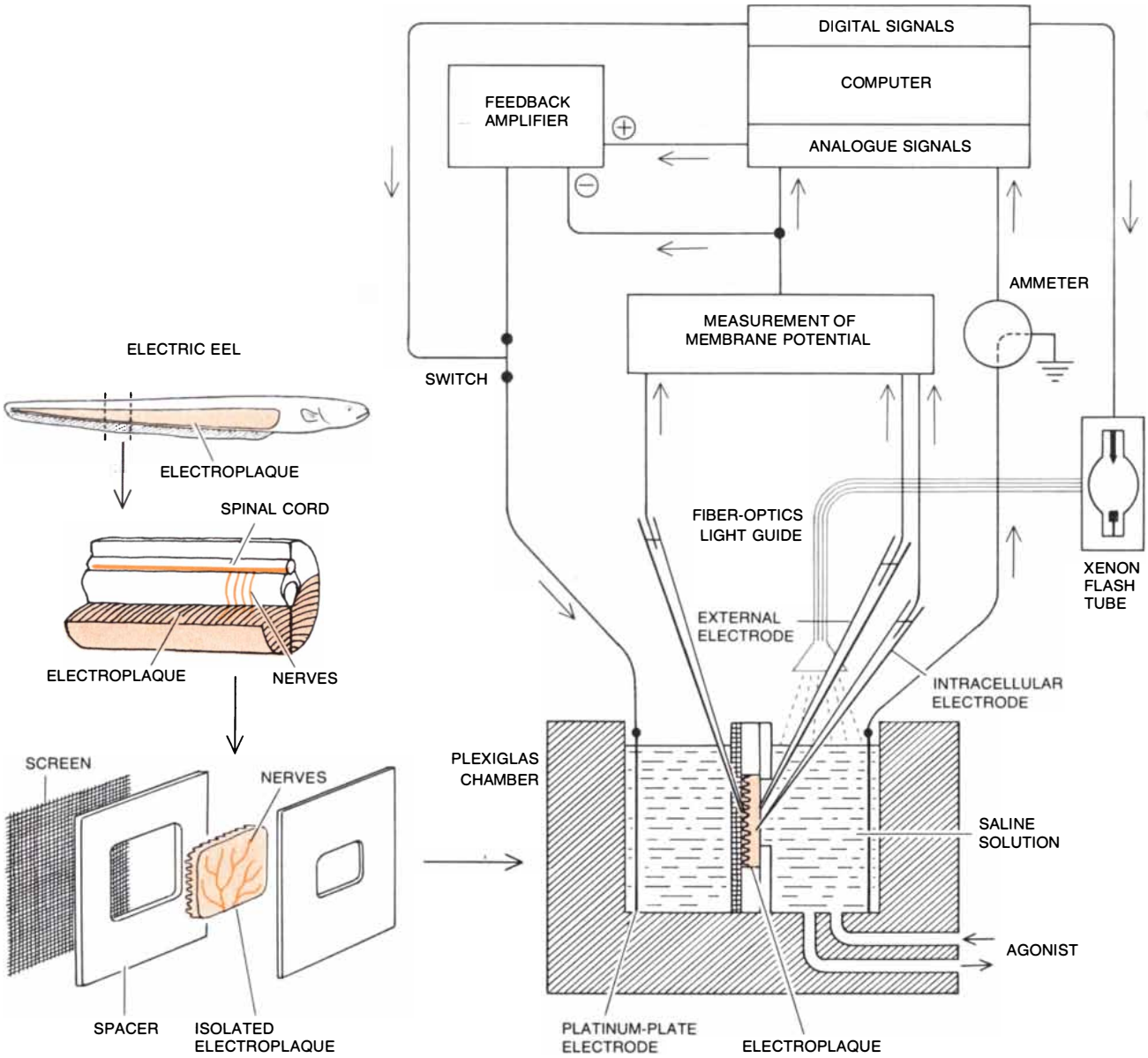


FLOW OF IONS through single acetylcholine receptor channels in frog muscle was recorded under exceptionally favorable circumstances by Erwin Neher and Bert Sakmann of the Max Planck Institute for Biophysical Chemistry in Göttingen. The tip of a micropipette containing agonist and physiological solution was pushed against the muscle membrane, isolating a small region of membrane containing several hundred channels. Conditions were adjusted so that the agonist opened only one channel at any given time, enabling electric current to flow through an electronic ammeter connected to the fluid in the pipette. Recordings shown here, from an oscilloscope screen, indicate that each channel produces a pulse of current with a square form and lasting a few milliseconds (*vertical arrows*). Channels opened by suberyldicholine last longer than those opened by acetylcholine, whereas channels opened by carbachol are briefer.

line to depolarize the membrane by an average of 8.5 millivolts there were small additional variations, on a time scale of milliseconds, that could be described mathematically by the statement that the acetylcholine-induced conductance was fluctuating with a standard deviation of a 200th of the average value.

Such fluctuations are precisely what one would expect if the response to acetylcholine is in fact a summation of channels that open and close at a certain average rate, with each molecular event occurring independently. For such a case the average number of open channels is approximately equal to the square of the standard deviation around that average from one moment to the next. For example, the average conductance mentioned above—200 times the standard deviation—implies the existence of 200^2, or 40,000, simultaneously open channels. On the basis of this figure Katz and Miledi were able to estimate the conductance of a single channel by dividing their measured value for the average conductance by 40,000. Recent improvements on their technique have shown that a net entry of about 12,000 ions into the postsynaptic cell occurs each millisecond a channel remains open.

The channel concept has been strikingly confirmed by recent measurements on single channels made by Erwin Neher and Bert Sakmann, working together at the Max Planck Institute for

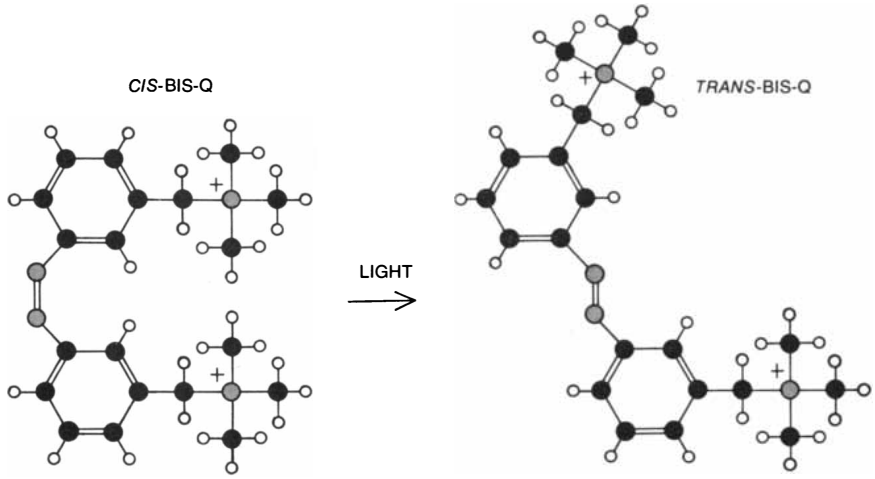


VOLTAGE-CLAMP APPARATUS used by the author and his colleagues at Cal Tech allows the potential difference across the innervated membrane of an electroplaque to be "clamped," or fixed, at a constant value so that the movement of ions through the receptor channels can be measured directly. An isolated electroplaque, about one centimeter long, is placed vertically in a small Plexiglas chamber, with part of the cell's innervated face exposed to a saline solution containing agonists or other compounds under test. Three micropipette electrodes, one internal and two external, detect the potential difference across the innervated face. In the feedback amplifier this voltage is compared with the one established by the computer; if the two are different and if the electronic switch has been opened by the computer, the feedback amplifier passes a correcting current through the platinum plates and across the cell membrane, returning its potential to the predetermined level. An electronic ammeter connected to one plate measures the current, which is then combined in the computer with the measured potential to give the membrane's conductance. In some experiments the computer triggers a flash of a xenon flash lamp that rapidly converts the potent agonist, bis-Q, from its inactive *cis* isomer to the active *trans* isomer.

Biophysical Chemistry in Göttingen and at the Yale University School of Medicine. Taking advantage of several technical improvements, they pushed the tip of a micropipette containing agonist and physiological solution against the muscle membrane; when the agonist opened one of the channels at the tip of the micropipette, the resulting electric current flowed through an electronic ammeter connected to the fluid in the pipette. The initial results show that each channel produces a pulse of current with a square form and lasting a few milliseconds. Channel openings therefore appear to be statistical, all-or-nothing molecular events.

At room temperature a channel opens for about a millisecond when the agonist is acetylcholine, about 50 percent longer when it is suberyldicholine and a third as long when it is carbachol (an agonist that experimenters often use because it is not broken down by acetylcholinesterase). Channels also stay open three times longer for every decrease in temperature of 10 degrees Celsius. Antagonists do not change the conductance or lifetime of the channel; they merely decrease the frequency of the opening events.

Charles F. Stevens and his colleagues at the University of Washington School of Medicine have shown that in frog muscle the lifetime of the open channel also depends on the potential across the postsynaptic membrane: the receptor channels close more rapidly when the membrane is depolarized. In my laboratory at Cal Tech, Robert E. Sheridan and I found the same to be true in *Electrophorus* electroplaques.



LIGHT-INDUCED CONVERSION of the agonist bis-Q from its inactive *cis* isomer to the active *trans* one was used by the author and his colleagues to bring about an abrupt increase in the concentration of agonist bathing the innervated face of an electroplaque. The isomerization reaction was produced by means of a millisecond-long flash from a xenon flash lamp projected onto experimental chamber with a fiber-optics light guide (*see illustration on opposite page*). Agonist solution was later analyzed to determine concentrations of the two isomers.

Why is the receptor-channel lifetime sensitive to the membrane potential? The answer is that in the muscle cells and electroplaques considered here the depolarizing postsynaptic potential merely serves as the trigger for an impulse that travels through the entire membrane of the postsynaptic cell, a much larger depolarization. The impulse therefore tends to close the very channels that triggered it. Furthermore, acetylcholine probably leaves the receptor as the channel closes, and once it is free in the synaptic cleft it can be inactivated by acetylcholinesterase even more quickly than it can in the absence of an impulse. In addition to readying the synapse for the next presynaptic stimulus such a mechanism prevents the receptor channels from short-circuiting the membrane-wide impulse and interfering with its propagation, although in muscle this does happen to a small extent. In *Electrophorus* electroplaques the effect is crucial, as Harry Grundfest of the Columbia College of Physicians and Surgeons and Michael V. L. Bennett of the Albert Einstein College of Medicine in New York have pointed out; the fish must direct its electric current into the highly resistive fresh water around it. A short circuit in the membranes of its electroplaques would drastically reduce its efficiency in shocking its prey.

In order to gain more information on the factors governing the transition between open and closed channels my colleagues and I devised a series of experiments on individual electroplaques from *Electrophorus*. Rather than observing spontaneous fluctuations from the equilibrium state, we produced large, rapid changes in the conditions that determine the equilibrium state and then measured the time it took for the receptor population to "relax" to a new equilibrium. We used a "voltage clamp" apparatus, which fixes, or clamps, the membrane potential at a level set by the experimenter so that the usual depolarizations are not allowed to occur. The apparatus both generates and measures the amount of current necessary to clamp the voltage. This current is proportional to the number of open channels in the membrane, and the circuit follows changes in the channel population within a fraction of a millisecond. For example, if the membrane is clamped to the normal resting potential and no receptor channels are open, no current is required. Each channel that opens then contributes an equal increment of current. For experiments on receptor channels various blocking drugs and subtraction techniques must be exploited in order to eliminate the ion currents due to other types of channels, such as those that give rise to the propagating impulse of the muscle-cell membrane once its threshold has been reached.

Our first experiments were based on the work of Stevens and his colleagues, who found in a series of voltage-clamp experiments on frog muscle that under some conditions a presynaptic impulse stimulates the nerve ending to liberate a pulse of acetylcholine brief enough to result in a nearly synchronous opening of the ion channels. When acetylcholinesterase is active, free transmitter molecules disappear completely from the synaptic cleft before a substantial portion of the open channels have undergone the transition back to the closed state. Although it is not yet certain how acetylcholine molecules spread through the synaptic cleft during the brief period when the channels are opening, subsequent events represent the relaxation after the instantaneous removal of transmitter from the cleft. Like fluctuations and single-channel measurements, this postsynaptic response provides a measure of the average lifetime of an open channel. Experiments of this kind first showed that this period (or its reciprocal, the rate of channel closing) depends markedly on the potential at which the membrane is clamped.

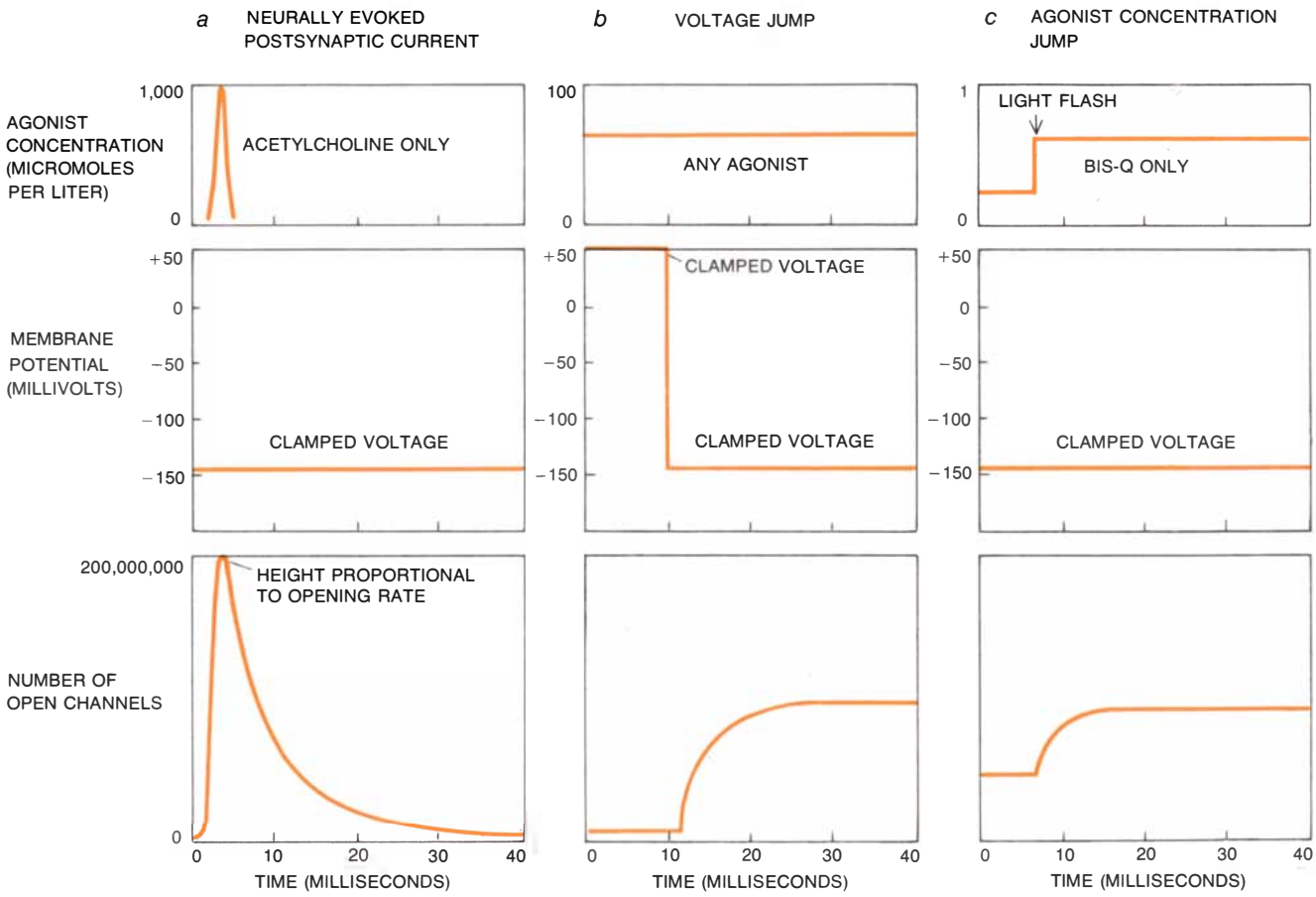
In our voltage-clamp experiments we were particularly interested in measuring the rate at which the ion channels open for a given agonist concentration and a given membrane potential. To determine these values Sheridan and I conducted a second type of relaxation experiment. In the presence of steady agonist concentrations the *Electrophorus* membrane was first clamped at one voltage and then rapidly jumped to another. Therefore the voltage-clamp circuit served both to initiate the relaxation and to measure the number of open channels. The channel population did not instantaneously adjust to the equilibrium value appropriate to the new voltage

level but relaxed with a time constant whose inverse was equal to the sum of the channel opening and closing rates. Since the closing rate was already known from the acetylcholine-pulse measurements, the experiment made it possible to determine the opening rate.

Knowing the opening and closing rates, we can reconstruct the behavior of channels during sustained or brief exposure to agonist. For example, at a temperature of 15 degrees C. and a voltage of −90 millivolts (the potential of the resting membrane) acetylcholine opens the channel for three milliseconds on the average. We found that once a channel is closed an acetylcholine concentration of 30 micromoles per liter will cause it to reopen in about three milliseconds. We are not yet sure whether the opening rate is constrained by the number of successful collisions between agonist and receptor molecules or by some conformational transition of the receptor protein. Whatever limits the rate, the implication is that under these experimental conditions half of the channels are open at any one time, and our results agreed roughly with this prediction. As the agonist concentration is increased the channels open more frequently. Unlike the closing rate, however, the opening rate seems to be independent of the membrane potential.

Recently Hai Won Chang of the Columbia College of Physicians and Surgeons and I made a more direct type of relaxation measurement in which the agonist concentration was suddenly jumped. We worked with an artificial compound known as bis-Q, which has two molecular forms. One, the *trans* isomer, is a potent agonist. The other, the *cis* isomer, has little effect on acetylcholine receptors. The two forms can be interconverted by light of appropriate wavelengths.

The experiment began with an *Electrophorus* electroplaque in a solution containing mostly the *cis* form of bis-Q. Light from a xenon flash lamp was brought to the experimental chamber with a fiber-optics light guide. During the flash, which lasted a millisecond, some of the *cis* molecules were converted into the potent *trans* form. The population of channel molecules was then shifted to a more open state, again not instantaneously but with a time course



RELAXATION EXPERIMENTS performed in the author's laboratory with the voltage-clamp apparatus measure the rate at which the receptor channels in the electroplaque membrane open and close. This is done by examining the length of time required for the channel population to attain a new equilibrium state after being perturbed. The first perturbation, a brief pulse of agonist (*a*), is produced by evoking an impulse in the nerve terminals, which then release acetylcholine. Since the transmitter is broken down within a few milliseconds by the enzyme acetylcholinesterase, the channel population opens synchronously and then closes at a rate that reveals the average channel lifetime. The second type of perturbation is based on the observation that the channel stays open longer (the closing rate decreases) as the membrane potential is made more negative. In the presence of a steady concentration of agonist the voltage across electroplaque membrane is first clamped at +50 volts and then rapidly jumped to −150 volts (*b*). The channel population then shifts to a new equilibrium with a time constant whose inverse is equal to the sum of the opening and closing rates. The third perturbation experiment begins with the electroplaque bathed in a solution containing the inactive isomer of bis-Q (*c*). A flash of light converts some of this compound to the active isomer, and the channel population readjusts with the same time constant as that obtained in the voltage-jump experiment. Since the closing rate is known from the first experiment and the sum of the opening and closing rates is known from the second and third experiments, the opening rate can be easily calculated. When the temperature is 15 degrees Celsius, the agonist is acetylcholine at 30 micromoles per liter and the membrane potential is −90 millivolts, channels appear to open every three milliseconds.

SCIENCE/SCOPE

Clear, color closeups of the giant planet Saturn, its rings, and its satellite Titan will be transmitted to earth beginning in 1979, when Pioneer 11 is closest to the planet. Regular observations will begin in July 1977. Two instruments aboard the spacecraft were built by Santa Barbara Research Center (SBRC), a Hughes subsidiary. One, an imaging photopolarimeter, will take the pictures; the second, an infrared radiometer, will measure the temperatures of the planet and its rings.

Once the spacecraft has arrived, the temperatures it takes will be telemetered home so that scientists can continue to study the delicate heat balance of the solar system.

As part of the US Navy's standard hardware program, the Hughes-built AN/UYK-30 microprocessor has been designed onto six Standard Electronic Modules (SEMs) in a 20-cubic-inch space. The SEM-2A modules are 1.9 x 5.6 inches. The 16-bit UYK-30 has already been integrated in 11 military-system programs that involve application with the Navy, Army, and Air Force.

Like the existing production version of the UYK on three 5.6 x 6.5 inch modules, this new SEM version will use multisource, off-the-shelf, bipolar Schottky TTL LSI microprocessor chips for a capability of 340-660 thousand operations/sec, using up to 65,000 words of memory. Value of the SEM concept, of course, is a family of off-the-shelf, reliable, electronic modules, each performing certain standard functions. This facilitates the design, production, and support of electronic systems.

Hughes Missile Systems Group has many immediate openings, in Canoga Park, California, for engineers and scientists in new, expanding, long-range R&D. Typical openings include circuits engineers (RF/IF, digital, or analog), systems analysts (missile-system preliminary design), electronic product engineers (product designs for state-of-the-art systems), RF systems engineers (microwave systems design & test), RF product engineers (product designs of state-of-the-art RF components), and many others. Graduation from an accredited university, varying amounts of experience, and US citizenship are all required. Please send resume to: Engineering Employment, Hughes Aircraft Company, Canoga Park, California 91304.

During the recent Big Thompson River disaster in Colorado, lives were saved through use of a heat-sensitive infrared viewer. A police sergeant aboard a US Army helicopter, during a 2-day period, scanned the entire length of the canyon through a Probeye(R) Infrared Viewer, which identifies heat, rather than light, patterns. The sergeant was able to locate people stranded or clinging to the canyon walls in woods and heavy brush. The scanning operation enabled the rescue teams to avoid searching the canyon by foot.

precisely matching that of a voltage-jump relaxation under the same conditions. We are interested in extending this experiment, because a jump of agonist is of course what activates receptor channels in the functioning synapse.

Stephen W. Kuffler and his colleagues at the Harvard Medical School have recently studied such normal responses in careful detail. They estimate that after a single packet of acetylcholine (probably the contents of one synaptic vesicle) is released into the synaptic cleft, the transmitter concentration is not the 30 micromoles per liter that leads to the activation of half of the channels but is at least 300 micromoles per liter for .3 millisecond. Kuffler and his colleagues also estimate that of the receptors subjected to that concentration for that time roughly half to three-fourths open their channels. Helen C. Fertuck and Miriam M. Salpeter of Cornell University have recently estimated from electron-microscope studies that the acetylcholine concentration in the synaptic cleft is even higher, more than 1,000 micromoles per liter. Since our experiments suggest that the rate of channel opening increases as the concentration increases, it is easy to understand how more than half of the channels can be open only .3 millisecond after a packet of acetylcholine is released.

Let me now summarize the neurophysiological events leading to the generation of an impulse in the membrane of the muscle cell. In response to an impulse in the presynaptic nerve terminal about 100 synaptic vesicles liberate their contents synchronously at different release sites along the synapse. The acetylcholine molecules contained in each vesicle then open about 2,000 receptor channels in the muscle-cell membrane, producing a small depolarization called a miniature end-plate potential. The 100 miniature end-plate potentials generated by the contents of 100 synaptic vesicles add up to an excitatory postsynaptic potential, which triggers the propagating impulse in the muscle-cell membrane, thereby causing the muscle fiber to contract. One may conclude that the end-plate potential is the product of some 200,000 channel-opening events and a net flow across the muscle-cell membrane of about three billion ions.

In addition to the nerve-muscle synapse there are hundreds of different types of synapse in the brain and in the rest of the nervous system, most of which do not rely on acetylcholine as the chemical transmitter. Some of these inhibit postsynaptic impulses rather than excite them. Many operate on a much longer time scale, and some may even change their characteristics as a result of their operation. Their investigation will doubtless uncover new and exciting neurobiological principles.

Ancient animals. Lost worlds.

Come with us now to see the dinosaurs, the saber-tooth cats, and the ancestors of man...

In the pages of FOSSILS MAGAZINE, the strange worlds and wonderful animals of past ages still live. Dinosaurs still stalk through forests of tree-size ferns. Gigantic flying reptiles still soar in the skies. In the sea, fishes twice as large as the Great White Shark still swim. And our primitive ancestors struggle to survive.

As you watch, generations of life pass in an instant. New creatures evolve from old. The earth is uplifted into mighty mountain ranges, and worn down again by the relentless forces of erosion. Vast oceans flood most of North America . . . and then evaporate. Before your eyes, the spectacular 3½-billion-year history of life unfolds. Of all the stories that may be found on earth, surely this is the largest and grandest of all — and FOSSILS MAGAZINE tells it like it has never been told before.

A picture window on the past

To begin with, FOSSILS *shows you* the worlds and creatures of the past more fully and beautifully than ever before. In every issue there are more than 200 paintings, drawings and photographs — many printed in full color. You see superb reconstructions of ancient animals, plants and landscapes . . . as well as the beautiful fossils that have told us so much about past ages. FOSSILS is, quite simply, one of the most beautiful magazines in the world.

A translation into English

During the past 50 years, scientists have been digging up many important new facts about the earth's past — but most of these discoveries have not been revealed to the public. Instead, they have been "re-buried" in scientific journals, described in language so technical that they are inaccessible to most people.

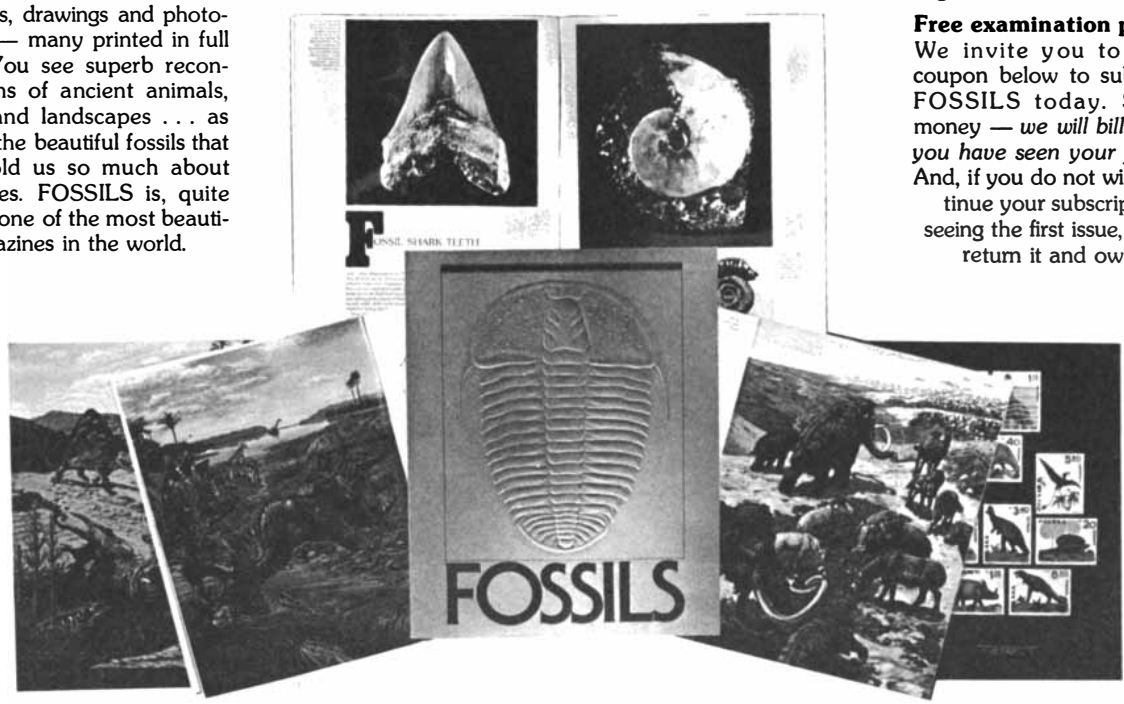
In every issue of FOSSILS, these important discoveries are made available to non-specialists for the first time — "translated" into language that any intelligent person can easily understand. Quite literally, a whole new world of knowledge and enjoyment has been opened up.

A Collector's item

Every issue of FOSSILS is more like a book than a magazine — bound like a quality softcover book, with 116 pages of the finest quality paper and a handsomely embossed cover. The magnificent Charter Issue of FOSSILS is already becoming a collector's prize . . . *but if you subscribe now, your subscription can still begin with the Charter Issue.*

Free examination privilege

We invite you to use the coupon below to subscribe to FOSSILS today. Send no money — *we will bill you after you have seen your first issue.* And, if you do not wish to continue your subscription after seeing the first issue, you may return it and owe nothing.



FREE TO NEW SUBSCRIBERS

A MAGNIFICENT 4-FOOT-LONG FULL-COLOR WALL CHART. This unique chart shows many animals from the past and the names and durations of geological time periods for the past 600-million years. It retails for $4.95 in museum shops, but it's yours FREE when you subscribe to FOSSILS today.

Mail today to:

FOSSILS MAGAZINE
4011 Ibis Street
San Diego, California
92103

Please enter a subscription to FOSSILS for the period of time I have checked at right. I understand that I may cancel my subscription after seeing the first issue, return the issue, and owe nothing. I also understand that a **FREE WALL CHART OF GEOLOGICAL AND LIFE HISTORY** will be sent as a part of the subscription.

☐ **1 Year $12**
☐ **2 Years $21** (You Save $3)
☐ **3 Years $29** (You Save $7)

Add $3.50 postage and handling per year for Canada & Mexico; $3 per year for all other foreign countries.

FOSSILS is published quarterly, 4 times a year.

Name _____

Address _____

City _____

State _____ Zip _____ SA2

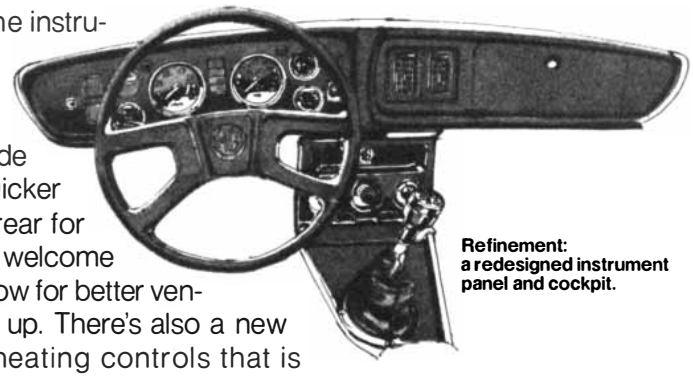
Send no money now — we will bill you after you receive your first issue.

A great classic sports car, refined.

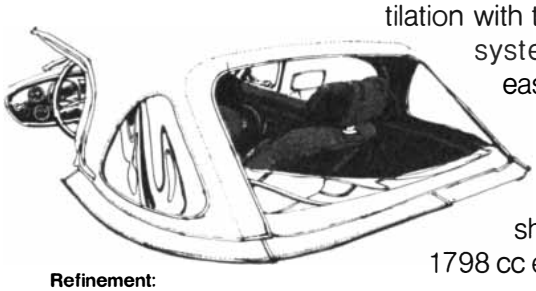
Introducing the 1977 MGB.

How do you improve on a living classic? Very thoughtfully. But very consistently. For, while MGB remains a classic wide-open convertible sports car, lean and low and nimble enough to win the SCCA Class E Championship again this year for a total of five wins in six years, it is also being continually refined.

This year, for example, we have redesigned the instrument panel to make the tachometer, odometer and gauges more clearly visible. The car handles even better than previous MGs because we improved the rack gearing to reduce turning effort and made the padded steering wheel smaller in diameter for quicker response. We also added anti-roll bars front and rear for increased handling stability. We've added small but welcome improvements in the form of a zip-down rear window for better ventilation with the top up. There's also a new system of heating controls that is easier to use.



Refinement: a redesigned instrument panel and cockpit.



Refinement: a zip-down rear window.

And it all comes wrapped in the brisk, lithe, responsive sports car America has long loved. The 1977 MGB comes equipped with decisive disc brakes, quick rack and pinion steering, short-throw four-speed stick, race-proven suspension and a gutsy 1798 cc engine.

What it adds up to is more fun in a car that is world-famous for pure pleasure in driving. Drive the newest edition of the wide-open MGB. For the name of the dealer nearest you, call these numbers toll-free: (800) 447-4700, or, in Illinois, (800) 322-4400.

MGB. The wide-open sports car.

British Leyland Motors Inc. Leonia, New Jersey 07605.

BRITISH LEYLAND

MATHEMATICAL GAMES

The flip-strip sonnet, the lipogram and other mad modes of wordplay

by Martin Gardner

Finnegans Wake continues to be the towering example of how serious literary intent can be combined with outrageous wordplay. Other instances are e e cummings' eccentric typography, Gertrude Stein's nonsense verse and the constant wordplay in Vladimir Nabokov's fiction.

For the past 15 years the most sophisticated and amusing examples of literary wordplay have been produced by a whimsical, slightly mad French group called the Oulipo. The name comes from Ouvroir de Littérature Potentielle (Workshop of Potential Literature). Although this column will be mostly about the Oulipo, I shall digress frequently to cite the work of comparable experts in English.

Most of what follows derives from three sources: (1) *La Littérature Potentielle (Créations Re-créations Récreations),* a paperback by the Oulipo (Éditions Gallimard, 1973); (2) a marvelous article on the Oulipo by its only American member, Harry Mathews, which appeared last year in *Word Ways,* a quarterly journal of recreational linguistics, edited and published by A. Ross Eckler, a statistician at Bell Laboratories (subscriptions are $8 per year, $9 outside the U.S., obtainable from Eckler, Spring Valley Road, Morristown, N.J. 07960), and (3) correspondence with Mathews, who lives part of the time in Paris.

The Oulipo was founded in 1960 by two brilliant Frenchmen: François Le Lionnais and the late Raymond Queneau. Le Lionnais is a mathematician and the best composer of chess problems in France. Queneau, who died last October at the age of 73, was one of France's most influential writers. He is best known for his novel *Zazie dans le Métro,* about the adventures of an 11-year-old Parisian nymphet. (It was made into a popular motion picture by Louis Malle.) Another of Queneau's well-known works, *Exercises in Style,* consists of a trivial anecdote told in 99 different ways. Queneau studied mathematics in his youth. It remained a major interest that permeated his novels, poetry and criticism.

The other French members of the Oulipo are, in alphabetical order, Noël Arnaud, Marcel Bénabou, Jacques Bens, Claude Berge, Paul Braffort, Jacques Duchâteau, Luc Étienne, Paul Fournel, Jean Lescure, Michèle Métail (the only woman in the group), Georges Perec, Jean Queval and Jacques Roubaud. The foreign members are André Blavier (Belgium), Italo Calvino (Italy) and Mathews. All members are mathematicians or writers or both.

Mathews was born in New York City in 1930. He was graduated from Harvard College in 1952 with a degree in music and has been living in Europe ever since. Apart from books of poetry he has written three wild and funny novels: *The Conversions* (Random House, 1962), *Tlooth* (Doubleday, 1966) and *The Sinking of the Odradek Stadium and Other Novels* (Harper & Row, 1975). The "other novels" are reprints of the two earlier ones. All three books are filled with quasi-Oulipian wordplay, notably a four-page scene in *Tlooth* where the pornography is obscured by continuous spoonerisms of mounting combinatorial complexity.

Tlooth is a picaresque tale of blue, blasphemous, black humor. Nephthys Mary Allant is the bisexual catcher of the Baptist baseball team at Jackson-

a	cause	fat	lecture	palace	rude
ache	caution	fee	l'egal	pan	
ail	chair	fend	legs	pane	sale
allege	champ	fin	Lent	par	sang
amends	chat	fit	lice	pare	saucer
an	choir	fond	lie	pat	scare
ante	chose	font	l'imitation	pate	signet
appoint	coin	for	l'ion	pays	singe
are	collier	forage	lit	pester	son
as	comment	fore	l'izard	pet	sort
at one	con	fort	location	Peter	sot
attend	confection	four	loin	pie	spire
audit	corner	fur	longer	pied	stage
averse	cote		l'oser	pin	stance
axe	courtier	gale	love	pincer	store
	crane	gate		pine	sue
Bade	crisper	gave	ma	plains	suit
bail	cure	gaze	mail	plate	super
ballot		gene	main	plier	supplier
barber	dam	gent	mange	plies	
bard	D'ane	gourd	manger	plot	tale
baste	d'are	gout	mare	pour	tape
bat	d'art	grief	mariner	pries	tenant
be	defiance	grime	men	prone	the
beat	defile	groin	mien		these
bee	dent	guise	mince	rang	tiers
Ben	derive		mire	range	tin
bide	design	hair	miser	ranger	tine
bled	d'etain	hale	moult	rape	tint
blinder	dime	harder	mute	rate	tire
bond	dire	hate		rave	ton
bore	dive	have	n'est	rayon	toper
borne	don	here	net	rebut	tort
bout	don't	hurler	Nil	reel	tot
bribes	dot		noise	regain	tout
bride	dresser	if	n'ose	regal	tries
but	drill		n'ote	rein	
butter	d'un	jars		relent	van
	d'une		oil	rend	vent
can		labour	on	report	venue
cane	edit	lad	once	ride	verge
canner	emu	laid	or	ripe	verse
cap	engraver	l'air	ours	river	vie
car	enter	lame		robin	viol
carrier	entrain	l'ane	pain	rogue	
carter	ere	layer	pair	Roman	
case	fade	lecher	pal	rot	

Harry Mathews' short dictionary of "L'Égal Franglais"

In Eden, I

ADAM: Madam—
EVE: Oh, who—
ADAM: (No girl-rig on!)
EVE: Heh?
ADAM: Madam, I'm Adam.
EVE: Name of a foeman?
ADAM: O stone me! Not so.
EVE: Mad! A maid I am, Adam.
ADAM: Pure, eh? Called Ella? Cheer up.
EVE: Eve, not Ella. Brat-star ballet on? Eve.
ADAM: Eve?
EVE: Eve, maiden name. Both sad in Eden? I dash to be manned, I am Eve.
ADAM: Eve. Drowsy baby's word. Eve.
EVE: Mad! A gift. I fit fig, Adam . . .
ADAM: On, hostess? Ugh! Gussets? Oh, no!
EVE: ???
ADAM: Sleepy baby *peels*.
EVE: Wolf! Low!
ADAM: Wolf? Fun, so snuff "low."
EVE: Yes, low! Yes, nil on, no linsey-wolsey!
ADAM: Madam, I'm *Adam*.
Named under a ban.
A bared, nude man—
Aha!
EVE: Mad Adam!
ADAM: Mmmmmmmm!
EVE: Mmmmmmmm!
ADAM: Even in Eden I win Eden in Eve.
EVE: Pure woman in Eden, I win Eden in—a mower-up!
ADAM: Mmmmmmmm!
EVE: Adam, I'm Ada!
ADAM: Miss, I'm Cain, a monomaniac. Miss, I'm—
EVE: No, son.
ADAM: Name's Abel, a male base man.
EVE: Name not so, O stone man!
ADAM: Mad as it is it is Adam.
EVE: I'm a Madam Adam, am I?
ADAM: Eve?
EVE: Eve mine. Denied, a jade in Eden, I'm Eve.
ADAM: No fig. (Nor wrong if on!)
EVE: ???
ADAM: A daffodil I doff, Ada.
EVE: 'Tis a—what—ah, was it—
ADAM: Sun ever! A bare Venus . . .
EVE: 'S pity! So red, ungirt, rig-nude, rosy tips . . .
ADAM: Eve is a sieve!
EVE: Tut-tut!
ADAM: Now a see-saw on . . .
EVE: On me? (O poem!) No!
ADAM: Aha!
EVE: I won't! O not now, I—
ADAM: Aha!
EVE: NO! O God, I—(Fit if I do?) *Go on.*
ADAM: Hrrrrrrh!
EVE: Wow! Ow!
ADAM: Sores? (Alas, Eros!)
EVE: No, none. My hero! More hymen, on, on . . .
ADAM: Hrrrrrrrrrrrrrrrrrrrh!
EVE: Revolting is error. Resign it, lover.
ADAM: No, not now I won't. On, on . . .
EVE: Rise, sir.
ADAM: Dewy dale, cinema-game . . . Nice lady wed?
EVE: Marry an Ayr ram!
ADAM: Rail on, O liar!
EVE: Live devil!
ADAM: Diamond-eyed no-maid!
BOTH: Mmmmmmmmmmmmmmmmmmmm!

A palindromic dialogue by J. A. Lindon

grad, a Siberian labor camp. We do not learn her name or sex until 10 pages from the novel's end. Mary had been a violinist until her former friend Evelyn Roak, a surgeon, needlessly amputated two fingers of her left hand. Dr. Roak is also an inmate of the camp, having been sent there for selling her amputations to a delicatessen. She plays on a rival ball team. Mary tries unsuccessfully to kill her. An infection in Mary's finger stumps prevents her from practicing dentistry, the profession for which she is in training.

Evelyn is released from the camp, and Mary later escapes. After wandering through Asia and Europe looking for Evelyn, Mary (her infection now cured by folk medicine) opens a dental office near Lyons. Evelyn shows up as a patient, Mary's finger bones dangling from her charm bracelet. Mary intends to finish her off in the chair, but Evelyn's gums disclose that she is dying of smallpox. Mary gives her medication and sends her off "to her stars."

The book's title is an enigmatic word gasped by the warm mud of an oracular bog after Mary completed the ritual of inserting her bare leg in the ooze for 68 seconds at vespers, then withdrawing it quickly. Reading the book, said one critic, is "like riding a bumper car through a dictionary whose definitions are askew."

Mathews is currently writing his fourth novel, which is based on what the Oulipo calls "Mathews' algorithm." In this procedure the elements of a work are cyclically permuted in two ways to form two matrixes, which are then read by taking the columns of one matrix from the top down and the columns of the other matrix from the bottom up. The elements can be letters, words, sentences, paragraphs, chapters, ideas—anything you like. Unfortunately there are no good examples in English.

Mathews' first contribution to *Word Ways* was a list of common words that are spelled the same in both French and English but have entirely distinct meanings. This short dictionary of "L'Égal Franglais" was compiled to aid Oulipo members in producing ambivalent Anglo-French texts. Mathews' entire list, which was not meant to be exhaustive, is presented in the illustration on the preceding page for readers who would like to experiment with sentences that have one meaning in English and another in French.

The Oulipo's first manifesto was Queneau's *Cent Mille Milliards de Poèmes* (*A Hundred Thousand Billion Poems*), published by Éditions Gallimard, where Queneau was a senior editor. The book consists of 10 basic sonnets, each one on a right-hand page that is sliced into 14 strips (a strip for each sonnet line). By flipping strips to the left or right one can obtain 10^{14} (100,000

billion) sonnets, all structurally perfect and making sense. (Mechanical books for children have employed the same format to produce pictorial combinations of parts of animals or people, sometimes also scrambling syllables of vertically printed names to get such bizarre beasts as the elepotamus and the kangaboon.) Flip the strips and you can read a sonnet that (probably) no one has read before and no one will ever read again.

The lipogram, an ancient type of wordplay, is a sentence or a longer work that omits one letter or more of the alphabet. The major specimen in English is *Gadsby,* a novel by Ernest Vincent Wright that was published in Los Angeles in 1939. It does not contain a single *e,* the letter that appears most frequently in both English and French. (For a sample page of *Gadsby* see page 36 of the September 1972 issue of *Scientific American.*)

Experiments with lipograms by the Oulipo culminated in Georges Perec's novel *La Disparition* (*The Disappearance*), published in 1969 by Denoël, Les Lettres Nouvelles. In it too *e* is the disappearing letter. The novel is much longer and better than *Gadsby.* Mathews describes it as an "elaborate, funny story of unbelievable virtuosity," so well written that some critics praised it without noticing anything strange!

Perec is currently working on a novel called *La Vie, Mode d'Emploi* (*Life and How to Use It*) that is based on, among other things, a Greco-Latin Square of order 10. The great Leonhard Euler had conjectured that such a square could not exist, but one was found in 1959, and it provided a colorful cover for the November issue of *Scientific American* that year. Although Perec is a prolific French writer, only his first book, *Les Choses: Une Histoire des Années Soixant,* has been published in the U.S.

Perec is also responsible for the Oulipo's longest palindrome. It is about palindromes and contains more than 5,000 letters that begin and end:

Trace l'inégal palindrome. Neige. Bagatelle, dira Hercule. Le brut repentir, cet écrit né Perec. L'arc lu pèse trop, lis à vice-versa.... Désire ce trépas rêvé: Ci va! S'il porte, Sépulcral, ce repentir, cet écrit ne perturbe le lucre: Haridelle, ta gabegie ne mord ni la plage ni l'écart.

Mathews translates this passage as follows:

"Trace the unequal palindrome. Snow. A trifle, Hercules would say. Rough penitence, this writing born as Perec. The read arch is too heavy: read vice versa.... Desire this dreamed-of decease: Here goes! If he carries, entombed, this penitence, this writing will disturb no lucre: Old witch, your treachery will bite into neither the shore nor the space between."

The most skillful composer of English palindromes (in my opinion he is also England's best writer of comic verse) is J. A. Lindon. *Word Ways* has published many of his palindromic poems; others can be found in this department for August, 1970, on palindromes and in Howard W. Bergerson's Dover paperback, *Palindromes and Anagrams.* Lindon's finest palindromic achievement, a dialogue about the seduction of Eve, appears in the illustration on the opposite page. Every line is a letter-unit palindrome, and so is the title.

A famous Oulipo algorithm called $S + 7$ (for "Substantif plus 7") was invented by Lescure. In English it is $N + 7$. The procedure is to replace each noun in a familiar prose passage with the seventh noun that follows it in a specified dictionary. $N + 7$ is a special case of the more general algorithm $M \pm n$, where M is any kind of *mot* (word) and n is any positive integer. In both the text and the dictionary unhyphenated compound words, such as "high school," are ignored. Here, for instance, are the first two sentences of *Moby Dick,* which I have altered $N + 7$ by using *Webster's New Collegiate Dictionary:*

"Call me islander. Some yeggs ago—never mind how long precisely—having little or no Mongol in my purulence, and nothing particular to interest me on shortbread, I thought I would sail about a little and see the watery partiality of the worriment."

Another Lescure algorithm is to reverse the order of a given type of word, switching first and last instances, then the second from each end and so on. Applied to nouns in the first chapter of *Moby Dick,* the opening sentences are:

"Call me air. Some hills ago—never mind how long precisely—having little or no phantoms in my whale, and nothing particular to interest me on processions, I thought I would sail about a little and see the watery soul of the purpose."

Queneau's booklet *Les Fondements de la Littérature* transforms David Hilbert's axioms for Euclidean geometry by replacing the words "points," "lines" and "planes" respectively with "words," "phrases" and "paragraphs" to obtain a new set of axioms for which Queneau provides a witty commentary. Another Oulipo algorithm is to replace words with dictionary definitions or with freer definitions of the kind found in crossword puzzles. The new statement is transformed again by the same method until all original meaning is lost. A special challenge is to begin with two statements that have entirely different meanings and then transform them in the fewest number of steps until they are identical.

Joining the first half of one proverb to the second half of another produces the "perverb," a form explored by Mathews in both French and English. His *Selected Declarations of Dependence* (Eternal Network, Toronto, 1976) consists of poems and prose pieces that explore hundreds of perverbs derived from 46 English proverbs. Here are some examples:

A Partial Survey of Western
European Holiday Migrations

EXODUS A

Leeds' roads roam to all?
Rome's Leeds' road to all—
All Leeds rode to Rome.

EXODUS B

All Rome leads to roads.
Rome leads all to roads,
Leads Rome all to roads:
"Roam all leads to roads!"
Roads lead Rome to all?
All leads roam to Rhodes,
Lead all Rome to Rhodes.

RETURN A + B

Rhodes roams leads to all?
Roads lead all to Rome,
Lead all Rhodes to Rome.
Rome-roads lead to all?
All roam roads to Leeds!
Rome rode all to Leeds.

SUMMARY

All roads roam to Leeds

Mathews' permutations of a proverb

Sleep Falls
by Elinor Millay

Sleep falls, with limpid drops of rain
(My candle burns at both ends)
upon the steep cliffs of the town.
It will not last the night.

Sleep falls, men are at peace again.
But ah, my foes and oh, my friends,
while the small drops fall softly down,
It gives a lovely light.

My Candle
by Edna Wylie

My candle burns at both ends.
Sleep falls with limpid drops of rain
(it will not last the night)
upon the steep cliffs of the town.

But ah, my foes and oh, my friends,
sleep falls, men are at peace again.
It gives a lovely light
while the small drops fall softly down.

Interwoven poems for a Möbius strip

Winter Reigns

Shimmering, gleaming, glistening glow—
Winter reigns, splendiferous snow!
Won't this sight, this stainless scene,
Endlessly yield days supreme?

Eyeing ground, deep piled, delights
Skiers scaling garish heights.
Still like eagles soaring, glide
Eager racers; show-offs slide.

Ecstatic children, noses scarved—
Dancing gnomes, seem magic carved—
Doing graceful leaps. Snowballs,
Swishing globules, sail low walls.

Surely year-end's special lure
Eases sorrow we endure,
Every year renews shared dream,
Memories sweet, that timeless stream.

Mary Youngquist

A poem with a hidden structure

"A rolling stone gets the worm."
"A bird in the hand waits for no man."
"The road to hell has a silver lining."
"It's an ill wind that spoils the broth."

One may also modify a proverb by substituting homophones—words that sound much the same but have different meanings. Two classic English examples are "There's no fuel like an oil fuel" and "There's no police like Holmes." Proverbs can also be changed in startling ways simply by truncating them:

"People who live in glass houses shouldn't."
"All work and no play makes jack."
"Familiarity breeds."

Lescure has experimented with sentences containing just four principal words by testing all 24 permutations.

CRU+ASTIONLE
+URESTLOINCA
CUITONRASEL+
IERCLOSTANU+
ITELARCOUS+N
C+RONETULIAS
LACOURIN+EST
RUCTI+LEASON
+LASCOURTNIE
RECULATON+IS
TOIRE+LANCSU
RLANUITEC+OS

Cru bastion, le mur est loin: ca cuit,
on rase l'hier clos, ta nudité, l'arc où,
synchrone, tu lias la cour indestructible
à son glas court nié, reçu là.

ton histoire:
blanc sur la nuit,
échos

An isogram by Georges Perec

The goal is to maximize the number of permutations that make sense. Homophones are allowed. An English example by Mathews is shown in the top illustration on the preceding page. The list is incomplete, he points out, because the remaining permutations are redundant.

Lines of poems are permuted by the Oulipo in many carefully defined ways. Luc Étienne uses a Möbius strip to interweave the lines of a poem to make a different poem. Write half of the poem on one side of a strip and the other half (upside down) on the opposite side. Twist and join the ends. Reading around the single side of the Möbius band interlaces the lines in the way that clasping your hands interlaces your fingers. The goal is to compose poems that have opposite meanings when they are read before and after the twist.

The Möbius construction can be applied to two stanzas of the same length by different poets. The resulting poem is usually grotesque, but not always. In the bottom illustration on the preceding page I have employed the Möbius transformation to combine Edna St. Vincent Millay's famous quatrain about candle-burning with the first quatrain of Elinor Wylie's beautiful lyric "Bells in the Rain." The composite poem can be read by starting either with Millay's quatrain or with Wylie's.

Oulipo members have written short stories and plays with junctures at which the reader or audience can choose between alternate transitions to obtain different plot combinations. (This technique should not be confused with the randomizing of fictional elements, as in the boring examples of Michel Butor's *Mobile* or the recent novels of William S. Burroughs.) *Hopscotch,* a novel by the Argentine expatriate (he too lives in Paris) Julio Cortázar, is closer to the Oulipo intent. Its 154 chapters are designed to be read in two ways. First you read conventionally from Chapter 1 through Chapter 56. Then you start at Chapter 73 and hopscotch through the book by taking chapters in a sequence given by the number at the end of each chapter. Many chapters are read twice, and one is read four times. A translation from the Spanish was published by Pantheon in 1966.

At the world's fair of 1967 in Montreal the Czechoslovak pavilion showed a motion picture that allowed audiences to vote on how to proceed at five binary forks. The offer was partly a fraud because there were just two films with plots designed so that they diverged only to come together again at the next juncture. According to Theodore H. Nelson, writing on "branching movies" in *Dream Machines* (half of a two-part book that he published in Chicago in 1974), the projectionist simply dropped an opaque slide in front of whichever portion of the film was not to be seen. Without self-intersection five genuine binary choices would produce 2^5 (32) different films, which would be a bit expensive for filmmakers, not to mention the excessive burden on the actors.

"Homosyntaxism" is an Oulipian term for replacing all the words of a passage with new words while preserving the underlying syntax. Something similar was done by Mortimer J. Adler in *Diagrammatics,* a curious little book of nonsense prose that he and Maude P. Hutchins (then the wife of Robert Maynard Hutchins) cooked up in 1932. Adler addled the text and Mrs. Hutchins provided illustrations.

It is sometimes possible to rearrange the words of a familiar passage of poetry to make an entirely different poem. Punctuation and capitalization can be varied. (A venture of this kind by Lindon and me appeared under the title "Pied Poetry" in *Word Ways,* May, 1973.) Here is one of my scramblings. Can you reconstruct the original? (The poet's name is an anagram of his real name.)

Prison Bloom and Withers?
Poison the air-well?
What good is there in that?
It is only in deeds
Vilest man
Wastes like weeds.

—S. WALDO RICE

In February, 1974, *Word Ways* published a poem by Mary Youngquist, a frequent contributor, that is reproduced in the top illustration on this page. What is so unusual about her poem?

What happens when one poet writes a poem and then gives another poet an alphabetized list of all the words in it, whereupon the second poet uses them to write a new poem without seeing the original? Oulipo members have not tried this, but *Word Ways* has published the remarkable results of several such experiments in what Eckler calls "vocabularyclept" poems. (See the issues for May, 1969, August, 1970, and May, 1975, and also Eckler's column in *Games and Puzzles,* July, 1976, and Chapter 4 of Bergerson's book mentioned earlier.) It is surprising how good a new poem can be produced, with almost no resemblance to the original except in mood. Eckler has published some interesting statistical results that emerge from comparisons of the two poems. As one might expect, the shorter the original, the closer the convergence toward two identical poems.

The 11 most frequently used letters in French can be arranged to spell *ulcérations.* (It has the same meaning in French as in English.) Perec has amused himself by writing what can be called isogrammatic poems—poems written entirely with these 11 letters. He has also published poems that contain the same 11 letters plus one "free" letter. The tech-

nique is shown in the bottom illustration on the opposite page. There the position of each free letter is indicated by a cross. Following that is Perec's poem after each cross has been replaced by a letter of his choice. Mathews translates:

"Believed a bastion, the wall is far off: this smarts—you skim over shut yesterday, your nakedness, the arch where you synchronously bound the indestructible courtyard to its short, denied knell, there received. Your story: white against the night, echoes."

When the American linotype machine was invented, it was believed the 12 most commonly used letters in English, in decreasing order of frequency, are etaoin shrdlu. These two nonsense words are spelled by the first and second columns of the traditional linotype keyboard. Sometimes a printer runs a finger down the columns to make a slug, for marking purposes, that he intends to remove later. If he forgets, the cabalistic words may get printed. Perhaps readers can produce some etaoin-shrdlu poems with or without a free 13th letter.

No one has succeeded, incidentally, in making a good dictionary word with the letters of etaoin shrdlu, although "outlanderish" and "tailhounders" come close. It is possible, however, to use the letters to form two words that name a region of a well-known country. Can the reader discover the region before I reveal it next month?

The Oulipo has also worked on what in English are called "snowball sentences." Each word is one letter longer than its predecessor. Mathews gives a 22-word snowball beginning with *O le bon sens* and ending with *pseudotransfigurations.* A good English specimen, from Dmitri Borgmann's classic *Language on Vacation,* is the following 20-word snowball:

"I do not know where family doctors acquired illegibly perplexing handwriting; nevertheless, extraordinary pharmaceutical intellectuality, counterbalancing indecipherability, transcendentalizes intercommunications' incomprehensibleness."

La Littérature Potentielle is packed with many other kinds of linguistic play, but I have room for only a few more. Jacques Bens writes what he calls "irrational sonnets." The 14 lines are partitioned into five parts: three lines, one line, four lines, one line, five lines. These five digits, 31415, are the first five digits of pi, an irrational number—hence the name given to the sonnet. The rhyme scheme is *aab, c, baab, c, cdccd.* The two single lines must end with the same word.

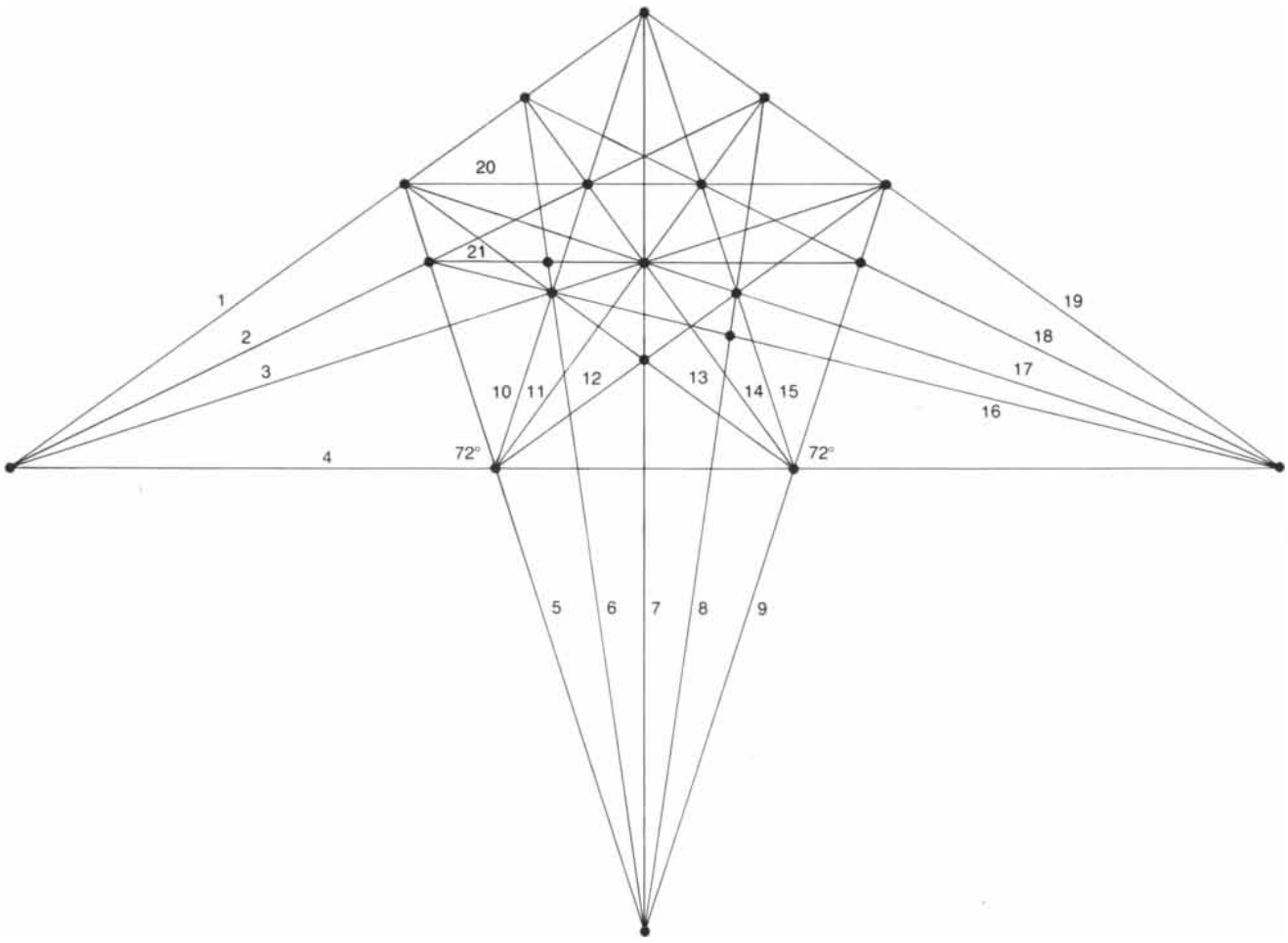
Noël Arnaud writes what he calls "heterosexual poems." They are poems in which lines with a masculine ending (stressed last syllable) alternate with lines that terminate in a feminine rhyme (unstressed last syllable).

The Oulipo has developed a variety of algebraic formulas that the members apply effectively to the plot structures of novels, stories and plays. Claude Berge, an eminent graph theorist, has shown how directed graphs (graphs with arrows that give each edge a direction) can assist in analyzing literary structures.

Les Horreurs de la Guerre (*The Horrors of War*) by Perec is a three-act play in which the entire dialogue is a recital of words that give in order a single recitation of the French alphabet. *Word Ways* has published a clever analogue in English by Eckler and the following remarkable passage by Mathews. It is spoken by a crow to a scarecrow:

"Hay, be seedy! He-effigy, hate-shy jaky yellow man, oh peek, you are rusty, you've edible, you ex-wise he!"

Ingenious, I hear you say, but how frivolous, and what a sad waste of creative energy! Yet does it not bring home to us how a culture's language, with its



Douglas McClean's improved solution for the tree-plant problem

mysterious blend of sound and meaning, is a structure with an independent life of its own? "The West is mad," writes Mathews in *The Sinking.* "I could not live without your words, no matter how you spell them." Had the crow's remark appeared somewhere in the bowels of *Finnegans Wake,* can you imagine a Joyce buff who would have found it out of place or who would not have enjoyed discovering for himself the hidden underlying form of the passage?

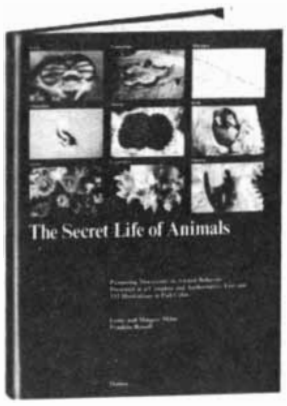
A tree-plant problem posed in August and answered in September was to arrange 20 trees in 20 rows of four trees each. The beautiful solution given was the one that Henry Ernest Dudeney admitted he could not prove maximum, although he said that in his "pious opinion" it could not be bettered. Two readers—Ton van Teeseling of Amsterdam and Douglas McClean of Cape Town—each went one better by producing 21 rows. The two solutions are not equivalent. McClean's pattern, which can be shown easily without the dodge of placing spots at infinity, is given in the illustration on the preceding page. There is no proof that 21 is maximal.

The unsolved no-three-in-line counter problem given in October brought a flood of letters. Many readers misinterpreted the problem, overlooking a clear statement that "line" is not confined to orthogonals or diagonals. Among those who understood the task, however, significant advances were made. Readers found solutions for previously unsolved orders of 13, 14, 15 and 16. Since letters are still arriving, I shall postpone giving these results and related ones until next month.

Many readers pointed out that Sam Loyd's solution to his Klondike puzzle has an alternate last move: a "bold strike" northwest also leads to freedom. Harold F. Bennett wrote that he had found many alternate solutions about 12 years ago and had devised an efficient hand method for exploring them. Maxim G. Smith also sent an excellent method for finding the alternate paths without the aid of a computer. He suggested that since all alternate paths eventually reach a cell (numbered 4) that can be reached in one move from the start, we should redefine precisely the sense in which Loyd's solution (with its two endings) is unique even without altering what I called the "troublesome 2." There are two ways, Smith says, in which Loyd's scheme can be more precisely defined: it is the shortest solution, and it is the only solution in which no cell is visited twice.

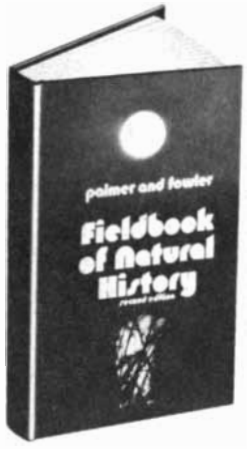
Virginia F. Walters lowered the record for a transfer of six marbles on the Chinese-checkers board of order 4 from 18 to 17 moves.

A great astronomer surveys the ideas, principles and processes of his discipline



Myth-shattering reality: the behavior you didn't expect

Trace the original Americans for 30,000 years



Everything you want to know about every plant and creature

Come! All the worlds of man and nature await you in the

Natural Science Book Club

34210. THE ARCHAEOLOGY OF NORTH AMERICA. *Dean Snow. Photographs by Werner Forman.* With nearly 200 photographs, maps and charts, resurrects the world of the North American Indian, from the first crossings onto this continent 30,000 years ago to the discovery of the last stone-age man who died in the 20th century. **$18.95**

36395. BLACK HOLES, QUASARS AND THE UNIVERSE. *Henry L. Shipman.* An absorbing exploration of the frontiers of astronomy. **$12.95**

56720. ISLAND OF ISIS. *William MacQuitty.* A beautifully written introduction to the culture, religion, history and geography of ancient Egypt. Illustrated. **$14.95**

61710. THE MEDIEVAL MACHINE. *Jean Gempel.* An enlightening look at the times, the men, the conditions and the remarkable inventions of the Middle Ages. Many illustrations. **$12.95**

69311. PLAGUES AND PEOPLES. *William H. McNeill.* A fresh, groundbreaking study of the history of infectious disease and its effect on civilizations, past and present. **$9.95**

34670. ASTRONOMY AND COSMOLOGY. *Fred Hoyle.* Over 700 pages, with 617 illustrations, provides a solid understanding of the physical processes and relationships at the core of astronomical phenomena. **$16.50**

50610. THE GREAT INTERNATIONAL DISASTER BOOK. *James Cornell.* Fascinating survey of every major disaster from the eruption of Vesuvius in A.D. 79 to the Guatemala earthquake of 1976. **$12.50**

36645. THE BOOK OF SHARKS. *Written and illustrated by Richard Ellis.* Covers all major types, with explanations of their biology and behavior, plus vignettes of the divers, photographers, filmmakers and fishermen who know them best. Illustrated. *Counts as 2 of your 3 books.* **$25.00**

50415. GOLD, GALLEONS AND ARCHAEOLOGY. *Robert F. Burgess and Carl J. Clausen.* Superbly researched account of the history of the 1715 Spanish Plate Fleet sunk in a hurricane off the coast of Florida . . . and the Great Florida "gold rush" to salvage the treasure. **$12.95**

41981. THE DESERT. *Russell D. Butcher.* A beautiful, guided tour of America's six desert regions, how they were formed, the persistence of their life-forms in intensely fragile ecologies. **$17.50**

87195. WILD CATS OF THE WORLD. *C. A. W. Guggisberg.* One of the world's leading authorities on wild cats offers definitive natural histories of eachsof the 37 species of wild cats. **$15.95**

55190. THE INCREDIBLE DR. MATRIX. *Martin Gardner.* The delightful, incredibly brilliant Dr. Matrix returns with more amazing feats and adventures in number theory, sleight of word, numerological analysis and puzzles. **$8.95**

Take any 3 books (values to $56.40) for only 99¢ each

if you will join now for a trial period and agree to take 3 more books—at handsome discounts—over the next 12 months

(Publishers' Prices shown)

85090. THE UNIVERSE. *Lloyd Motz.* Absorbing account of modern cosmological theory examines the origin, evolution, and future of the universe. **$15.00**

85820. VENOMOUS ANIMALS OF THE WORLD. *Roger Caras.* Explores the entire scope of this remarkable group of animals—from the common honeybee and ant to more deadly creatures. *Counts as 2 of your 3 books.* **$25.00**

77620. THE SECRET LIFE OF ANIMALS. *Lorus and Margery Milne and Franklin Russell.* Lavishly illustrated account of the dramatic discoveries recently made about the behavior of animals. Over 300 full-color photographs. *Counts as 2 of your 3 books.* **$29.95**

48705. FORECASTS AND FAMINES AND FREEZES. *John Gribbin.* Explores some fascinating questions about the earth's future, the greenhouse effect, a new ice age and shifting magnetic poles. **$8.95**

73337. THE RAPE OF THE NILE. *Brian Fagan.* The plundering of ancient Egypt's treasures and the rise of Egyptology. Illustrated. **$14.95**

MEMBERSHIP BENEFITS • In addition to getting three books for 99¢ each when you join, you keep saving substantially on the books you buy. • If you continue your membership past the trial period, you will be eligible for our Bonus Book Plan—an important way to save even more, at least 70% off publishers' prices. • Your Book Club News, describing the coming Main Selection and Alternate Selections, will be sent to you 15 times a year at three to four week intervals. • If you wish to purchase the Main Selection, do nothing and it will be sent to you automatically. • If you prefer one of the Alternates or no book at all, simply indicate your decision on the reply form always enclosed with the News and mail it so we receive it by the date specified. • The News is mailed in time to allow you at least 10 days to decide if you want the coming Main Selection. If because of late mail delivery of the News, you should ever receive a Main Selection without having had the 10 day consideration period, that Selection may be returned at Club expense.

36512. THE BOG PEOPLE/THE MOUND PEOPLE. *P. V. Glob.* Perfectly preserved 2,000-year-old bodies buried in peat bogs, all murdered . . . 6-ft-long oak coffins hidden within mounds of earth . . . two ancient mysteries solved by an eminent archaeologist. *The set counts as 2 of your 3 books.* **$25.00**

65220. ODDITIES OF THE MINERAL WORLD. *William B. Sanborn.* Handsomely illustrated, knowledgeable guide that spotlights some of the more peculiar and unusual mineral formations. **$9.95**

55000. THE ILLUSTRATED ENCYCLOPEDIA OF ASTRONOMY AND SPACE. *Ian Roxburgh.* Covers the full range of astronomical knowledge and space exploration, from ancient times to now. **$16.95**

48470. FIELDBOOK OF NATURAL HISTORY. *E. Laurence Palmer and H. Seymour Fowler.* The most authoritative and comprehensive guide to natural history available. With the aid of over 2,000 illustrations, it explores all major plant and animal species as well as rocks and minerals, the earth, moon, sun, and planets, and space exploration. **$19.95**

73240. QUASARS, PULSARS, AND BLACK HOLES. *Frederic Golden.* A thorough review of the spectacular discoveries in astronomy, as told by the science editor of *Time* magazine. Illustrated with twelve drawings and twenty-four color photographs. **$7.95**

Natural Science Book Club 4-5AK
Riverside, New Jersey 08075

Please accept my application for membership and send me the three volumes indicated, billing me only 99¢ each. I agree to purchase at least three additional Selections or Alternates during the first 12 months I am a member, under the club plan described in this ad. Savings range up to 30% and occasionally even more. My membership is cancelable any time after I buy these three books. A shipping and handling charge is added to all shipments.

3 books for 99¢ each.
Indicate by number the 3 books you want.

A few expensive books (noted in book descriptions) count as 2 choices.

Name _____

Address _____

City _____ State _____ Zip _____

(Offer good in Continental U.S. and Canada only. Prices slightly higher in Canada.)

BOOKS

Mechanical imagination in the 16th century and the baked-clay clues to Mycenaean life

by Philip Morrison

THE VARIOUS AND INGENIOUS MACHINES OF AGOSTINO RAMELLI (1588), translated from the Italian and the French, with a biographical study of the author, by Martha Teach Gnudi. Technical annotations and a pictorial glossary by Eugene S. Ferguson. The Johns Hopkins University Press ($100). "Engineer of the Most Christian King of France and Poland," Captain Ramelli was one of those clever men of Lombardy whose work in war and peace marked the bright morning of the machine age in Europe. As Ramelli was making his book of copper engravings ready for the press in Paris, his countryman Domenico Fontana, from a town just a few miles around the shore of Lago di Lugano from Ramelli's own birthplace, triumphantly set the Vatican obelisk up in the Piazza San Pietro. Fontana had won the contract in an international competition before a special commission established by Pope Sixtus V. Fontana was the consummately effective engineer at work; his wonderful report of 1590 shows his practical operations in managing the 400-ton load. Skill there was in plenty, and detailed organization too, but there was not much use of *"diverse et artificiose"* mechanisms.

Ramelli instead made his book of engineers' dreams. There are nearly 200 detailed engravings, careful perspective views, some full spreads, some with exploded sketches of mechanism, presented on big pages, each with a uniform frame of printer's flowers. The facing pages carry a brief descriptive text; the entire volume is presented in facsimile, but the original print in French and Italian is replaced in the same format by a careful English translation. One plate shows the base of a heavy obelisk slowly entering from outside the frame. But there is no square full of 50 capstans, 800 men, 100 horses and a skein of ropes passing simple pulley blocks, the means Fontana actually used in Rome. Instead a lone rigger coolly turns a crank, while a few others shoulder rollers into place. The heavy-framed machine they tend bears a wonderful train of right- and left-handed gears, worms and lanterns that draw its load—oh, how slowly!—by means of an array of eightfold blocks.

The erudite commentator remarks that this tour de force would undoubtedly have worked as designed, although with discouraging slowness. Ramelli understood force and mechanical advantage but not energy; indeed, his entire volume is a kind of epiphany of gearing. No form of gear in common use today remained unfigured by the Captain, up to an epicyclic gear train like the transmission of a Model T. A variety of cranks and crankshafts, cams, toggle linkages, box wrenches and much more were shown clearly by Ramelli, usually for the first time in print. The only earlier examples of many of his mechanisms are found in manuscripts that were circulating at the time or that were less generally known, such as those of Leonardo. This volume is the third pictorial presentation of machines we know in print; it was much more compendious than its predecessors, and through the 18th-century work of Jacob Leupold it was influential up to the rise of modern machine analysis.

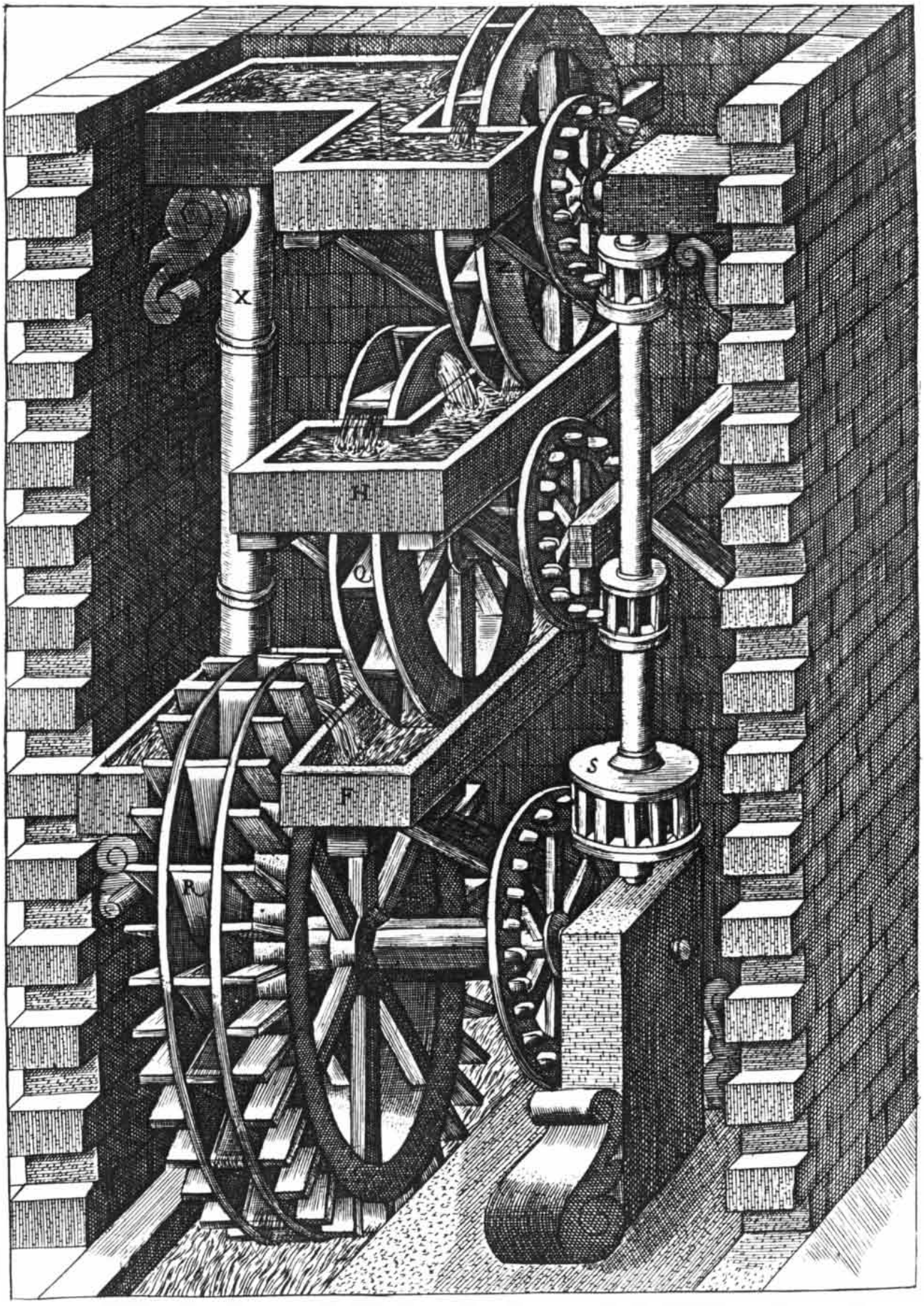
Many of these dreams of the early engineers were simply heightened reality. Ramelli's water-powered devices, mills and pumps, more than 100 of them, carry a good deal of conviction. Here he had power, and his clever rocking troughs and multiple busy gears could be reasonably brought to bear. The first of all roller mills for flour is shown, a hand-driven version far ahead of its time, with a grooved roller, a drum with matching serrations and possibly a means of adjusting fineness. The rotary-vane pump, the very kind of positive-displacement pump that makes the rough vacuum in every laboratory today, is shown here twice, hard at work pumping water. It seems entirely practical, and almost surely it was Ramelli's own invention.

There are many military engines; Ramelli was above all an experienced military engineer. He had seen plenty of service in sieges such as that of La Rochelle, where he was captured and held prisoner of war for several months. The military gear ranges from the plainly usable, such as a gunner's quadrant and a number of hurling devices, through a series of formidable portable bridges and moat-crossing amphibious vehicles that have some air of experience, although they are drawn on a pretty wishful scale. There are a dozen military burglar's tools, screw jacks and toggle joints arranged to pull bolts and force open gratings of fortified places. They look workable, but they are often drawn in action with the light mechanisms rending heavy wrought-iron bars twice the diameter. Ramelli says little about materials; maybe he had metallurgical consultants of great skill! The text explains how "one man alone can break the iron gratings of a portcullis easily and with little noise," but the figure leaves us a little in doubt.

The learned editors of this big and beautiful volume (the recently deceased Martha Gnudi is mourned by her colleagues) supply much matter of interest. The most helpful is a penetrating "pictorial glossary," isolating the principal elements of Ramelli's machines for inspection in clear line drawings by Maureen A. Hammond. The book is printed in Britain and published there by the Scolar Press; most of the many large figures are crisp and evocative reproductions of the original engravings. High Renaissance dreams these may be, but they are not lies. It is good that this celebrated work is at last available in a worthy edition.

THE MYCENAEAN WORLD, by John Chadwick. Cambridge University Press ($17.95). "I have gazed upon the face of Agamemnon," Heinrich Schliemann wired excitedly to his sponsors just about a century ago. He had found a superb death mask of beaten gold in Shaft Grave 5 at Mycenae; hyperbolic as usual, the great discoverer gave the most glamorous of readings to his wonderful find. It turned out to be the grave of an unknown nobleman, buried centuries before the time of the marshal of the war on Troy. To our time, however, it has been given to read the very written words of wise Nestor and doomed Oedipus. Well, not quite. For 25 years we can have entertained wild hopes that "we might come across, let us say, the muster of ships at Aulis for the expedition against Troy, or an operation order for the attack of the Seven against Thebes." The brilliant work of the late Michael Ventris in 1952 deciphered the syllabary in which Bronze Age Greeks wrote, the enigmatic Linear B script that was first found in ruined Knossos when Sir Arthur Evans dug there at the turn of the century.

Archaeology was turned by Ventris into epigraphy; this volume by Ventris' friend and learned colleague reviews for the general reader what the documents they have so cleverly managed to read tell. Most of the work has been done within the past two decades; piecing out the written record with the muter evidence of the spade, Chadwick presents a vivid account of the life Homer sang.



Mechanical linkages for raising the water of a canal to a higher level, from **The Various and Ingenious Machines of Agostino Ramelli**

based on inference that is extended and ingenious beyond any detective thriller.

The fact is that we have no histories, no journals, no letters, not even prayers. The only documents we have are marked clay tablets, account books, mere administrative files from a short period just before the destruction of a few Mycenaean palaces. Most of the record is simple arithmetic; 60 percent of the words that do occur are personal names; the rest are place-names, headings, titles of officials and a few ideograms that label goods, weights and measures and the like. Nearly all the documents are brief: single file cards, so to speak. Here a typical one is pictured and interpreted: Aniatos (a shepherd) keeps his flocks in the district of Phaistos, allocated to an official named Werwesios. The sheep are listed as male, female and "old," with the remainder needed to reach a nominal total and one correction. Only the three proper names, four numbers, three related ideograms and two words in abbreviation are found on the document. Context and abundance alone can give life to such dusty bones.

Those we have. We hold some 1,200 tablets from the mainland city of Pylos, which was Nestor's, about 3,000 from Knossos in Crete, a small number from Mycenae and Thebes and a very few from Tiryns. The tablets were broken and scattered; the key to our gain has been the heroic piecing together of the fragments—thousands of jigsaw puzzles with unknown missing pieces—and the reestablishment of sets that had been filed together in wooden boxes and baskets, mainly by the handwriting, the details of the marks left by the sharp thorns that were used to engrave the damp clay. As a rule one clerk made a single file; there were many hands, scores of them at Knossos, implying that ordinary officials were literate, not leaving their writing to a few professional scribes, as was done in the Middle East. There are many tallies and a few doodles on the reverse sides.

The tablets are little cigars of clay first rolled in the palms, then flattened for writing and finally air-dried. They were memorandums, meant not for long storage but for transcription. At each site the tablets contain no year designations; only months occur as dates, with references to "this year" and "the last." These careful accountants surely posted the ephemera annually; perhaps the account books were entered on sheepskin. But no such books remain; all we have are the clay notes, baked unexpectedly to permanence by the very fire that destroyed the archive rooms and the rest of the palace. The records meant to be permanent were lost forever; the quick memorandums alone endured for 33 centuries.

How much is squeezed out of the files! Chadwick and his associates have been joined by some two dozen scholars over the entire world, from Japan to Uppsala, who supply the conjectures and the arguments expounded in this well-illustrated book. The land and the people, their society, religion, husbandry, crafts and weapons can be discerned through the dusty millenniums. The place-names of the kingdom of Pylos can be mapped, some of the locations coming from what we know of Greek place-names today and from the poets, some by fitting the administrative grouping in the record with the natural divisions on the ground. The people are harder to see; the palace records deal with the landholders on the one hand and the dependents and palace slaves on the other. Ordinary working folk do not enter much. Yet we learn from payments and rations quite a lot of the social structure.

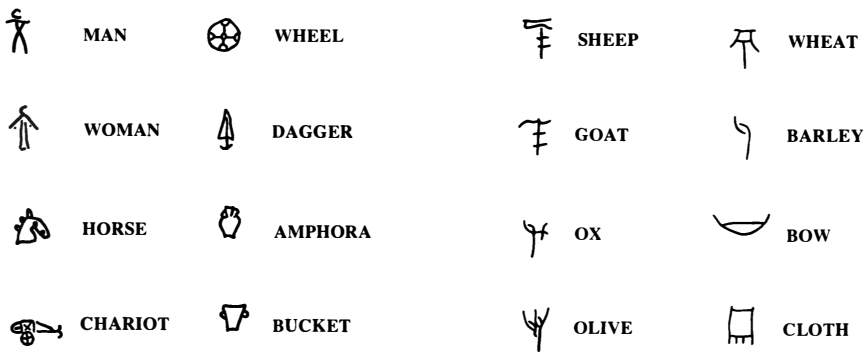
The recoveries from the digs give us weights and measures; their ideograms can be made out. One tablet tells us that 18 units of oil were given by one Kokalos, and 38 jars came from Ipsewas. Let us suppose the jars fit the oil; the result is consistent with the rations assigned for two grains, which have to be wheat and the bulkier barley. "A truly remarkable series of documents" from Knossos lists ox-drivers and their oxen. The names of the teams are intelligible as Greek words: "Dapple, Dusky, Noisy, Whitefoot are rough equivalents." This establishes that the ordinary farmers of Mycenaean Crete spoke Greek; the Greeks (who occupied Knossos after the fall of Minoan culture in the generations following the cataclysmic eruption of Thera) were no mere ruling aristocracy. Greeks farmed the land as well.

Eight hundred tablets at Knossos deal with sheep, not one tablet with more than a single flock. The sheep census runs to 100,000. Why, however, are so many listed as rams? No farmer will believe that. It was worked out by John T. Killen at Cambridge. The bulk of the woolly flocks were wethers, castrated rams. The scribes had no separate sign for them; they called them rams, and threw in the female sheep kept for wool, where it made no difference. The female ideogram was reserved for the breed ewes, whose names were paired with those of other sheep accompanied by an abbreviation. These were obviously young ones. In this way the records hang together, and the wealth of the kingdom is found in wool.

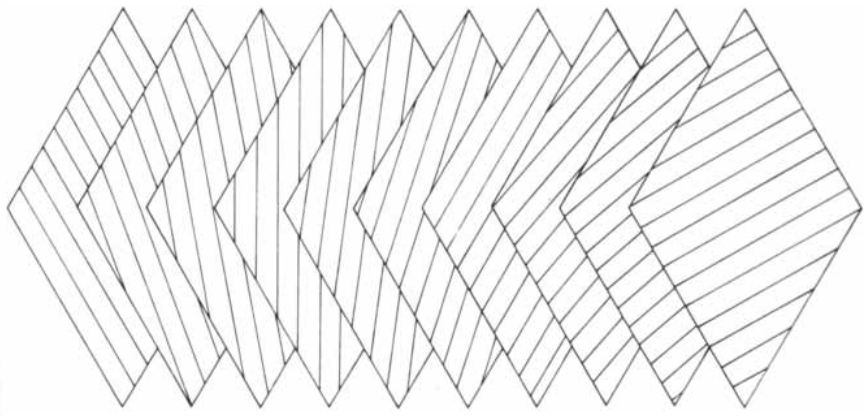
Of course, there are missing tablets. One good estimate is provided by a list of bronze workers at Pylos. Smiths are listed by name and place, and each is assigned a government issue of scarce imported bronze. Then one document gives a very large weight of bronze: a sum of all the metal that had been issued. The difference between the total and the sum of the surviving memorandums implies that about a third of the tablets are missing.

A number of important documents are page-size tablets, which yield a complete tale. One of these describes the coast-guard deployment at Pylos, an order of battle that can be read to make vivid the last years of the kingdom. The regiments were defeated; the palace was looted and burned. The archaeological evidence indicates that the population was reduced to a tithe. The attack was in the spring; there are records of sheep but not of shearing, and there is no trace of harvest or vintage. Suspicion points to the sea peoples, but the evidence is insufficient to convict. It seems likely that the seas were unsafe, because bronze, an import, was being severely rationed, even collected from old objects in the shrines.

Greece entered a Dark Age, but memories of the old grandeur rang down the centuries in the voices of the poets who sang of Troy and of Odysseus. Finally Homer "took the oral tradition and transformed it into superb poetry." He inherited the narrative but not the written word. In Homer's day the writing of the past was only a dim memory; the Greeks were beginning to write again, now using an alphabet from the East, not the forgotten Minoan legacy of syllables. Homer knew a great deal, but he was no historian. Homeric heroes are



Recognizable Mycenaean ideograms **(left)** *and conventional ideograms* **(right)**



Exploded diagram of arthropod cuticle showing direction of fibers

cremated, whereas actually Mycenaean rulers were buried in the great circular vaults that still amaze us. Perhaps at war in the distant theater of Asia Minor they were forced to observe simpler rites, yet nowhere does Homer hint of the huge tombs that so dominated the royal Mycenaean world. Linear B tips the balance, Chadwick argues, against the historicity of Homer. But we lose nothing; we do not really care about the forgotten warrior princes of the Peloponnesus. Our concern is the illumination of human nature. We find it not in the tablets but in the poetry—two "different universes."

MECHANICAL DESIGN IN ORGANISMS, by S. A. Wainwright, W. D. Biggs, J. D. Currey and J. M. Gosline. John Wiley & Sons ($19.50). The squid, the snail and the buttercup stem are all cylindrical forms with a centrally located fluid volume under pressure, held by a fiber winding. The stem that wilts turns out to be wrapped by a thin sandwich of honeycomblike cells, with the cellulose microfibrils of the walls arranged lengthwise in a striking deviation from the usual pattern. "Mechanically speaking, cellulose is the best tensile material for its weight available to organisms . . . and plant parts are as simple and elegantly designed as any organisms on earth." The coconut-palm leaf is an elegant fiber-reinforced cantilever. If you remove the unsightly fabric from the leaf bases, the leaves, weighing six kilograms each, will fall on your head. Or consider the lowly wormlike onychophoran of the tropical forest floor. It dwells in the leaf litter there, able to move freely through it because it can radically change its cross section. The only hard parts the beast owns are a pair of jaws made of chitin and two claws to a leg. Around its one fluid-filled cavity is a folded but unstretching skin. It can get through a round hole a ninth of its full diameter, if you give it 20 minutes for the feat. What an escape act!

Orb webs and kelp stipes, the sea anemone as strong as an old sock and a fair number of other examples are here given the kind of mechanical analysis implied by the remarks excerpted above. Vertebrate skeletons are not much treated; indeed, the rigid materials of living forms are considered more as a basis than as a system. The entire sophisticated and interesting volume gives the impression of a prologue: these are principles of design of great generality and persuasiveness. About the only optimum one can see, however, is the spiderweb, a kind of one-horse shay in pure tension, a least-weight framework that carries out the ideal of Clerk Maxwell's lemma, an old and difficult result. This mixed team—English, American, Canadian, materials scientists and biologists—has made a rich and inviting book, full of aids, but there is a long way to go. It looks as though a microanalysis, an ecological study and a good deal of structural insight are the necessary equipment for understanding the evolved engineering design of each living species.

The text is certainly a strong framework. It begins with an unusually up-to-date approach to strength of materials, both on the level of the macroscopic world and at the molecular scale. Not only elastic theory but also fracture, creep, viscous behavior and crack propagation are well described, for glassy and polymeric materials as well as the more familiar engineering substances. The bulk of the text summarizes and rationalizes the tensile polymers of life, such as the protein rubbers that hold the wing of a fly or reinforce the wall of an artery, and their composites, such as the "three-dimensional feltwork" of the skin. (Your skin is prestressed. The built-in strain is 10 to 30 percent, which is easy to see when you press your forearm skin to shorten it. The skin will fold once the tension is removed.)

The rigid materials follow: natural versions of fiberglass and ceramic, from bone to the remarkable single-crystal spines of the sea urchin. Here the au-

thors cite the apt and wry comment of Libbie Hyman some years back; she felt constrained to "salute the echinoderms as a noble group especially designed to puzzle the zoologist." Consider their porous crystal skeleton, half voids in even the smallest pieces. Does that function to stop cracks? Does the smooth surface show the effect of living tissue acting to suppress surface flaws?

Structural systems are discussed in relation to bending, compression, torsion and joints of all kinds, but there is not much said about the application of such knowledge. The last quarter of the book aims at the treatment of particular living forms, and even here much is conjectural and incomplete. There is a lot to do; it all leads the reader to recognize that the comparative anatomy of the future has hardly begun. The engineering of natural selection has yet to find its appreciative scholarly audience, although it has had its unwitting customers for a long time. This is less a chart book than a set of sailing orders, knowingly and carefully laid out.

THE BOWELS OF THE EARTH, by John Elder. Oxford University Press ($13.25). Original, persuasive, intensely individual, this brief book, elementary in its methods but packed full of formulas, is a remarkable essay on scale. We dwell on the earth without much sense that viewed from beyond the moon it is only a small rock ball. In the first of many rich illustrations Professor Elder, a New Zealand geophysical theorist, shows us six earth sections, the first that featureless stone sphere, the last a cut through the surface zone of hot springs in a famous geothermal park in New Zealand. Scale entails more than size. It is strength too: the rock of a crustal slab the size of a county would be butter-soft in a faithful mechanical model at desktop size. So can we characterize matter at each scale, by size, mass, viscosity, temperature and a measure of porousness. In 200 pages Elder has modeled the subterranean earth, from the ringing of earthquake waves to the fearful geysers of magma foam that are the Vesuvian volcanoes.

The first quarter of the book builds a model of the earth as a whole. From the mere static ball we advance rapidly to a study of energy. The table at the end of Chapter 5 lists the eight energy stocks of the globe; dominated by gravitational energy, they descend through elastic and thermal energy stores to the earth-moon motion. So prepared, we consider the earth in time. "Has the interior always been hot?" On this premise ("I stay with Mr. Laplace") is the book built. The next three chapters construct our present earth. They are far from simple; they treat the fluid mechanics of turbulence better than any other first text one can recall. The earth's interior is not turbulent in the same way that the wind and the sea are, endlessly mixed by inertial motions that friction is inadequate to quell. Its turbulence, slow but irresistible, is instead the convective turbulence of temperature difference. The energy of heat spreads in a ceaselessly intricate way even in the sluggish fluid of molten rock. To understand this we read a brief but physical account of the controlling parameters of any such system of complex motions: the dimensionless numbers named after the heroes Reynolds, Rayleigh, Peclet, Prandtl, Nusselt. Photographs of hot mineral oil in a pot on the laboratory bench hint at the complexities summed up in the turbulent spectra.

One finds the key to the evolution of the motions in the surfacemost layers, where bulk motion is dominated by the effects of the molecular processes of heat conduction and viscosity; this boundary, like the stagnant boundary layer at the surface of the windswept airplane wing, controls the pattern in the larger mass. Out of these arguments arises a model that fits not only the earth but also the rest of the planets. The rollover time for mixing the upper mantle of the earth—the controlling layer for all crustal rearrangements on the global scale—is lengthening as the earth cools. Time itself scales, in a way: after the first 10 million years the earth was thermally a Jupiter ("apart from the methane, of course"), after the first 10 billion years it will be a Mars and after 10^{20} years it will be as changeless as the moon. The simple conduction of heat, like the depth distribution of the radioactive elements that supply heat by their decay, plays no role in this story.

So does the analysis proceed. First, the drifting continents (modeled by a skin of oil-based paint allowed to set on the surface of hot dissolved gelatin) are not rigid plates but a thin skin, self-propelled by a subtle interaction with rising eddies under them. Rising hot blobs on every scale enter, from models of the processes of volcanoes of all kinds down to the local heating of water. The sweep is wide; Newton and Euler and the engineers laid down the laws so well that not much special apparatus is needed for the earth. Here and there one needs chemistry (water is soluble in hot molten rock) or probability (a flank eruption of Kilauea is a reservoir system that is controlled by regular triggerings but has a chance size).

The book is plainly a tour de force, and it may set a new model for scientific exposition in a happy era to come. It has a hybrid vigor: it is part general exposition, with some humor and analogy, part textbook, with rather demanding problems and quite elaborate theoretical derivations set apart in special sections, and part monograph for the knowing, drawing strongly on the au-

thor's own premises, with very little standing back to see what the others say. References are few, limited to a short list of good books and the names of two journals. Much detail is cleverly packed into an index-glossary that lists specific words in the text and contains definitions, extended formulas or data and explicit literature references. It may not be easy to go deeper into all the data represented, but the outcome is a smooth-reading, if unusually dense, argument, perhaps intimidating to the nonmathematical, although the author hopes not. The prose of the book is direct and evocative.

Continental drift is a good term for certain models of crustal processes; for the model elaborated here it is not suitable. ("The difference between the two models is simply the difference between a raft and a raft with a motor.") Elder makes this suggestion about seismology: "Record the seismometer signal on a magnetic tape and play back the tape, say, 10,000 times faster. We can then, as it were, listen to the earth. . . . Generally it sounds like being in a forest on a windy day. . . . Every now and again there are sharp noises that sound like a branch breaking. On rare occasions there are sounds like a herd of animals stampeding." A serious student can take Elder's argument a long way, in particular the basic understanding of convection and its application to a wide set of situations, not only to the great globe itself but also to its model the little pot.

The fully numerate reader prepared to face arguments from physical quantity will thrive. How can we expect otherwise? This is a treatise on quantity, indeed a triumph of that regime. Elder's models are flawed now and again; his TNT is weaker than most by one power of 10, and his glaciers flow viscously where the modern student of ice streams know they creep. He teases us with diamonds and their startling origin but only murmurs when he might have shouted. We see his home landscape superbly but get little idea of the wilder things on the marches. Above all, it is a book satisfying those who, like the author, care more about the recipe than the cake.

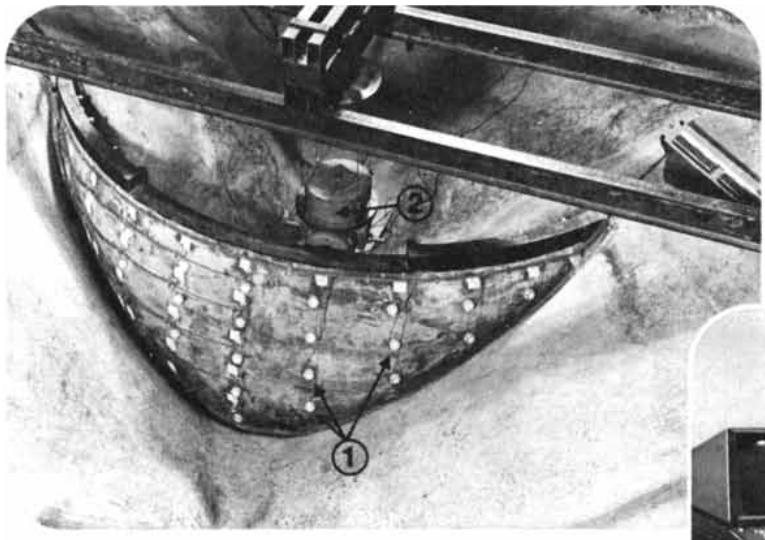
ANALYSIS OF ESSENTIAL OILS BY GAS CHROMATOGRAPHY AND MASS SPECTROMETRY, by Yoshiro Masada. John Wiley & Sons, Inc. ($37.50). This specialist's volume is a kind of field guide to the molecular components of the essential oils of commerce. Those substances, aromatic and flavorful, are obtained primarily by the steam distillation of plants, sometimes only of their flowers or fruits. The book ranges over 65 oils, with a few pages for each one. The text gives the source, the uses, a physical description of the substance and sometimes a little more. Then follows the

identifying visualization: for each oil there is at least one full-page gas chromatograph. The main molecular peaks are identified as they have been measured by the author with his modern programmed high-resolution instrument, using an open glass capillary tube internally coated with a special hydrocarbon solvent. (As the vapor is slowly swept through the chromatograph tube by an inert nitrogen stream, the varying partition of the volatile compounds between the vapor phase and the dissolved phase draws the diffusing material out into well-separated peaks; the time of passage through 100 feet of tube is the "spectral" variable.) With this technique, one of the most powerful means of organic analysis in wide use (including a couple of portable installations now on Mars), from a single run you get a reasonable quantitative analysis for many dozens of related complex molecules.

The compounds are detected by some general atomic property. Here it is the degree of ionization by a flame. The terpenes, aldehydes, alcohols, ketones and esters that make up most of the active constituents of these oils are well resolved. They can be more rigorously identified by the passage of the effluent peaks into a mass spectrometer, where the molecule is ionized and its fragments are sorted by magnetic focusing. Professor Masada also includes a good many of these results for key compounds.

The worldwide nature of the cultivation (cloves from Zanzibar, patchouli from Indonesia, caraway from Holland and menthol from the peppermint varieties grown on Brazilian plantations), the sense of variety, the fragrant harmonies that are formed, the 100-odd molecular notes analyzed source by source—all give this laconic and technical book of reference a curious charm. A few up-to-date phrases about the trade in each oil and references to the cosmopolitan literature add to the ring of an authentic expertise. There is a summary in Japanese for each entry and an introductory chapter on the chemistry and the analytical methods in Japanese only (apart from a few inviting headings and diagrams).

The beer you drink gets its special bitter aroma mainly from the monoterpene myrcene, even though hops is visibly complex. What lies between the lines of this authoritative compendium is hinted at in its account of vervain oil, obtained originally from the verbena. "The oil is produced in very small quantities and its price is very high, therefore the usual commercial vervain is a compound oil of the same chemical proportions as natural true vervain oil." One can count 45 peaks, small and large, in the chromatograph of the true oil, an exacting recipe.



Dam model at left is .775 meters (30.5 inches) high. Accelerometers **(1)** placed at points along the structure's surface monitor its response to earthquake-simulating vibrations produced by an electrodynamic exciter **(2)**. Modal information thus generated is analyzed by the HP 5451B (below), which displays the animated mode shapes on a CRT screen and/or records the shape on a plotter for future reference.

Modal analysis of scale models accurately predicts structural response to earthquakes.

Investigators at ISMES rely heavily on Hewlett-Packard's computerized modal analysis system to study the response of geomechanical scale models to simulated earthquakes. The results of these tests help them to predict the safety of the full-scale structure more accurately than by conventional means.

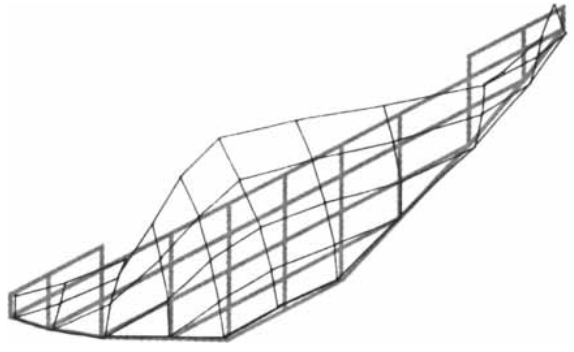
Because large architectural or engineering structures are likely to be complex, dynamic tests on simulation scale models are often essential to verify their behavior under dynamic loads. To which end, the Hewlett-Packard 5451B Fourier Analyzer with modal analysis package is being used extensively at ISMES (Istituto Sperimentale Modelli e Strutture—or Experimental Institute for Models and Structures), in Bergamo, Italy, for performing dynamic tests both on scale models and full-scale structures.

Modal analysis, briefly, is a technique for identifying modes of vibration in a structure when subjected to dynamic loads. One characteristic of each mode of vibration is called a mode shape—a spatial description of the relative motion of each point on the structure. The mode shape reveals important information about behavior at each resonant frequency, helping the designer locate weak points in a design that could result in structural failure.

One important test area is the interaction of dam foundations and dam reservoirs under varying reservoir conditions, in terms of their response to seismic and hydrodynamic loads. Of critical interest are vibration modes in the frequency range of 0-15 Hz, which represent the structure's response to earthquake. In one dam design test typical of the method, the HP modal analysis system measured transfer functions between the input point, where a broadband excitation force is applied, and numerous response accelerometers mounted at points of interest on a 1:100 scale test model. These transfer functions contain all structural modes within the excitation bandwidth and can be used to define the response at each measurement point.

With this HP 5451-produced information, ISMES investigators can accurately visualize the dynamic behavior of the model, identify its weak points, and thus suggest to the designer where the full-scale structure should be strengthened.

The 5451B Fourier Analyzer, with modal analysis package, has a basic cost of $81,440* with a complete operating system including all necessary hardware, software, and peripherals.



Mode shape of the undeformed dam (gray) is compared with a typical mode shape (black) showing deformation at one mode of vibration.

A new line of small computer systems with all the facilities needed to become departmental servants.

Now you can afford a "departmental computer": The HP 1000. As a facile servant, it can be configured to handle scientific computing, instrumentation control, and operations management.

In a few words, the HP 1000 family of computer systems can manipulate large amounts of data in a variety of ways concurrently, with fast response to a number of users. Consisting of a new, high-performance computer, fast, rugged disc memory, and CRT terminal (its basic configuration), the HP 1000 represents the kind of price/performance advance that makes the "departmental computer" an economic practicality.

With the flexibility characteristic of the perfect servant, the HP 1000 effectively plays a number of roles:

- A system for scientific/engineering computing;
- The controller in an instrument system for automated measurement, control, and testing;
- The central system to control an entire computer network;
- A complete data base management system for a virtually unlimited number of applications.

Each member of the HP 1000 family has the ability to perform as a multiterminal, on-line, interactive system serving several users concurrently—and it does batch processing at the same time. Each has multilingual capabilities that include FORTRAN, ALGOL, HP Assembly, and Multi-User Real-Time BASIC.

Dynamic microcycle timing, a singular HP technical concept, allows the processor to execute most instructions in 175 ns while taking 280 ns for the occasional slower functions.

New enhanced user-microprogramming is a second design innovation that allows you to increase the computing power of the HP 1000 system as the need arises. For example, a user can improve FORTRAN performance in a given application by 2 to 20 times over conventional techniques: the sine X function, e.g., is executed 20 times faster; and a typical shell sort operation, 9 times faster.

The HP 1000's versatile real-time operating system manages the computer hardware so efficiently that several users can access the system to perform different tasks simultaneously—and they'll all think the computer is their own slave. (For the countless thousands who have resented serving the computer, this turnabout is fair play.)

Prices* for the HP 1000 systems range from $33,500 for the cabinet-mounted Model 31, to $37,500 for the Model 30, housed in a contemporary desk-style work center (pictured above), to $61,200 for the Model 80 and $62,200 for the Model 81 data base management systems.

*Domestic U.S. prices only.

HEWLETT hp PACKARD

1505 Page Mill Road, Palo Alto, California 94304

For assistance call: Washington (301) 948-6370, Chicago (312) 255-9800
Atlanta (404) 434-4000, Los Angeles (213) 877-1282.

Mail to: Hewlett-Packard, 1505 Page Mill Road, Palo Alto, CA 94304.
Please send me further information on

( ) HP 5451B Fourier analyzer/modal analysis system
( ) HP 1000 computer system

Name _____

Company _____

Address _____

City _____ State _____ Zip _____

00741

BIBLIOGRAPHY

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

CRUISE MISSILES

THE CRUISE MISSILE AND ARMS CONTROL. Richard Burt in *Survival,* Vol. 18, No. 1, pages 10–17; January/February, 1976.

EFFECTIVE MILITARY TECHNOLOGY FOR THE 1980S. Richard L. Garwin in *International Security,* Vol. 1, No. 2, pages 50–77; Fall, 1976.

THE CRUISE MISSILE: THE END OF ARMS CONTROL? Alexander R. Vershbow in *Foreign Affairs,* Vol. 54, No. 4, pages 133–146; October, 1976.

PHOBOS AND DEIMOS

THE SATELLITES OF MARS: PREDICTION AND DISCOVERY. Owen Gingerich in *Journal for the History of Astronomy,* Vol. 1, Part 2, No. 2, pages 109–115; August, 1970.

MARINER 9 TELEVISION OBSERVATIONS OF PHOBOS AND DEIMOS. J. B. Pollack, J. Veverka, M. Noland, Carl Sagan, W. K. Hartmann, T. C. Duxbury, G. H. Born, D. J. Milton and B. A. Smith in *Icarus,* Vol. 17, No. 2, pages 394–407; October, 1972.

MARINER 9 TELEVISION OBSERVATIONS OF PHOBOS AND DEIMOS, 2. J. B. Pollack, J. Veverka, M. Noland, C. Sagan, T. C. Duxbury, C. H. Acton, Jr., G. H. Born, W. K. Hartmann and B. A. Smith in *Journal of Geophysical Research,* Vol. 78, No. 20, pages 4313–4326; July 10, 1973.

A MARINER 9 ATLAS OF THE MOONS OF MARS. Joseph Veverka, Michael Noland, Carl Sagan, James Pollack, Lynn Quam, Robert Tucker, Botand Eross, Thomas Duxbury and William Green in *Icarus,* Vol. 23, No. 2, pages 206–289; October, 1974.

PHOBOS: CONTROL NETWORK ANALYSIS. Thomas C. Duxbury in *Icarus,* Vol. 23, No. 2, pages 290–299; October, 1974.

A FRONTIER POST IN ROMAN BRITAIN

RESEARCH ON HADRIAN'S WALL. Eric Birley. Titus Wilson & Sons, Ltd., 1961.

BRITANNIA: A HISTORY OF ROMAN BRITAIN. Sheppard Frere. Harvard University Press, 1967.

EXCAVATIONS AT CHESTERHOLM-VINDOLANDA 1967–1969. Robin Birley in *Archaeologia Aeliana,* Series 4, Vol. 48; 1970.

VIABLE BACTERIAL SPORES RECOVERED FROM AN ARCHAEOLOGICAL EXCAVATION. M. R. D. Seaward, T. Cross and Bridget A. Unsworth in *Nature,* Vol. 261, No. 5559, pages 407–408; June 3, 1976.

GLOBAL SATELLITE COMMUNICATIONS

THE BEGINNINGS OF SATELLITE COMMUNICATIONS. J. R. Pierce. San Francisco Press, Inc., 1968.

SATELLITE COMMUNICATIONS ENGINEERING. K. Miya. Lattice Company, Tokyo, 1975.

COMMUNICATION SATELLITE DEVELOPMENTS. Edited by G. E. LaVean and W. G. Schmidt in *Progress in Astronautics and Aeronautics: Vols. 41 and 42.* American Institute of Aeronautics and Astronautics, 1976.

SATELLITE COMMUNICATIONS SYSTEMS. Edited by I. Kadar in *AIAA Selected Reprint Series: Vol. XVIII.* American Institute of Aeronautics and Astronautics, 1976.

THE ORIGIN OF ATHEROSCLEROSIS

THE GEOGRAPHIC PATHOLOGY OF ATHEROSCLEROSIS. Edited by Henry C. McGill, Jr., in *Laboratory Investigation,* Vol. 18, No. 5; May, 1968.

THE PATHOGENESIS OF ATHEROSCLEROSIS. Edited by R. W. Wissler and J. C. Geer. The Williams & Wilkins Company, 1972.

EVIDENCE FOR A MONOCLONAL ORIGIN OF HUMAN ATHEROSCLEROTIC PLAQUES. Earl P. Benditt and John M. Benditt in *Proceedings of the National Academy of Sciences of the United States of America,* Vol. 70, No. 6, pages 1753–1756; June, 1973.

THE CORONARY DRUG PROJECT: FINDINGS LEADING TO DISCONTINUATION OF THE 2.5-MG/DAY ESTROGEN GROUP. The Coronary Drug Project Research Group in *The Journal of the American Medical Association,* Vol. 226, No. 6, pages 652–657; November 5, 1973.

IMPLICATIONS OF THE MONOCLONAL CHARACTER OF HUMAN ATHEROSCLEROTIC PLAQUES. E. P. Benditt in *Beiträge zur Pathologie,* Vol. 158, No. 4, pages 405–416; September, 1976.

LASER SEPARATION OF ISOTOPES

ISOTOPE SEPARATION PROCESSES. William Spindel in *American Chemical Society Symposium Series: No. 11.* American Chemical Society, 1975.

EXPERIMENTAL AND THEORETICAL STUDIES OF LASER ISOTOPE SEPARATION. Jack P. Aldridge III, John H. Birely, Cyrus D. Cantrell III and David C. Cartwright in *Physics of Quantum Electronics: Vol. 4,* edited by Stephen F. Jacobs, Murray Sargent III, Marlan O. Scully and Charles T. Walker. Addison-Wesley Publishing Company, 1976.

LASER ISOTOPE SEPARATION. V. S. Letokhov and C. B. Moore in *Soviet Journal of Quantum Electronics,* in press.

SOCIAL AND NONSOCIAL SPEECH

SPEECH ACTS: AN ESSAY IN THE PHILOSOPHY OF LANGUAGE. John Searle. Cambridge University Press, 1969.

COGNITIVE BASIS OF LANGUAGE LEARNING IN INFANTS. John Macnamara in *Psychological Review,* Vol. 79, No. 1, pages 1–13; January, 1972.

MOTHERS' SPEECH TO CHILDREN LEARNING LANGUAGE. Catherine E. Snow in *Child Development,* Vol. 43, No. 2, pages 549–565; June, 1972.

THE DEVELOPMENT OF COMMUNICATION SKILLS: MODIFICATIONS IN THE SPEECH OF YOUNG CHILDREN AS A FUNCTION OF LISTENER. Marilyn Shatz and Rochel Gelman in *Monographs of the Society for Research in Child Development,* Vol. 38, No. 5; 1973.

THE DEVELOPMENT OF ROLE-TAKING AND COMMUNICATION SKILLS IN CHILDREN. John H. Flavell in collaboration with Patricia T. Botkin, Charles L. Fry, Jr., John W. Wright and Paul E. Jarvis. Robert E. Krieger Publishing Company, 1975.

THE RESPONSE TO ACETYLCHOLINE

THE SYNAPSE in *Cold Spring Harbor Symposia on Quantitative Biology,* Vol. 15; 1976.

SINGLE-CHANNEL CURRENTS RECORDED FROM MEMBRANE OF DENERVATED FROG MUSCLE FIBRES. Erwin Neher and Bert Sakmann in *Nature,* Vol. 260, No. 5554, pages 799–802; April 29, 1976.

RATES AND EQUILIBRIA AT THE ACETYLCHOLINE RECEPTOR OF *ELECTROPHORUS* ELECTROPLAQUES. Robert E. Sheridan and Henry A. Lester in *Journal of General Physiology,* in press.

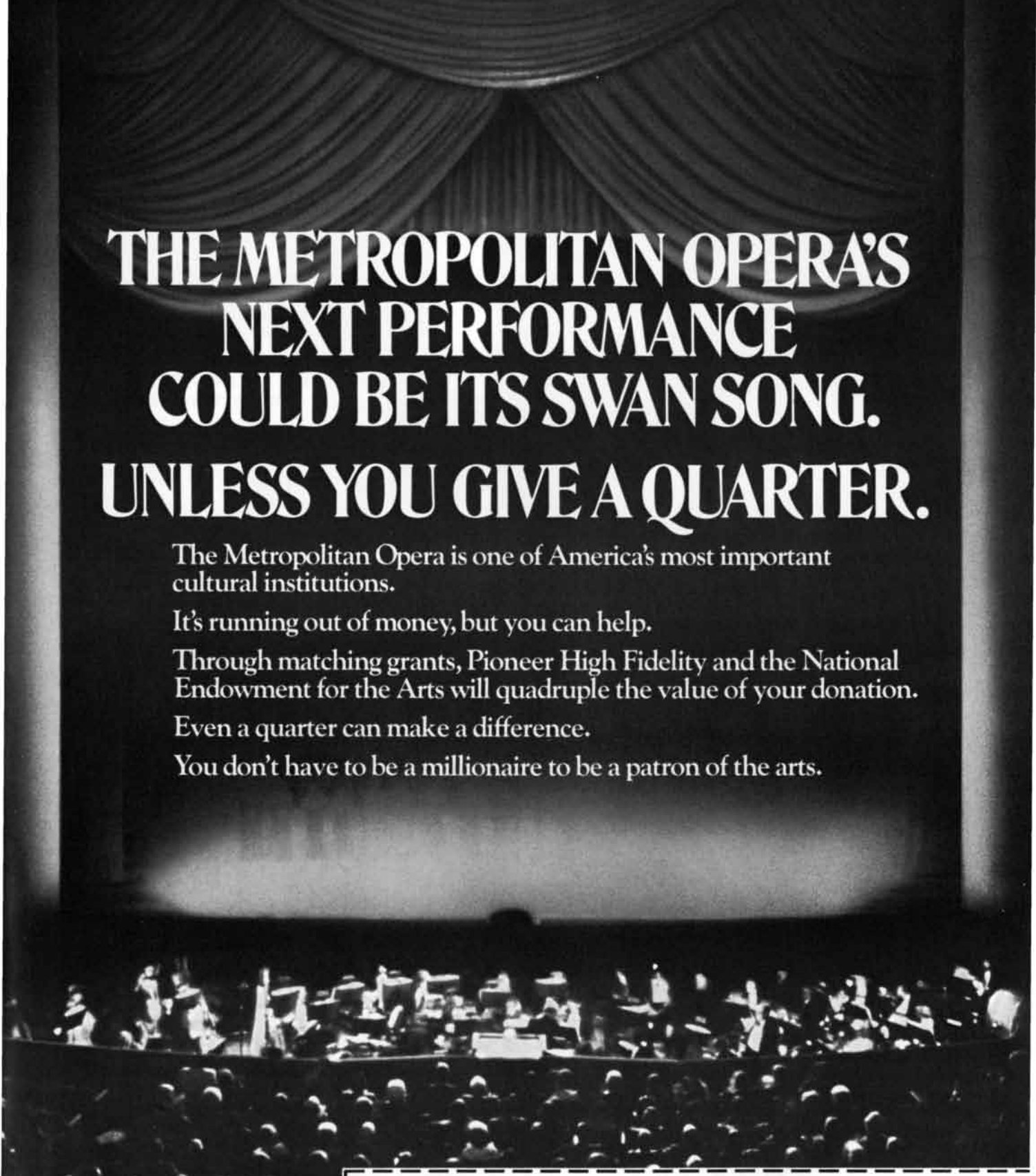
MATHEMATICAL GAMES

LANGUAGE ON VACATION: AN OLIO OF ORTHOGRAPHICAL ODDITIES. Dmitri A. Borgmann. Charles Scribner's Sons, 1965.

BEYOND LANGUAGE: ADVENTURES IN WORD AND THOUGHT. Dmitri A. Borgmann. Charles Scribner's Sons, 1967.

LA LITTÉRATURE POTENTIELLE (CRÉATIONS RE-CRÉATIONS RÉCRÉATIONS). Oulipo. Gallimard, 1973.

OULIPO. Harry Mathews in *Word Ways,* Vol. 9, No. 2, pages 67–74; May, 1976.



THE METROPOLITAN OPERA'S NEXT PERFORMANCE COULD BE ITS SWAN SONG.

UNLESS YOU GIVE A QUARTER.

The Metropolitan Opera is one of America's most important cultural institutions.

It's running out of money, but you can help.

Through matching grants, Pioneer High Fidelity and the National Endowment for the Arts will quadruple the value of your donation.

Even a quarter can make a difference.

You don't have to be a millionaire to be a patron of the arts.

When you give a quarter, the Met gets a buck.

I have enclosed a donation of $_____ for the Metropolitan Opera. (Checks should be made payable to The Metropolitan Opera/Pioneer Fund.)

Name _____

Address _____

City _____ State _____ Zip _____

Mail the coupon with your donation to:
U.S. Pioneer Electronics Corp., Dept. M.E.T., 75 Oxford Drive, Moonachie, N.J. 07074.

PIONEER HIGH FIDELITY We all owe a lot to music.

Merci, Monsieur You sure got

Look where the science of transportation is now.

Today, thanks to the inventiveness of people like Monsieur Cugnot, transportation is a science. A science that moves people and products from where they are to where they want to be. Efficiently. Economically.

Rockwell International is very much a part of that science with products that range from undersea navigation systems to the world's first reusable spacecraft... and many other forms of transportation in between.

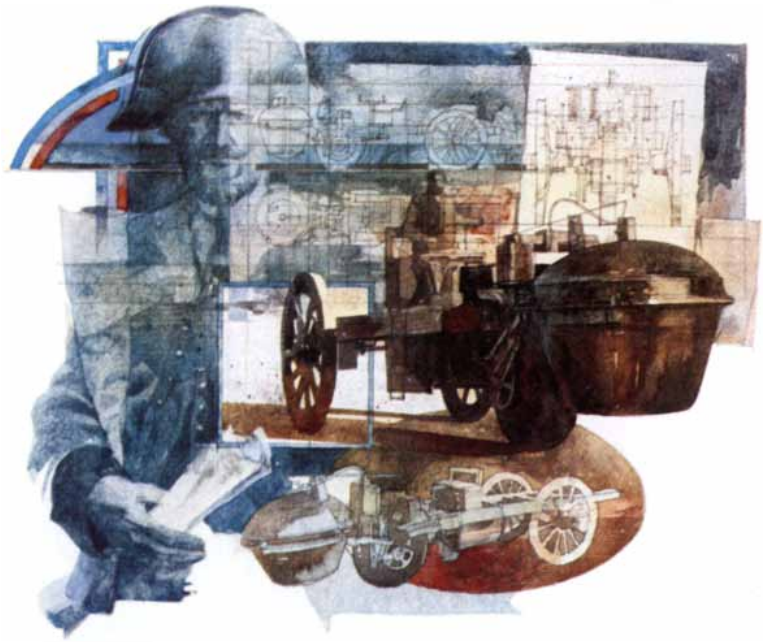
The science of transportation is just one of the sciences of Rockwell, one of the ways we're putting science to work for man.

Further information, including our Annual Report, is available by writing: Rockwell International, Department 815S, 600 Grant Street, Pittsburgh, PA 15219.

Over half of all on-highway heavy-duty trucks and tractors ride on Rockwell axles and stop with Rockwell brakes. Other Rockwell components for America's vital highway transportation system include: suspension springs, U-joints and reinforced plastic assemblies.

Rockwell builds driveline components and heavy-duty brakes for off-highway equipment used in mining, forestry, construction, agriculture and many other fields.

Nicolas Joseph Cugnot, of France, built the world's first self-propelled road vehicle. When? Over 200 years ago. It travelled at about three miles per hour with stops at 15-minute intervals to build up steam. Monsieur Cugnot is credited with another first: While motoring through the streets of Paris, he took a sharp turn too speedily and became the world's first automobile accident statistic. His vehicle was impounded, never to be driven on public streets again. It has been preserved in the Conservatoire des Arts et Metiers in Paris.



Cugnot. Things moving.

All 300 cars of the Washington Metropolitan Area Transit Authority will ride on undercarriages from the broad Rockwell line of components for the mass transit industry.

The Space Shuttle, which we're building for NASA, will become the space transportation system for the 1980s and beyond. Its payloads will help put space to work for man.

High-speed hydrofoil boats, such as this, have accumulated over 50-million passenger miles, powered by Powerjet® propulsors developed from Rockwell's rocket engine pump technology.

Our Rockwell Turbo Commander® 690B can take busy executives into untapped markets — fast. It outperforms every other existing business propjet in its class.

Rockwell International

...where science gets down to business

Jaguar XJC.
Above the beaten path.

Jaguars are, and always have been, strikingly individual cars. This newest coupe edition of the famous Jaguar XJ sedan series is a classic example of how Jaguar has won and maintained its enviable reputation in the very small world of luxury high-performance motorcars.

As with all Jaguars, the XJC was conceived and designed to handle with the precision and response of a sports car. It has all-independent suspension, four-wheel power disc brakes and power-assisted rack and pinion steering.

The Jaguar coupe offers you two superb engines. You may have the electronically fuel-injected, short-stroke V-12, a balanced blend of smoothness, quiet and huge reserves of torque at any speed. Or, choose the justly famous double overhead-cam Jaguar Six, proud descendant of the engine that originally swept Jaguars to five victories at LeMans.

The luxury of the coupe is uncommon in its scope and elegance. Burled walnut, topgrain leather, rich carpeting, self-adjusting thermostatic air conditioning, AM/FM radio, 8-track tape deck and stereophonic speakers are all standard equipment.

The Jaguar qualities of leadership are further exemplified in its warranty. For 12 months, regardless of mileage, Jaguar will replace or repair any part of the car that is defective or that simply wears out, provided only that the car is properly maintained. The only exceptions are the tires, which are warranted by the tire manufacturer, and spark plugs and filters, which are routine replacement items. Even then, if they are defective, Jaguar will pay to replace them.

There comes a time in everyone's life when anything but the best is insufficient. When that time comes for you, an uncommon luxury car is waiting. Call these numbers, toll-free, for the name of the Jaguar dealer nearest you: (800) 447-4700, or, in Illinois, (800) 322-4400. British Leyland Motors Inc., Leonia, New Jersey 07605.

BRITISH LEYLAND

Jaguar