SCIENTIFIC AMERICAN

TEACHING LANGUAGE TO AN APE

ONE DOLLAR

October 1972

Celestron

Schmidt-Cassegrain TELESCOPES.

For the Educator...Casual Observer...Astrophotographer

Celestron 14 | Celestron 5 | Celestron 8 (Astrophoto Lab.)

EXPANDING THE PERCEPTION OF MAN — A Celestron telescope increases manyfold your perception of the hidden worlds of nature, challenges you to learn more about the universe by presenting to you brilliantly sharp images of tiny lunar craterlets, the polar caps of Mars, the twirling moons and belt structure of Jupiter or the fascinating rings of Saturn. Your Celestron will carry you on an imaginary tour of our galaxy, and show your searching eyes the hues of hundreds of stars in a compact galactic cluster, the filamentary structure of the Great Orion Nebula or perhaps the smoke ring in Lyra. You will dash through the endless void of space with your Celestron to view the intriguing spiral structure of a galaxy millions of light years away.

CELESTRON — THE NEW LOOK IN TELESCOPES

Celestron . . . a new standard of optical excellence . . . the world's finest Schmidt-Cassegrain optics: they give sharper images over a wider flat field than any other commercially available telescope. They also optically fold a long focal length inside a compact, lightweight tube. And that means more than carrying-case portability: it also means apertures large enough to produce the bright detailed images that make higher powers worth using. Convenient adaptors quickly accept your 35mm SLR camera body for dramatic, extreme telephoto shots or guided deep-sky exposures, and you'll get crisp color negatives filled corner to corner. A rigid fork mount assures effortless pointing and jitterfree images at higher powers. And for really elegant simplicity of operation, large, finely-etched setting circles make it easy to dial celestial objects into the field of view, while a precision electric clock drive keeps them there. This is an instrument you'll display with pride in the center of your trophy case. If you'd like to know more, we have a library of color slides taken with these instruments, including resolution tests (send for listings), and we also publish **Celestron Techniques** (subscription, $2 for 4 issues). Prompt delivery . . . finance plan available.

CELESTRON	***. . . 5"***	***. . . 8"***	***. . . 14"***
Useful Powers	25-300X	50-500X	50-850X
Light Grasp	188X	510X	1,760X
Resolution (arc secs.)	0.8	0.5	0.28
Weight (lbs.)	12	23	100
Base Price	$595	$895	$3,600

Information requests promptly filled — write to:

Celestron Pacific

2430 Amsler Box 3578 A
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Background Photo — The Rosette Nebula, Celestron 225mm-f/1.65 Schmidt Camera

1973 VEGA. CAN YOU SPOT THE CHANGES?

There's more "new" in the new Vega than you might suspect.

But most of it is strictly internal. Technical stuff. Not very exciting, but certainly significant.

Better belts and jack.

For instance we've improved the emission controls in the 1973 Vega, and we're sure you're glad about that.

We've replaced both the 3-speed and the 4-speed manual transmissions. The new ones shift smoother.

There's an improved seat belt system, a new windshield washer control that's easier to use than the old one.

Even the bumper jack is better. (But don't worry. You probably won't use it very often.)

Like we said when Vega first came out two years ago, we're not going to mess around with the looks of the car just to make it look different.

If you look closely at the 1973 Vega you can see that the bumpers look different than they did last year. But that's for a stronger bumper, not styling.

And if this ad were in color, you'd be able to see that the car is painted "Chamois," which is one of eight new colors available for the '73 Vega. (There are new interior colors, too.)

Oh. The nameplate now reads "Vega by Chevrolet" instead of "Chevrolet Vega 2300."

Whoopee.

Free color brochure.

In conclusion, what we have here is a Vega that still looks like a Vega, still handles like a Vega, still rides like a Vega, still saves like a Vega.

And that's not all bad.

For the full story, in full color, pick up a free 1973 Vega brochure.

At your Chevrolet dealer's of course.

VEGA
CHEVROLET

GM
MARK OF EXCELLENCE

Chevrolet. Building a better way to see the U.S.A.

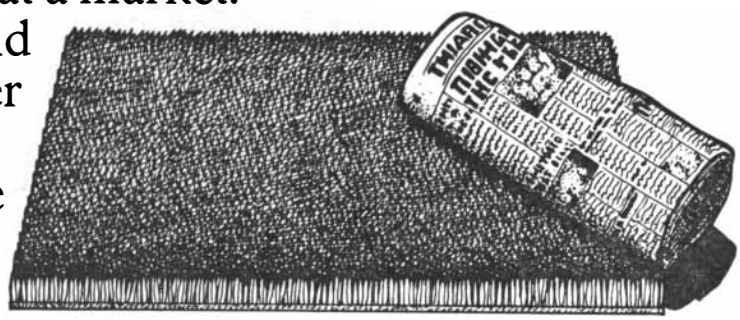
Welcome opportunity.

AstroTurf® surfaces are amazing products that almost seem to invent their own markets.

For instance, when we developed AstroTurf, doormats never entered our minds.

Doormats? Is that a market?

Your mind would boggle at the number of doormats sold each year. And at the number of doormats Monsanto sells.



But when it comes to the home market, we're not waiting at the doorstep. This year, we've launched AstroTurf 'Round-the-Home surface. For Patios, Porches, Poolsides, Putting greens; Decks, Docks, Dog runs....

And that's only two letters of the alphabet.

AstroTurf is one more example of what we can make with common chemicals and rare imagination at

Monsanto: the science company.

FOR MORE INFORMATION ABOUT MONSANTO'S ASTROTURF SURFACES, WRITE MA 5, MONSANTO COMPANY 800 N. LINDBERGH BLVD. ST. LOUIS, MO. 63166

Established 1845 **SCIENTIFIC AMERICAN** October 1972 Volume 227 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows a chimpanzee that has been trained to "write" in front of a magnetic board on which are arrayed several of the symbols it has learned (see "Teaching Language to an Ape," page 92). At left are three symbols meaning, from top to bottom, "chocolate," "is" and "brown"; they form the sentence "Chocolate is brown." At right between "brown" and "chocolate" is a fourth symbol meaning "color of"; these three symbols form the sentence "Brown color of chocolate." The trained chimpanzee is able to perceive that the two sentences have the same meaning. It chooses the symbol for "same," which it is holding in its right hand.

THE ILLUSTRATIONS

Cover painting by Tom Prentiss

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OLDSMOBILE INTRODUCES CUTLASS SALON.

IT'S NOT LIKE ANY OTHER CUTLASS.
IN MANY WAYS IT'S LIKE A EUROPEAN TOURING SEDAN.

IT'S GOT 2 RECLINING SEATS UP FRONT.
4 STEEL-BELTED RADIAL TIRES UNDERNEATH.
AND 1 SOPHISTICATED SUSPENSION SYSTEM IN BETWEEN.

**OLDS CUTLASS SALON.
IN THE GRAND
TOURING TRADITION.**

The front seats (upholstered in corduroy-like velour) are more like easy chairs than buckets. You turn a dial, they recline. Just as they do in some imported touring sedans.

Salon's powered by a Rocket 350 V8 with a 4-barrel carb. It stops on front disc brakes. Rides on steel-belted radial tires.

And like classic touring sedans, its suspension system (equipped with front and rear anti-sway bars and high-rate rear arm bushings) was especially designed for the road.

So it takes dips and bumps. With authority. And it takes back-road curves. With equal authority.

Cutlass Salon.

It's a new kind of 4-door sedan for the driving enthusiast. And we think you'll find it a lot like an expensive imported touring sedan, except for two interesting things.

It's priced much less.

And it's built in the U.S.A. Oldsmobile. Always a step ahead.

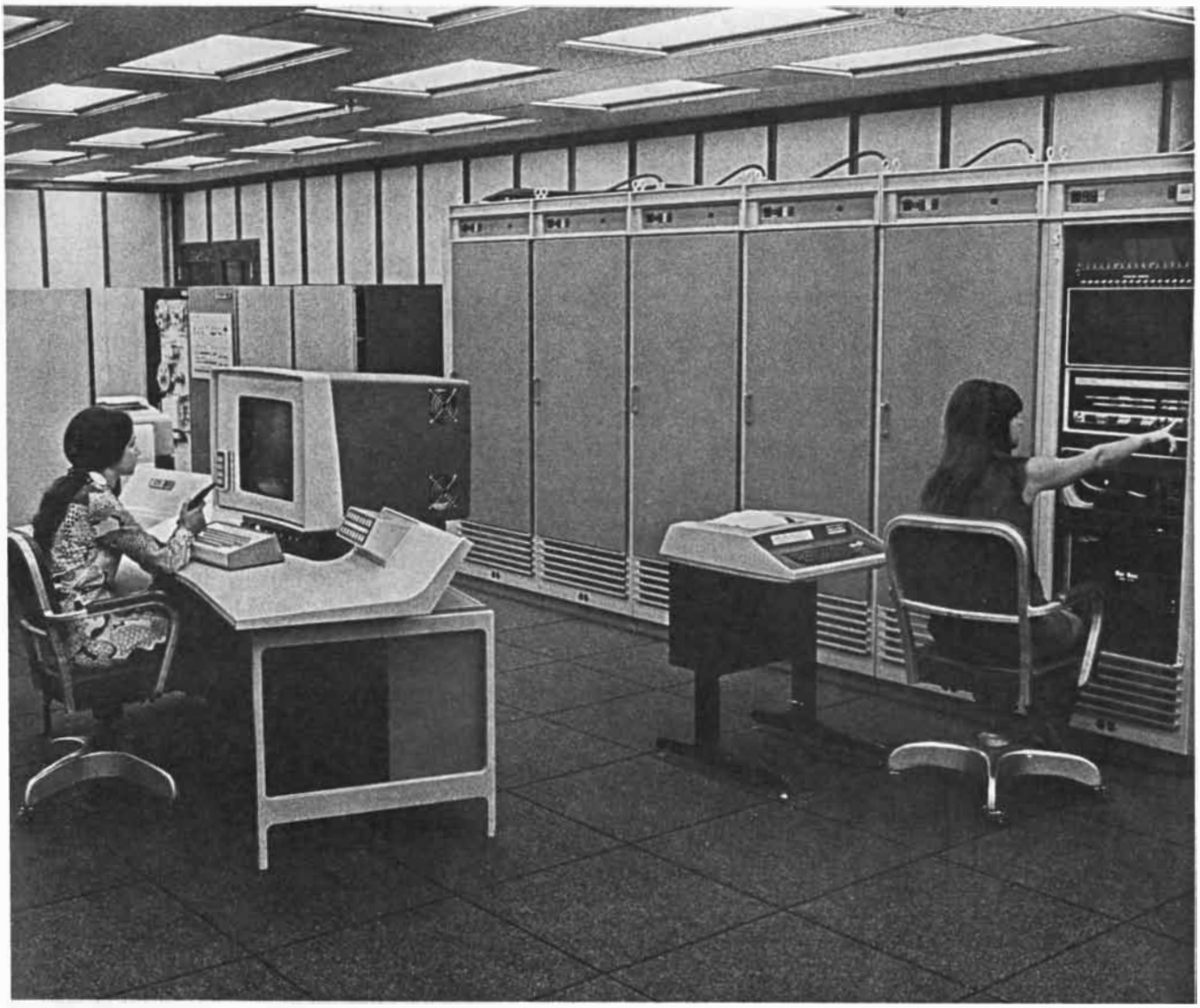
Test-drive Staran™

At our new Evaluation and Training your high-data-rate problems with a custom-

We've established a new Staran Evaluation and Training Facility, complete with all necessary peripheral equipment, at our Akron, Ohio, plant. Both hardware and software are adaptable to a wide range of potential users' data handling needs.

Here, our computer engineers and program experts will actually demonstrate for you how Staran can handle your specific data processing problems. And you can evaluate its performance in terms of your own hands-on experience.

Because Staran is like thousands of conventional computers operating simultaneously, it can achieve execution rates up to several hundred million operations per second. And input/output rates up to several billion bits per second. It is especially cost-effective for such high data volume applications as air traffic control. Weather prediction. Ballistic missile defense. Surveillance and control



Facility, we'll show you how to solve designed associative array processing system

systems. Electronic warfare. Intelligence data processing.

An evaluation of Staran is definitely indicated if your applications involve: a large, dynamic data base; extremely rapid response to unanticipated inquiries; many similar items in a data file that must be simultaneously active. Because Staran is not just a new generation—it's a whole new way of thinking.

For more information about our Staran Evaluation and Training Facility, or to plan a showing, write: Wayne Brubaker, Manager, Digital Systems Marketing, Dept. 920, Goodyear Aerospace Corporation, Akron, Ohio 44315. Or call him at (216) 794-3631.

GOODYEAR
AEROSPACE

LETTERS

Sirs:

Philip Morrison's review of *The Roots of Civilization* [SCIENTIFIC AMERICAN, July] states that the book is "a pioneer, a beauty and a new door ajar."

May I nevertheless offer two corrections? The book is reviewed as though its primary concern were with prehistoric lunar calendars. This is not the book's major concern. The book presents a mass of analytic data and images dealing with the spectrum of cognitive and symbolic systems of the Ice Age hunter. Among these systems the notations and calendars played a minor part.

The lunar "calendars," in fact, represent only one form of Ice Age notation. More than a dozen symbol systems were in contemporaneous use. These included notations of many types, each with its own semantics. These various systems are documented in the book. For this reason the review seems to be pointing to the umbrella stand within the "new door ajar" and not to what is really within.

Regarding the lunar notations, Morrison explains a few of the analytic steps I had taken in attempting to establish their calendric possibility. He writes that on two engraved examples the notation reaches "just 12 lunar months on one eagle bone and 13½ on the other. Thirteen and a half months? That touches the weak part of the impressive argument."

This type of variation is *precisely* that of the lunar "calendars" voluminously documented in the ethnographic literature (L. Cope, "Calendars of the Indians North of Mexico," 1919; W. R. Goldschmidt, "A Hupa 'Calendar,'" 1940; L. Spier, "Mohave Culture Items," 1955). Such variation is the essence of the prearithmetic tradition.

The North American Indian lunar "calendars" were not based on numbered years of 12 set months accurately following one another but were based on sequences of "moons" that were seasonally and phenomenologically named. This observational lunar "year" was either nine, 10, 11, 12 or 13 "moons" long. The 13-month year was quite common and a 13½-month notation could represent a year that began within the "moon" of the spring equinox and ended officially with the full moon of the same month at the next spring equinox.

In the continuing analysis and evaluation of the Ice Age cultures at a remove of 20,000 years and more it would be wise to avoid ethnocentric assumptions based on our culture and usage. This holds particularly for our modern, ordered, arithmetical calendar round.

ALEXANDER MARSHACK

New York, N.Y.

Sirs:

If I may lift a phrase from the gentle Niels Bohr, Alexander Marshack and I agree more than he thinks. After all, the review said: "A general reader comes easily to a verdict: There *is* abstract symbolism in the Old Stone Age."

I fear I remain unregenerate in my integricentric view that, while 13½ *could* be many things, it could not be, for example, nine, 10, 11, 12 or 13.

P. MORRISON

Cambridge, Mass.

Sirs:

Thanks for the piece about the SALT I agreement ["Science and the Citizen," SCIENTIFIC AMERICAN, July]. I wonder about those "obvious gains registered."

Twenty-six years ago it was widely understood that deterrence cannot provide a rational preventive for nuclear war. If, say, Soviet bombs were to destroy New York, then it would be too late to restore it to life, and a rational U.S. soldier would withhold his finger from the button to destroy Moscow. So much the more so if all that the Soviet bombs had destroyed were some hardened silos. The point seemed clear, and it was expounded in what seemed memorable form in Theodore Sturgeon's science-fiction story "Thunder and Roses."

Since then the story has been forgotten and the insight has been lost sight of. A generation of strategists have made careers of erecting theoretical nonstructures on the nonfoundation of deterrence. Their theory, unfit to produce rational conclusions, seems nevertheless to produce political consequences....

CHANDLER DAVIS

University of California
Berkeley

Sirs:

The article "Doctor-Patient Communication," by Barbara M. Korsch and Vida Francis Negrete [SCIENTIFIC AMERICAN, August], is excellent, but it does not mention the classic treatise by Stephen Potter, "Doctorship" (*One-Upmanship,* by Stephen Potter, London, 1952). Potter describes the natural "one-upness of doctors" ("Take off your shirt, please") and their use of elitist jargon to subdue the patient ("Nurse, get me a Watson-Dunn, will you?"). Most important, Potter outlines defensive procedures, including (a) name-dropping (by the patient) of other physicians who are, by implication, superior to the doctor, (b) the "Patient's Deskside Manner Counter to the Doctor's Bedside Approach" (for example, patient, during stethoscopic examination of chest, sings "I'm ninety-nine to-day, I'm ninety-nine to-day"), (c) implied derogation of the doctor's professional qualifications (asking a surgeon if he is a psychiatrist). As Potter points out, however, retaliation by the doctor is to be expected, for example implication that the patient is illiterate (Physician: "That heart is a sort of pump... it goes squeez-o, squeez-o").

THOMAS H. JUKES

University of California
Berkeley

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NAME

NEW ADDRESS

OLD ADDRESS

Saab vs. Volvo

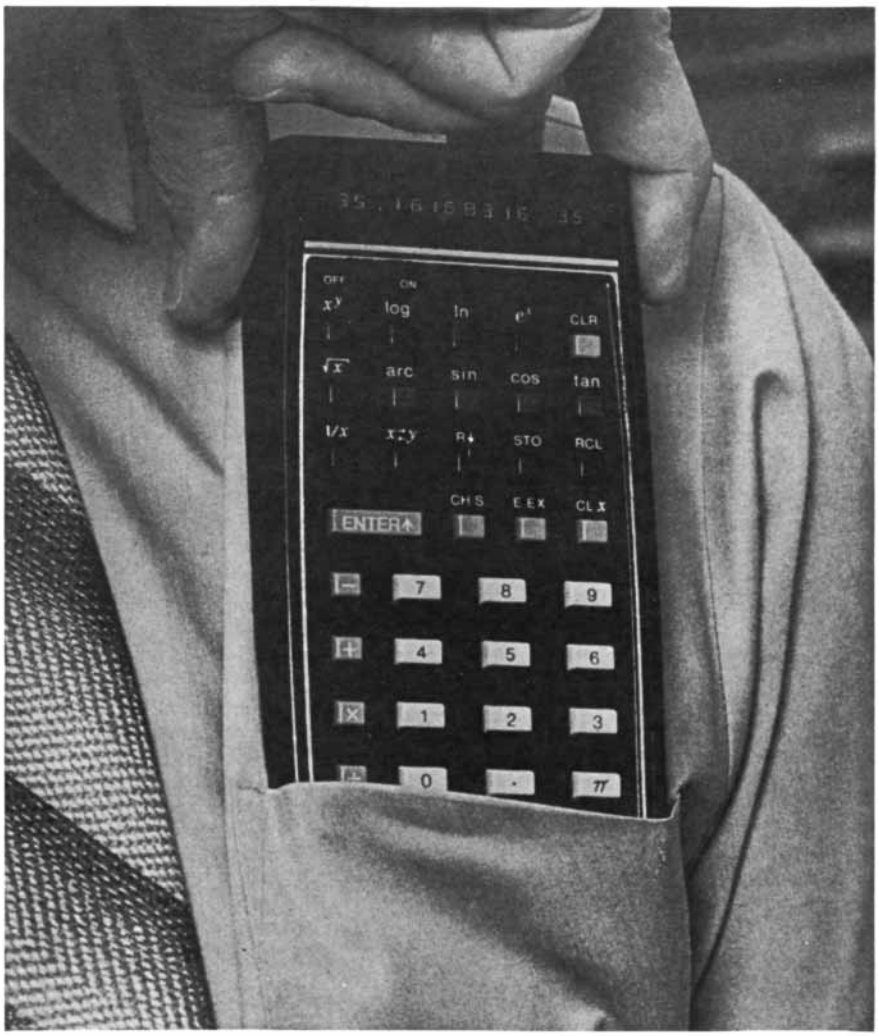
1972 Saab 99E, 4-door	Model	1972 Volvo 144 E, 4-door
4 cylinders, in-line, water-cooled	Engine Design	4 cylinders, in-line, water-cooled
Yes	Overhead Cam	No
95 hp (SAE) at 5200 rpm	Maximum Engine Output	125 hp (SAE) at 6000 rpm
113.1 cubic inches	Displacement	121 cubic inches
Yes	Electronic Fuel Injection	Yes
4-speed manual/3-speed automatic OPTIONAL	Gearbox	4-speed manual/3-speed automatic OPTIONAL
Yes	Front Wheel Drive	No
0 to 60 in 12.5 seconds	Acceleration	0 to 60 – N/A
197 feet	Stopping Distance Maximum Load at 60 mph	185 feet
99 mph	Top Speed	N/A
97.4 inches	Wheelbase	103.4 inches
172 inches	Overall Length	182.7 inches
66.5 inches	Overall Width	68.1 inches
34 feet	Turning Circle Diameter	30.4 feet
3.5	Steering Wheel Turns, Lock to Lock	4
23.3 cubic feet	Trunk Space	23.6 cubic feet
2550 lbs.	Curb Weight	2677 lbs.
Yes	Electrically Heated Driver's Seat	No
Yes	Heating Controls for Rear Seat Passengers	No
Yes	Fold-down Rear Seat	No
Yes	Impact Absorbing Bumpers	No
Yes	Rack and Pinion Steering	No
Yes	Disc Brakes On All Four Wheels	Yes
Yes	Dual-Diagonal Braking System	No
Between rear wheels	Fuel Tank Location	Under trunk
1 year/unlimited mileage	Factory Warranty	1 year/unlimited mileage
$3,795	Base Price	$3855

Before you buy theirs, drive ours. Saab 99E.

All information compiled from manufacturers own printed material wherein it states, all specifications subject to change without notice. Prices listed exclude dealer preparation, transportation, state and local taxes if any. For the name and address of the dealer nearest you, call 800-243-6000 toll free. In Connecticut, call 1-800-882-6500.

Some things are changing for the better.

Many people know us as an instrument manufacturer: we make more than 2,000 products for measurement, test and analysis. Others know us as a computer company: more than 10,000 own our programmable calculators and computers. We prefer to think that our business is to serve measurement, analysis and computation needs . . . in science, industry, medicine and education. That is the rationale behind every new instrument, computer or system that we tell you about in these ads. This month:



The HP-35 Shirt Pocket Calculator lets you make complex calculations like this one approximately five times faster than with your slide rule . . . with 10 place accuracy . . . and without a single scratch note!

$$\alpha_H = 1 + [3\times10^{-2}](10^{7.21}) + [8.7\times10^{-3}](10^{2.16})$$

$$pH = -LOG\sqrt{\frac{1}{\alpha_H}\left(\frac{3\times10^{-2}}{10^{11.7}} + \frac{8.7\times10^{-3}}{10^{7.21}}\right)}$$

**Chemists will recognize this as a calculation of the pH of a buffer solution for the mixture of Na_2HPO_4 @0.03 M/ℓ. and NaH_2PO_4 @8.7 x 10^{-3} M/ℓ.*

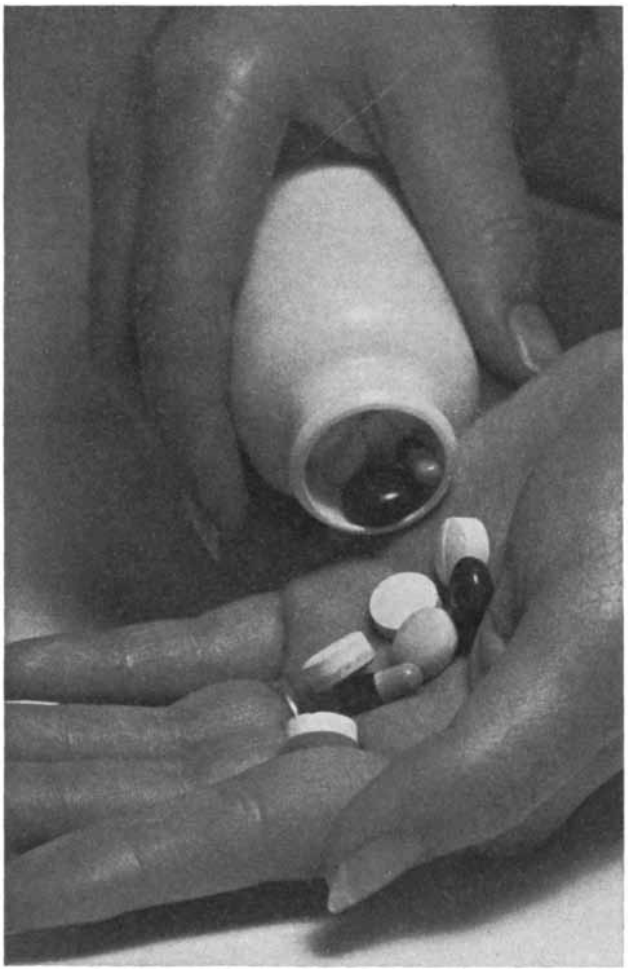
The new HP-35 Pocket Computer: a boon for scientists, engineers, or almost anyone.

When you first hear about it, it sounds like an electronic slide rule, the kind that's been available only in science fiction. Although it's only 3 by 6 inches and weighs 9 ounces, with rechargeable battery, it computes transcendental functions with a single keystroke, in less than a second. It calculates positive and negative numbers in floating point or scientific notation, automatically keeps track of the decimal throughout its 200-decade range, and displays answers that are accurate to the 10th significant digit.

And when you use it, you soon realize that it is more like a computer than a super slide rule. The secret is its 4-register operational stack. Solidly based on computer theory, it holds intermediate answers in a higher register and *automatically* brings them back when they are required for further calculations. The calculator also has a fifth register that lets you store any number and recall it to the working register at the touch of a key.

The power of our little wonder is illustrated in the calculation shown above. The HP-35 solves this problem in about 60 seconds and displays the answer to 10 significant digits, without a single scratch note.

The new HP-35 Pocket Calculator contains the equivalent of 30,000 transistors in specially designed MOS/LSI circuits. Yet it costs just $395 (domestic US price only). You may have to wait a while because demand has been so great. But if your people need this kind of computation power, it's worth the wait. Just use the coupon and we'll send full information to you.

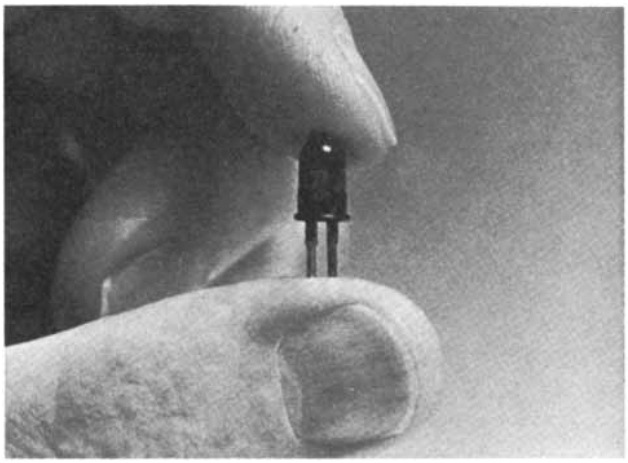


A faster, more efficient way to analyze drugs.

Not much can happen – neither emergency treatment for a drug overdose victim, nor prosecution of the pusher – until the drug has been positively identified. In large cities, where drug emergencies often reach into the hundreds daily, the chemist faces an enormously difficult problem, especially with traditional methods of chemical analysis. But there is a better way.

A laboratory in Charlotte (N.C.) recently sent us some powder from a confiscated pill for analysis on the new HP Gas Chromatograph/Mass Spectrometer/Computer System. Twenty minutes later, the analysis was complete: the pill contained heroin, morphine, and barbituric acid.

Fast, complete and positive, the analysis satisfied all medical and legal requirements. The HP system also takes a load off the lab's scientific staff because it can be successfully operated by technicians who have no special knowledge of mass spectroscopy or computers. The computer itself controls the operation of the spectrometer and records the mass spectrum while it makes all the necessary calculations, automatically. It can also compare the results of the analysis against a taped library of suspected components (in this case, a library of the mass spectra of 100 dangerous drugs) and automatically identify each of the sample constituents by name, positively. Where drugs are involved, that's an essential requirement. Just check the coupon for full information.



Try our solid-state lamp, free.

When Thomas Edison invented it, the incandescent lamp was one of the brightest ideas ever. It still is, if your object is illumination. But for display or indication, the new solid-state lamps (LED's) win hands down: they last at least 10 years and use only a few milliamps of current.

Because we are convinced that hands-on experience with an LED surpasses any description, we'd like to send you one of our 5082-4400 Series free. Use it even once, and we'll wager you'll never use any other kind of display lamp again.

Our LED is a gallium arsenide phosphide diode that's hard to ignore. You can see its red glow several yards away at any angle to 180°. It lights up when you connect a mere 1.6 volts to its rugged leads, draws only 2 to 10 milliamps, and includes a clip for easy panel-mounting.

Use the coupon to send for your free LED. If it turns you on, we're ready to ship quantity orders immediately.

For more information on the calculator, our systems or a free LED fill out the coupon and send to: Hewlett-Packard, 1510 Page Mill Road, Palo Alto, California 94304; Europe: P.O. Box 85, CH-1217 Meyrin 2, Geneva, Switzerland; Japan: YHP, 1-59-1, Yoyogi, Shibuya-Ku, Tokyo, 151.

00219

IF WE GOT A CALL TODAY AT 3PM TO BUILD A MID-OCEAN TERMINAL, WE COULD GO TO WORK ON IT AT 3:05.

It's night. And an English container ship slips out of its berth for America. That same night an American container ship sails for England.

But part of the English ship's cargo will never reach America. And part of the American ship's cargo will never reach England.

Instead, both ships will dock in the mid-Atlantic.

At a mid-ocean transfer terminal.

Here's why.

Both ships were loaded to capacity, but some of their cargo was bound for other destinations. So they off-load some containers and take on others.

Then each ship continues on, completely filled with cargo for one specific destination.

Think of it. Mid-ocean terminals for all the oceans on earth. And we could start to build them today.

Look at it this way.

We've been innovators in marine systems and shipbuilding for nearly a century. And today, we're the only shipyard that builds all three types of Naval nuclear ships. Submarines. Frigates. And carriers.

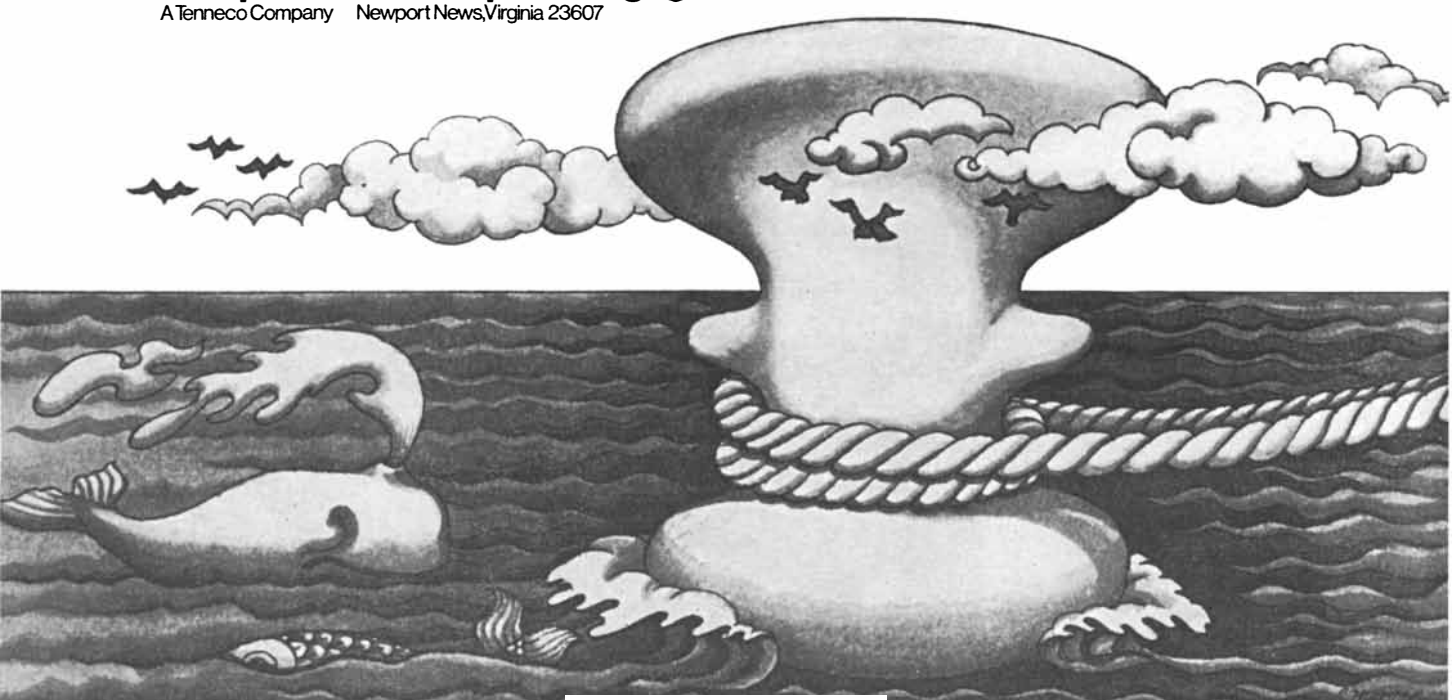
And our interest and expertise in commercial markets continues to expand. Especially in the marine and energy industries. From super oil tankers and high-technology liquefied natural gas carriers to components and services for land-based nuclear power plants.

So you see, we have the experience and confidence. Experience and confidence to go to work on tomorrow's marine systems. Right now.

Today the world has plenty of seaports. And tomorrow there will be plenty of ports at sea.

Newport News Shipbuilding TENNECO **Where tomorrow is. Now.**

A Tenneco Company Newport News, Virginia 23607



50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1922: "Seeing one's invention develop from a crude laboratory toy to a means of communication involving millions of conversations daily throughout the world—what more could an inventor wish for? Such was the experience of Dr. Alexander Graham Bell, who died on his estate, Beinn Bhreagh in Nova Scotia, on August 2. Dr. Bell, during his 75th and last year, lived to see broadcasting by radio—a more efficient, more expansive, more wonderful development than he would have dared to predict during his early demonstrations. Meanwhile the usual kind of telephone has become an everyday necessity. Bell's telegraphic aspirations have been exceeded by far. The operating of a typewriter keyboard at the transmitting end operates automatically a typewriter at the receiving end that types the actual telegram! All these things have come to pass in the short span of 46 years."

"The steam turbine is no longer a novelty, but of the man whose name is so intimately associated with its development the public has heard very little. Sir Charles Algernon Parsons was born on June 13, 1854, a son of the third Earl of Rosse. He was taught by tutors at his home in Ireland and was graduated from Cambridge in 1876 with high honors in the Mathematical Tripos. His knowledge of hydraulics convinced him that a thoroughly effective turbine motor could not be developed without moderate surface velocities and speeds of rotation. He decided to split up the fall in pressure of steam into small fractional expansions over a large number of turbines in series, so that the velocity of the steam nowhere should be great. From the first Parsons realized the possibilities of turbine propulsion for ships and devoted much study to the problem. The first large ocean-going ship to be fitted with turbines was completed in 1904. Twelve months later Mr. Parsons had the gratification of learning that the Cunard company had decided to install his system of propulsion in the twin ocean giants, *Mauretania* and *Lusitania*. Today its supremacy in the steam world is unchallenged, although there are indications that the internal-combustion engine will become a serious rival."

"With the production and sale of electron tubes for use with radio sets already reaching 300,000 a month, the new prospect of energizing these tubes directly from the lighting socket makes the subject of radio of even greater interest to the central station company. The National Bureau of Standards has now pointed out how vacuum tubes can be operated on the usual lighting current, thus doing away with troublesome storage batteries."

SCIENTIFIC AMERICAN

OCTOBER, 1872: "American genius stands preeminent in the development of mechanical appliances to supersede manual work. Invention to this end is the offspring of necessity in the United States, where the scarcity of hand labor has forced forward, to an almost inconceivable degree, human ingenuity. In this special branch of invention there can be no dispute that the Yankee can give the world long odds and beat him. There is scarcely an industry too humble, a labor too common to escape the attention of the inventor, who, with almost infinite ingenuity, sets himself to combine all the known mechanical movements and invent new ones, until the sleight of the hand of the operator is imitated to the life, and the dead metal is endowed with life and power with which flesh and blood cannot compete."

"There are several forces of which we have knowledge—heat, light, electricity, magnetism, attraction of gravitation, life. For many centuries these various forces were considered as so many distinct entities, but in our age it is understood that they are merely different manifestations of a single force. The identity of light and radiating heat has been distinctly demonstrated, as well as that of electricity and magnetism. Should we then preserve the two entities, force and matter, as having a distinct existence? Force and matter: these are abstract ideas serving to assist our comprehension of that which exists under a two-fold aspect."

"As currents of air and water act in accordance with certain unchanging laws, so tides of emigration and immigration are governed by stimuli presented by the natural and artificial advantages of different localities. To the mechanic, the artisan and the laborer our country presents inducements compared with most of the countries of the Old World that may be said to almost compel the influx of these classes. It is in vain, therefore, that the German government issues threatening circulars against emigrants and declares that they will be treated as outlaws over whom has been instituted special surveillance and supervision. There is room for them in our factories, our workshops, our industrial enterprises and our Western plains, and while there is room for them they will come."

"The petroleum oil producers of Pennsylvania have been holding conventions of late, and have finally agreed to suspend the pumping of oil and the drilling of new wells for a period of 30 days. The object of this movement is to secure an advance in the prices of crude oil, which at present are ruinously low, to wit $3 per barrel, placed on the cars. The total production of oil in this country is stated to be about 18,000 barrels per day, and there are now more than 900,000 barrels in stock. On account of this immense surplus the producers are able to keep the price of crude oil down. It is expected that by stopping production for 30 days the stock on hand will be reduced to somewhere between 400,000 and 500,000 barrels. The productiveness of the wells would not be more than 1,000 barrels per day on resuming, and the price of crude oil, it is calculated, would go up to $5 per barrel."

"The combined strike and lock-out in London, which has thrown the metropolitan building trades into confusion for the past 12 weeks, has terminated unsatisfactorily. Influenced by the general rise of prices and the increased demand for labor in the country, the London carpenters, joiners and masons demanded more wages and shorter hours, and as a matter of course these demands were stoutly, and not politely, resisted by the masters. The men demanded ninepence an hour and nine hours' work per day. At first all the building trades joined in the demand, and at one time there were between 10,000 and 12,000 men on strike in London. The masons, however, were the first to give way. They made, on their own account, without consultation or understanding with the amalgamated trades, arrangements with their employers on a modified basis of action. From that moment the strike phalanx was broken, and the prospects of a successful issue on the part of the men narrowed."

THE BIGGEST SELLING VS. THE BIGGEST SELLING

This year, millions of Americans will go out to buy their very first small car.

Many will find themselves confused as to which small car is best.

Which is why we think it might be helpful for you to know that in Europe, where they've been comparing small cars for three generations, they buy more Fiats than anything else.

Volkswagens included.

One of the big reasons for this is the Fiat 128, which we're bringing to America for the first time this year.

And to give you an idea of how good it is, here's how it stacks up, point by point, against America's favorite, the Volkswagen.

And not just the regular Volkswagen. But the Super Beetle.

OUR PERFORMANCE VERSUS THEIR PERFORMANCE.

The most obvious difference between the Fiat 128 and the Volkswagen Super Beetle is the engine.

Ours is in front—theirs is in back. We have front wheel drive—they have rear wheel drive.

Front wheel drive gives you better handling because the wheels that are moving the car are also the wheels that are turning the car. And also because pulling is a much more efficient way to move something than pushing.

Front wheel drive also gives you better traction on ice and snow. (As proof, last year, the Fiat 128 won the Canadian Winter Rally, which is run over ice and snow the likes of which we hardly ever see in the States.)

You'll also notice, if you glance at the chart on the right, that under passing conditions the Fiat accelerates faster than the Volkswagen. (If you've ever passed a giant truck on a highway, you know how important that is.)

Now, since engines alone do not determine how well a car performs, there are a few other subjects we'd like to cover.

For instance, the Fiat 128—which has self-adjusting front disc brakes—can bring you to a complete stop in a shorter distance than the Volkswagen, which does not have disc brakes.

Secondly, the Fiat 128 has rack and pinion steering, which is a more positive kind of steering system generally found on such cars as Ferraris, Porsches, and Jaguars. The Volkswagen doesn't.

And lastly, the Fiat comes with radial tires; the Volkswagen doesn't.

OUR ROOM VERSUS THEIR ROOM.

The trouble with most of the small cars around is that while they help solve the serious problem of space on the road,

SMALL CAR IN EUROPE
SMALL CAR IN AMERICA.

they create a serious problem of space inside the car.

And while the Volkswagen is far from the worst offender in this area, it still doesn't give you anywhere near the amount of space you get in the Fiat 128.

As you can see on the measurement chart, the Fiat 128 is a full 10 inches shorter on the outside than the Volkswagen. Yet it has more room on the inside than an Oldsmobile Cutlass, let alone the Volkswagen.

Compared to the Super Beetle, it's wider in front, wider in back, and 5 inches wider between the front and back seat. Which should be good news for your knees.

And in the trunk of the Fiat 128, where lack of room is taken for granted in small cars, you'll find 13 cubic feet of room. In the Volkswagen you'll find 9.2.

OUR COST VERSUS THEIR COST.

Aside from the fact that the Fiat 128 costs $167 less than the Super Beetle, there's another cost advantage we're rather proud of. According to tests run by the North American Testing Company, the Fiat 128 gets better gas mileage than the Super Beetle.

Now we don't for one minute expect that, even in the face of all the aforementioned evidence, you will rush out and buy a Fiat. All we suggest is that you take the time to look at a Fiat.

Recently, the president of Volkswagen of America was quoted as saying that 42% of all the people who buy Volkswagens have never even looked at another kind of car.

And we think that people who don't look before they buy never know what they've missed.

FIAT

ACCELERATION		
FIAT	20-50 mph	9.405 secs.
VW	20-50 mph	11.635 secs.
FIAT	40-70 mph	17.86 secs.
VW	40-70 mph	20.09 secs.
BRAKING		
FIAT	20-0 mph	13.2 ft.
VW	20-0 mph	14.6 ft.
FIAT	60-0 mph	139.7 ft.
VW	60-0 mph	155.2 ft.
BUMPER TO BUMPER		
FIAT		151.8 in.
VW		161.8 in.
FRONT SEAT–SIDE TO SIDE		
FIAT		53.50 in.
VW		46.0 in.
REAR SEAT–SIDE TO SIDE		
FIAT		49.875 in.
VW		47.125 in.
BACK SEAT–KNEEROOM		
FIAT		31.00 in.
VW		25.75 in.
COST		
FIAT		$1,992*
VW		$2,159*

*Manufacturer's suggested retail price, POE. Transportation, state and local taxes, optional equipment, dealer preparation charges, if any, additional. Overseas delivery arranged through your dealer.

THE AUTHORS

DAVID N. KERSHAW ("A Negative-Income-Tax Experiment") is vice-president of Mathematica Incorporated, where among other things he serves as director of the experimental project he describes. "The formation of an experimental group was interesting to me," he writes, "because it provided an unusual way to participate in policy making on important social issues. We have since expanded our group to include work on welfare reform, education, housing, health and experimental methodology. We work only for the Government and only on issues that we consider important from the standpoint of social policy." Kershaw was graduated from Williams College in 1964 and obtained his master's degree in public administration at the Woodrow Wilson School of Public and International Affairs of Princeton University in 1966. From 1966 to 1968, when he joined Mathematica, he was director of graduate admissions at the Woodrow Wilson School.

ARTHUR M. SQUIRES ("Clean Power from Dirty Fuels") is professor of chemical engineering and chairman of the department at the City College of the City University of New York. He has been concerned with physical chemistry since his university days (he obtained his bachelor's degree at the University of Missouri in 1938 and his Ph.D. from Cornell University in 1947), but he has also had a career as a professional musician, having been a founding artist of the New York Pro Musica, a chamber-music ensemble. After helping to set up the gaseous diffusion plant at Oak Ridge ("being," he writes, "the world's expert on the unsteady-state performance behavior of the plant") he spent a number of years with Hydrocarbon Research, Inc., and "was active in 'atomic politics.'" "[I was] saving the world from the atom from late 1945 until mid-1949, when I stopped suddenly with the intense feeling that I should work on problems that I thought I could solve." Squires's musical interest grew out of his activity as an amateur singer and led him to spend the period from 1953 to 1958 as a full-time artist with the Pro Musica. "I plotted the rise in number of concerts on semilog paper and was able to predict precisely the moment I would have to leave if I wished to protect my career as an engineer." For eight years beginning in 1959 Squires was a consultant, mainly on fluidized-bed processes. He joined the City College faculty in 1967.

JOHN CHADWICK ("Life in Mycenaean Greece") is reader in the Greek language at the University of Cambridge and fellow of Downing College. He has been teaching classics at Cambridge for 20 years. In collaboration with the late Michael Ventris he deciphered the Linear B script, which revealed the existence of Greek six centuries before Homer. Chadwick has also written on the history of the Greek language and the contribution linguistics can make to the reconstruction of prehistory. He was formerly on the staff of the Oxford Latin Dictionary and retains an interest in the problems of lexicography and the application of computer techniques to them.

GORDON S. KINO and JOHN SHAW ("Acoustic Surface Waves") are at Stanford University; Kino is professor of electrical engineering and Shaw is senior research associate and associate director of the Microwave Laboratory. Kino was born in Australia and received his bachelor's and master's degrees in mathematics at the University of London; his Ph.D. is from Stanford and is in electrical engineering. Shaw also has a Stanford Ph.D. in electrical engineering; he obtained his bachelor's degree at the University of Washington.

NORMAN KRETCHMER ("Lactose and Lactase") is chief of the division of developmental biology, professor of pediatrics and chairman of the program in human biology at the Stanford University Medical Center. He received his bachelor's degree in animal physiology at Cornell University in 1944, his master's degree and his Ph.D. in physiological chemistry from the University of Minnesota in 1945 and 1947 respectively and his M.D. at the State University of New York College of Medicine in 1952. He taught at the Cornell University Medical School and worked in pediatrics at New York Hospital from 1953 to 1959, when he went to Stanford. In 1970 and 1971 he was in Nigeria as visiting professor at the University of Lagos.

GEOFFREY EGLINTON, JAMES R. MAXWELL and COLIN T. PILLINGER ("The Carbon Chemistry of the Moon") are at the University of Bristol and also have worked together at the Lunar Science Institute, which is operated in Houston by the University Space Research Association under contract to the National Aeronautics and Space Administration. At Bristol, Eglinton is reader in organic geochemistry and head of the organic geochemistry unit; Maxwell is lecturer in organic geochemistry and research associate in the unit, and Pillinger is research assistant. Eglinton received his degrees at the University of Manchester: his bachelor's degree in 1948 and his Ph.D. (in chemistry) in 1951. Maxwell, who was born in Scotland, received his bachelor's degree and his Ph.D. from the University of Glasgow. Pillinger was graduated from the University College of Swansea of the University of Wales in 1965 and obtained his Ph.D. there in 1968.

ANN JAMES PREMACK and DAVID PREMACK ("Teaching Language to an Ape") are respectively a free-lance writer and professor of psychology at the University of California at Santa Barbara. Mrs. Premack received her bachelor's degree at the University of Minnesota and was an early member of the ape-teaching group. "Born and raised in Shanghai," she writes. "Passionately devoted to ballet. Enjoy the company of three teen-age children, one German-shepherd puppy and a myna bird." David Premack received his bachelor's, master's and doctor's degrees from the University of Minnesota. "Introduced to chimpanzee on first job at Yerkes Laboratories of Primate Biology in Florida in 1955," he writes. "Also work on reinforcement and learning theory. More exotic birthplace than Shanghai, namely Aberdeen, S.D."

CHRIS D. ZAFIRATOS ("The Texture of the Nuclear Surface") is professor of physics at the University of Colorado. He writes: "I made two false starts at college, flunking out the first time, then serving as a radio mechanic in the Air Force during the Korean-war period, then dropping out of college after two quarters when I returned to civilian life. I finally became serious about my education in 1954 and attended Lewis and Clark College in Portland, Ore. In the spring of 1957 I married my college sweetheart and took a bachelor of science degree from Lewis and Clark. During those college years I worked at various jobs including television repair, radio maintenance for a commercial airline and ski instructor. My wife, Joellen, worked in child welfare and helped to put me through graduate school until the first of our children was born in 1960. I took my Ph.D. in physics at the University of Washington in 1962." Zafiratos taught at Oregon State University for four years before going to Colorado.

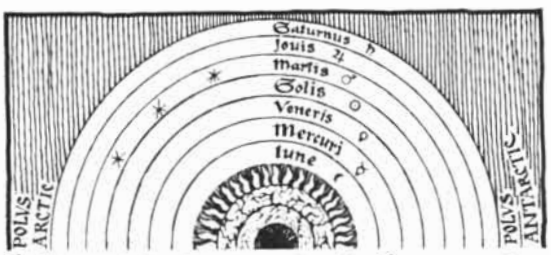
Conversation Pieces

Technically intriguing items from TRW, guaranteed to add luster to your conversation and amaze your friends.

How the Days Got Their Names — On Thursday, March 2, our Pioneer 10 spacecraft left for Jupiter, the first of the outermost planets. Although Pioneer travels so fast it swept past the Moon's orbit in a mere 11 hours, the voyage to distant Jupiter (a half a billion miles away) will take two years.

Pioneer 10's departure took place on a peculiarly appropriate day. Thursday, it happens, is named after Jupiter. In fact, it we look back through astronomical history, we find that every day of the week is associated with an object in our solar system.

Early astronomers named the planets after gods and goddesses, and believed that each planet "ruled" or had primary influence on one day of the week. Jupiter, they held, ruled Thursday and so named the day Jove's day, or *jeudi* in the French*. Our Anglo-Saxon forebears replaced the Roman Jove with their equivalent deity, Thor. Hence we know it as Thor's day or Thursday.



THE NAMES OF THE DAYS COME FROM THE PTOLOMEIC SYSTEM.

Here, for your information, is the complete planetary week. Woman's lib advocates will be pleased to note that we should thank a goddess it's Friday.

Day	*Ruling Planet/ Divinity*	*Anglo-Saxon Equivalent*
Monday	Moon	—
Tuesday	Mars	Tiw
Wednesday	Mercury	Woden
Thursday	Jupiter	Thor
Friday	Venus	Freya
Saturday	Saturn	—
Sunday	Sun	—

*Those of you familiar with the French will see the planet's names clearly in *lundi, mardi, mercredi, jeudi, vendredi,* and *samedi.*

Burn Coal (But Not Throats)! Must a high standard of living and low quality of life always go hand-in-hand? The argument for the case is as follows. A high standard of living requires the consumption of large amounts of energy (e.g., lights, air conditioners, cars, home appliances). In producing and using this energy, however, we pollute our environment. If the air you breathe is toxic or the water you drink causes you to retch, be happy; your discomfort is proof positive you have a high standard of living.

To add to this dilemma, our so-called clean sources of energy are dwindling fast. A logical replacement is coal, the Earth's most abundant fossil fuel. Yet coal is a major polluter. When burned, it produces sulfur dioxide, a gas noxious to lungs, eyes, and throats. In 1970, for example, the U.S. pumped around 28 million tons of sulfur dioxide into the air.

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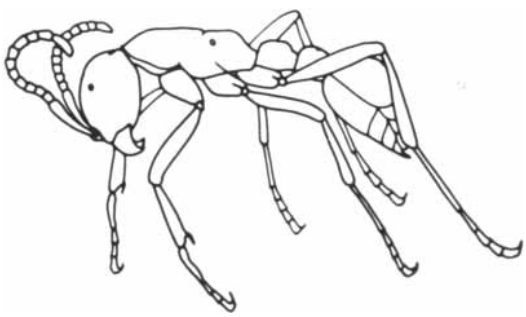

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JOHN O. LOGAN, PRESIDENT, UNIVERSAL OIL PRODUCTS COMPANY, DES PLAINES, ILLINOIS

Q: A UN Report in March said that mankind was in serious jeopardy due to adverse effects on the environment...

A: At the present rate, I believe vast areas of America could be virtually uninhabitable in a few decades.

Q: Ignoring theories, Mr. Logan, what can be done quickly?

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Q: Do cars account for nearly half the pollution in the nation now?

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A Negative-Income-Tax Experiment

Would payments to those who earned less than a certain amount reduce their incentive to work? The initial results of an unusual test with 1,300 families indicate that the payments would have no such effect

by David N. Kershaw

The welfare-reform proposals of both President Nixon and Senator McGovern embody the concept of the negative income tax: a downward extension of the income-tax system that would pay out cash (negative taxes) to families at the low end of the income scale. An essential feature of the concept is that as a family's income rises above the poverty level the tax payments are reduced by an amount less than the earnings, so that the family is always better off the higher its own earnings are. The concept was first presented to a broad public in 1962 by Milton Friedman of the University of Chicago, who argued that the negative income tax would strengthen the market economy and individual initiative by enabling poor people to make their own decisions on spending and saving and would cut back on the large and growing apparatus of social-welfare programs.

It is difficult to predict what the impact of a negative-income-tax plan would be on the people covered and on the economy. The word "experiment" is often applied to new social programs, but it is not used in the normal scientific sense. For the past four years, however, my colleagues and I at Mathematica Incorporated, working with a group at the Institute for Research on Poverty of the University of Wisconsin, have been conducting a more rigorous kind of social experiment to test the effects of a negative income tax. Money for the experiment was provided by the U.S. Office of Economic Opportunity. The main objective of the work has been to explore the key question about the negative tax, namely the extent to which it would reduce the incentive of the recipients to work. The extent of such a work reduction will determine both the actual cost of a new program and whether or not it is acceptable to the taxpayers. Our preliminary findings indicate that a negative income tax does not significantly reduce the earnings of the recipients. We think the findings also point to the value of social experimentation as a tool for policy makers.

The need for some such technique arises from the large sums that the Government regularly commits to the eradication of one social ill or another: additional housing for the poor, health facilities for the elderly, medical care for the indigent, school lunches for poor children and so on. Since the supply of skills and money for these activities is limited, the legislative process becomes essentially a system of bargaining or of trading off one set of programs for another. On what basis do Government officials recommend one set of programs rather than another? What criteria do legislators employ to measure the probable effectiveness of one idea as opposed to another? The fact is that there have been few effective ways for determining the effectiveness of a social program before it is started; indeed, in most cases it is impossible even to forecast the cost of a new social program until it has been in operation for some time.

Clearly this situation is not conducive to sound and effective decision making. Moreover, it results in such unforeseen disasters as the Medicaid scandals, empty public-housing projects and relentlessly increasing costs for welfare programs. Social experimentation of the kind I am discussing is a tool that has been developed and tested in the past five years for avoiding unanticipated developments in new social programs and for measuring in advance what the programs will cost.

What is usually unforeseen in a new program is how the people affected by it will behave. What they do, of course, is likely to have a profound effect on the program. For example, in the Medicaid program unexpectedly high fees charged by physicians and hospitals and unexpectedly high use of the services took policy makers by surprise. Various behavioral changes induced in the recipients similarly determine the cost and effectiveness of new income-transfer programs. Since most major social programs will induce changes in behavior, which in turn will affect the program, it is clearly vital for policy makers to understand the magnitude and direction of such changes in behavior in advance in order to make the most rational choices among new programs.

A social experiment as we view it has the same general design as an experiment in the natural sciences. One under-

takes to identify the experimental population, then to change one of the variables affecting its behavior and finally to compare its subsequent behavior with that of a control population in which the variable has not been changed. If the experiment is well designed, the investigator can attribute any difference in the behavior of the experimental population to the stimulus. The question we faced was whether or not this approach would work when the population consisted of human beings, when the laboratory was the community and when the stimulus was a complex new social program.

Our experiment was the first attempt to answer the question. The experiment has been conducted as the New Jersey Negative Income Tax Experiment because its first operations were in Trenton, although it was later extended to Scranton, Pa., as well as to three other cities in New Jersey: Paterson, Passaic and Jersey City. Negative-income-tax payments were begun in Trenton in August, 1968, and were ended in Scranton last month. The only part of the experiment now in progress is the analysis of the data.

The welfare-reform proposals of the two presidential candidates are among a number of negative-tax plans that have been advanced in recent years. Although the various plans differ in many ways, all of them are defined by two common variables: the guarantee level and the rate of reduction (sometimes called the tax rate) applied to the guarantee.

The guarantee is the amount paid to a family or an individual with no other income. In a negative-income-tax system the guarantee would be in effect a floor under incomes, providing a basic level of income for everyone. Various guarantee levels have been proposed, ranging from $2,400 annually for a family of four (the amount in H.R. 1, a House of Representatives bill incorporating the Administration's proposals for welfare reform) to $6,600 per year (advocated by the National Welfare Rights Organization).

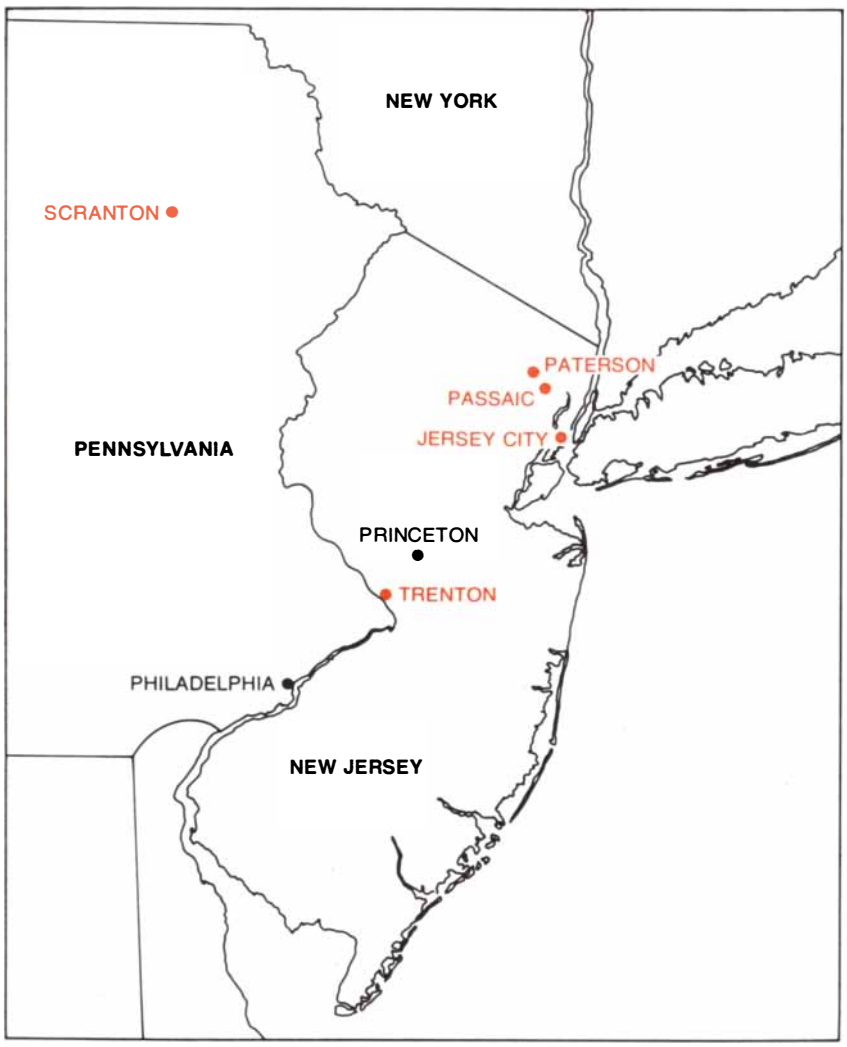
The rate of reduction is the rate at which the negative-tax payments are reduced as the family's other income rises. The reduction is always less than the amount of the rise in other income. That is to say, for each dollar of other income the family receives, the negative-tax payment is reduced somewhat, but not dollar for dollar. A dollar-for-dollar reduction formerly applied in welfare programs, and the rate in such programs remains high today.

The guarantee and the rate of reduction can be combined in many ways. Suppose the guarantee is $3,000 and the rate of reduction is 50 percent [*see illustration on opposite page*]. A family with no earned income receives the full $3,000, and the reduction is not applied. If in the next year the family's earned income is $1,000, the rate of reduction of 50 percent means that the negative-tax payment to the family is reduced by $500. The family now receives $2,500 in negative-tax payments and $1,000 of its own income for a total of $3,500. The reduction works just as the positive income tax works; in this example the family is effectively in a 50 percent marginal tax bracket.

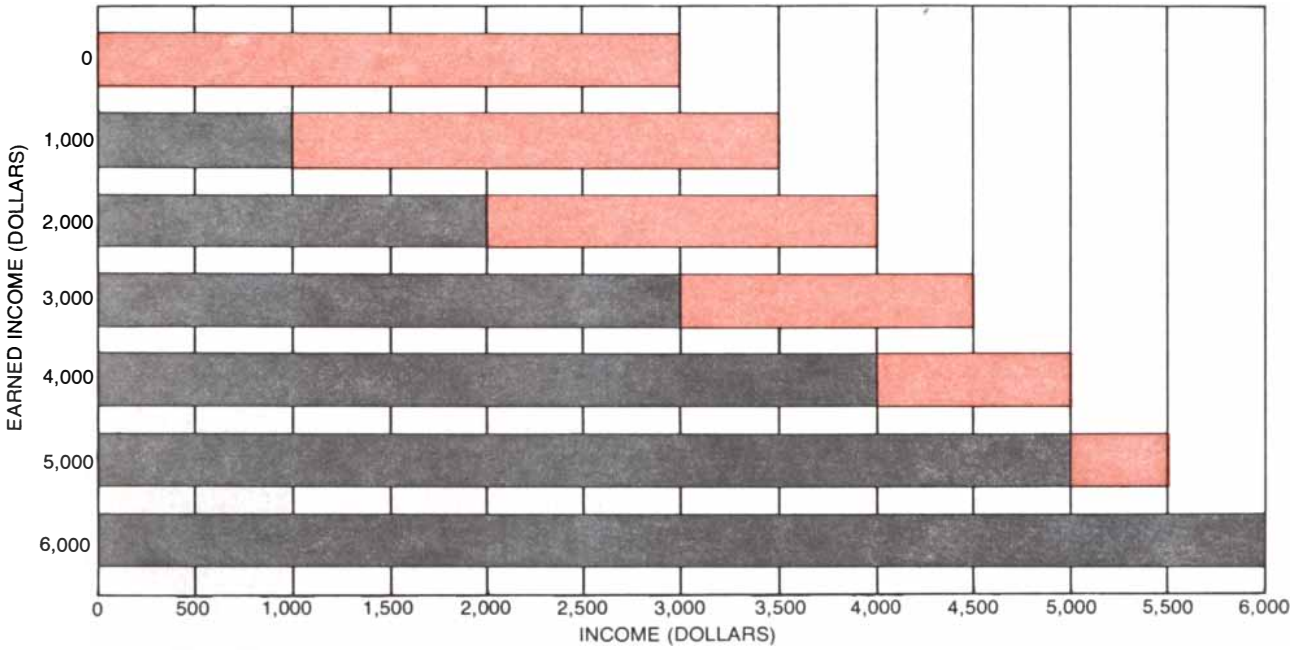
The key point is that the family's total income continues to rise as its earned income rises, notwithstanding the reduction in negative-tax payments. Just as in the positive-tax program, the family is always better off with a higher earned income. The point is important because it shows that the negative-income-tax system is designed to minimize the disincentive to work that has often been associated with welfare programs. People who are able to work keep a portion of their earnings just as people in the positive-tax system do.

In the example I have given, the family would continue to receive negative-tax payments until its own income reached $6,000. At that level the family would become a taxpayer rather than a tax recipient. As long as the level remained above $6,000 the family would receive no payments. If the income dropped below $6,000, the payments would be resumed.

Choosing the "best" combination of guarantee level and rate of reduction is a difficult problem. The two things one is most concerned with in a welfare sys-



FIVE CITIES (*color*) where the negative-income-tax experiment was conducted were chosen from the Northeast because it is densely populated and has many working poor people. An ethnic balance was also sought. The negative-tax payments began in Trenton in 1968.



RELATION between the guarantee (*color*) and the earned income (*gray*) is charted for a guarantee of $3,000 and a rate of reduction of 50 percent. The guarantee is the amount paid under a negative-income-tax plan to a family with no other income; the rate of reduction is the rate at which negative-tax payments are reduced as other income rises. The reduction is always lower than the amount of the rise in other income, so that the recipient is always better off by having earnings than by relying solely on the negative tax.

tem are (1) how much it will cost and (2) whether or not it will have a strong tendency to make the recipients disinclined to work. Unfortunately the objectives of low cost and minimum work disincentive are in direct conflict [*see illustration on next page*].

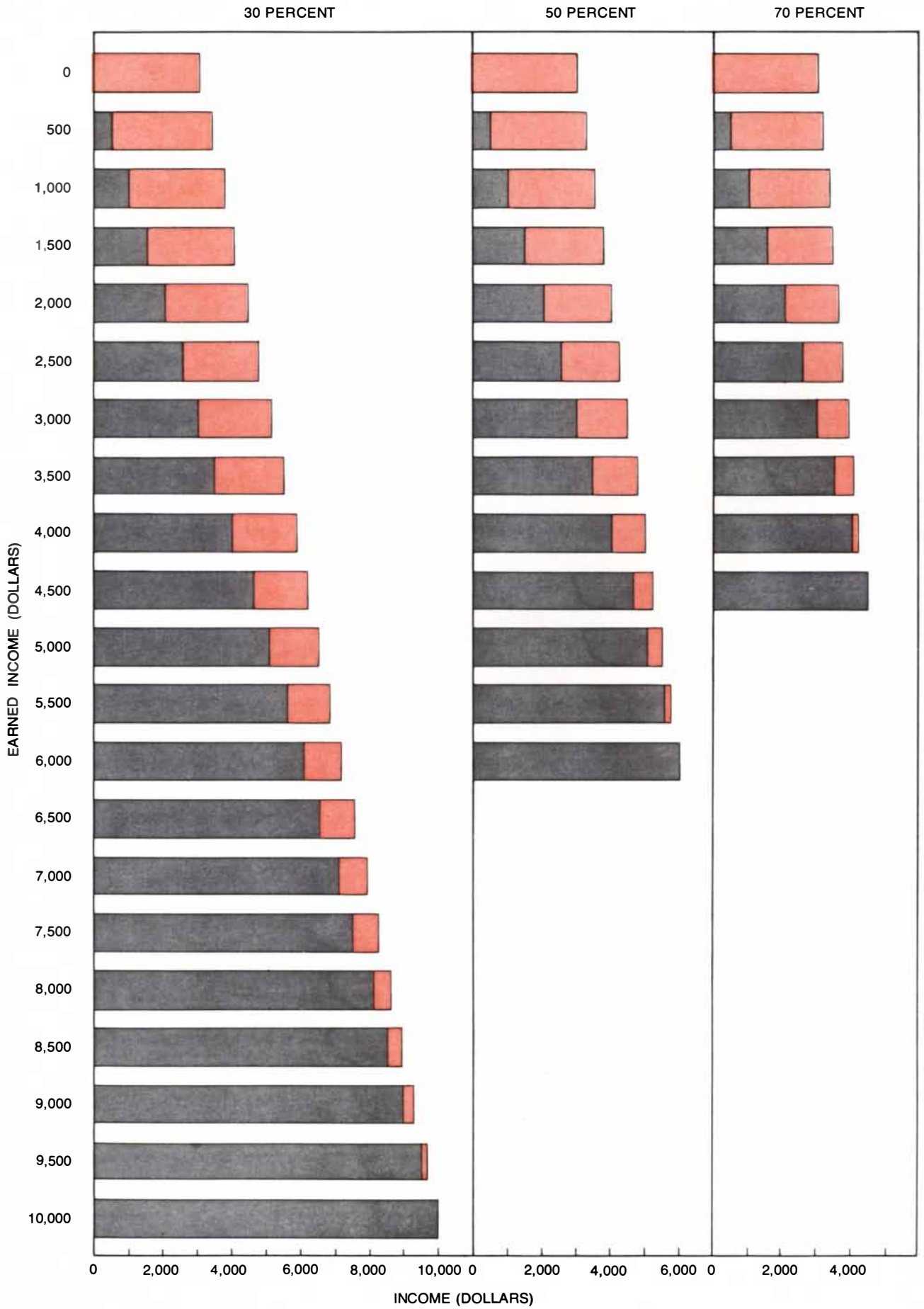
The problem is evident if one envisions plans applying rates of reduction of 30, 50 and 70 percent respectively to a guarantee of $3,000. At 30 percent a family would continue to receive payments until its earned income reached $10,000, which is close to the median income in the U.S. for a family of four. Under this plan half of the families in the nation would be recipients of negative-tax payments. Although the low rate of reduction would presumably keep the work disincentive low, the cost would be very high. On the other hand, a rate of reduction of 70 percent would keep the cost of the system down but could severely limit the incentive to work.

The problem of establishing an appropriate guarantee level and rate of reduction, of ascertaining the effect of various combinations on work behavior and of estimating the cost of a national program led to a decision by the Office of Economic Opportunity that a field experiment should be undertaken as a way of obtaining evidence. In 1967 the office gave money for the experiment to the Institute for Research on Poverty and to Mathematica, which has its headquarters in Princeton, N.J. These organizations shared the responsibility of designing the experiment and of analyzing the data, and Mathematica set up the administrative system.

The design of the experiment was focused on the work-response issue. Given a guaranteed annual income, how much, if any, would recipients reduce their work effort? The designers of the experiment decided that the population of most interest consisted of intact families among the working poor. The work response of single-parent families and of the aged and disabled were of less interest. Data on the work response of single-parent families were partly available through the program of aid to families with dependent children, and it appeared that the cost of a guaranteed income for the aged and the disabled could be estimated without a field test since the variability of their response to negative-tax payments was limited. For these reasons the designers decided that the sample for the experiment should consist of intact families with able-bodied males between the ages of 18 and 58 who were either in the labor force or physically capable of entering it.

A second major decision concerned the method of choosing the participants. The designers considered a national sample, which would consist of families chosen on a random basis from places in every region of the country; a "saturation" experiment, consisting of all the eligible families in a given area, and a "test-boring" approach involving a limited number of families from several geographic areas. It appeared that a national sample would cost too much and would be risky administratively in view of how little was known about conducting a social experiment of this kind. The saturation approach was rejected both for its cost and because it was difficult to see how data from a single area would be helpful in making generalizations about a national negative-tax program. We decided on the test-boring approach.

Choosing the site involved several considerations. The first decision was to concentrate on an urban area, since most of the working poor live in cities. Second, we focused on the Northeast because it is densely populated and is close to Washington, so that the Office of Economic Opportunity could more easily participate in the decision making. In the end we settled on New Jersey because it is densely populated and has a substantial number of poor people. Moreover, the state government was interested in the experiment. Trenton was chosen as the pilot site because it is close to Princeton (and so to Mathematica) and because as the capital of New Jersey it facilitated liaison with state officials. Paterson, Passaic and Jersey City were added later because they are fairly large cities, and Scranton was added because



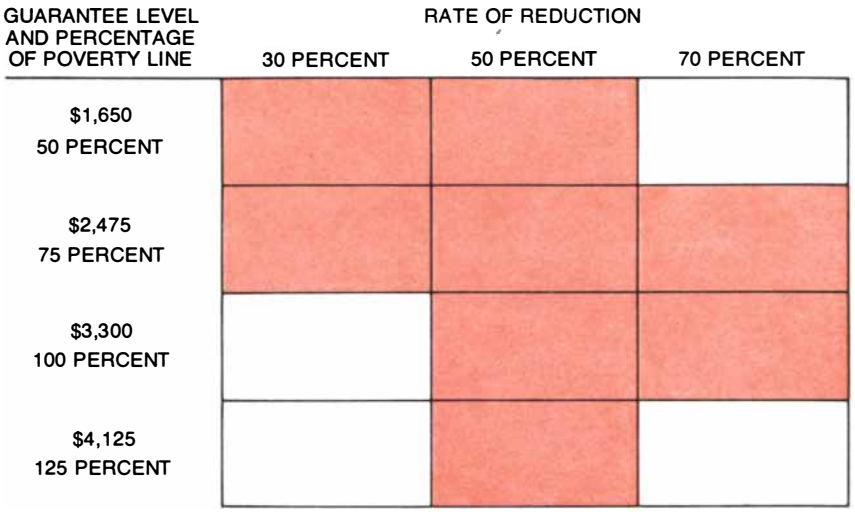
its preponderance of white residents would bring an ethnic balance to a sample that was otherwise largely black or Puerto Rican.

The selection of families was based on two preliminary interviews: a 44-question screening survey administered to about 30,000 families in the five cities and a 340-question "pre-enrollment" interview administered to 2,300 families. Both interviews obtained information on the composition of the family and on income. In addition the pre-enrollment interview provided baseline measurements of certain other sociological and economic variables.

The designers decided to test three rates of reduction: 30, 50 and 70 percent. The reasoning was that this group of rates covered the relevant policy range, inasmuch as a national program would never be designed with a reduction rate lower than 30 percent (on cost grounds) or higher than 70 percent (on work-disincentive grounds). Four guarantee levels were established, ranging from $1,650 (half of the official poverty level for a family of four in 1967) to $4,125 (125 percent of the poverty level). Eight combinations of reduction rate and guarantee level were established, and each one was designated as a "plan" [*see illustration on this page*].

More than 1,300 families have been involved in the program, although some have dropped out and are not reflected in our data. Somewhat more than half of the 1,300 families were assigned to one or another of the eight negative-tax plans. The other families constituted a control group that received no negative-tax payments, although they were interviewed periodically just as the experimental families were. A control group is necessary in order to be able to compare the families receiving payments with families of similar situation who are not. In this way the experimenter can be sure that random events in the cities are not responsible for the results he is measuring.

In order to participate in the experiment the families in the group receiving payments were required only to report their correct income and any changes in family composition. The reports, which we verified through various auditing procedures, were made every four weeks to the Council for Grants to Families, a corporate body set up by Mathematica and the Institute for Research on Poverty to process and disburse payments. On the basis of income reported to the council, families were paid every two weeks by check sent by mail from Princeton. The council also had an office in each of the experimental cities to answer questions from the families and from Princeton.



EIGHT COMBINATIONS of guarantee and rate of reduction employed in the negative-tax experiment are indicated by the colored squares. The "poverty line" was established in 1967, when the negative-tax experiment was designed, as $3,300 per year for a family of four.

Families were free to do whatever they wished with the payments. They also could move anywhere in the U.S. If a member left the original family unit, he or she still received a share of the family grant. Payments were excluded from taxable income under a ruling obtained from the Internal Revenue Service.

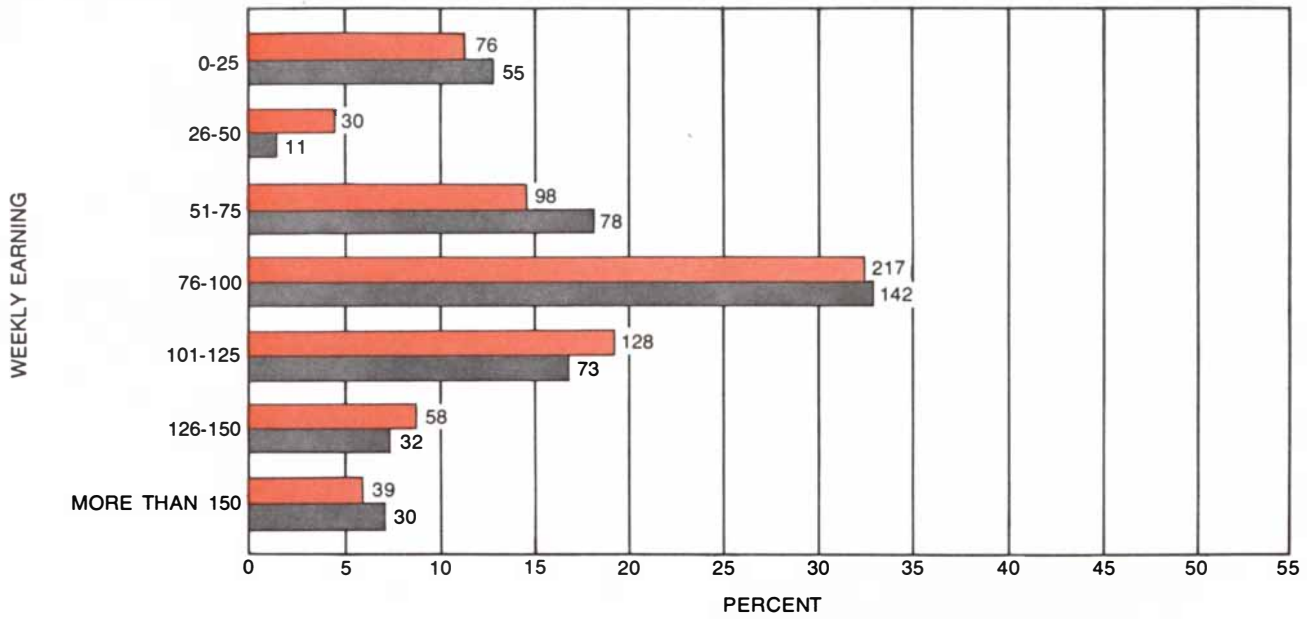
In addition to the income data on the forms mailed in by the experimental families every four weeks, information on the work response and other characteristics of the sample was obtained from interviews administered every three months by the Urban Opinion Surveys Division of Mathematica to both the experimental and the control families. The questionnaires sought information on such matters as participation in the labor force, financial status, medical and educational histories, family structure and political and social integration. Twelve such interviews were made, and a 13th quarterly interview was undertaken to ascertain what understanding the families had of the experiment.

We have now obtained a great deal of information about the 1,300 families. We shall be analyzing the results for another year. Unanalyzed portions of the data will be made available, under controlled conditions, to investigators over the next few years. Even though the analysis is not complete, we have reached a stage where it is possible to describe the principal results in a preliminary way.

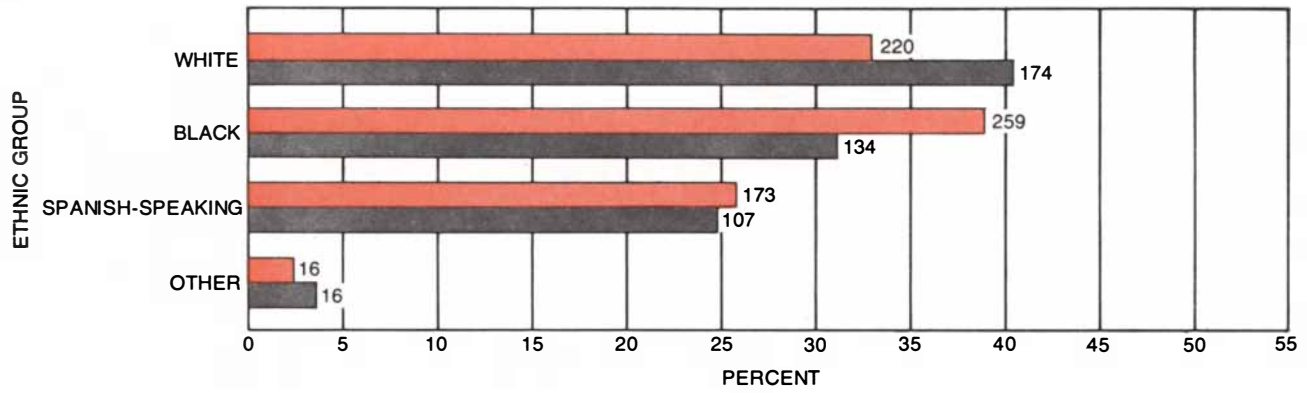
The most important results, of course, are those that bear on the work response. The question to be asked here is: How did the work behavior of the families in the experimental group compare with the work behavior of the families in the control group? The preliminary results give no evidence indicating a significant decline in weekly earnings as a result of the introduction of the payments [*see illustration on page 25*]. About 31 percent of the families in the experimental group showed earning increases of more than $25 per week, compared with about 33 percent of the controls. About 25 percent of the experimental families showed earning declines of more than $25 per week, compared with 23 percent of the controls. These differences are too small to be regarded as statistically significant. That is a most encouraging finding.

A second finding in terms of work response was identified when improvements in the computer system enabled us to analyze indicators other than earnings. One such indicator was the number of hours worked. An analysis primarily made by Harold Watts of the University of Wisconsin, who is the principal inves-

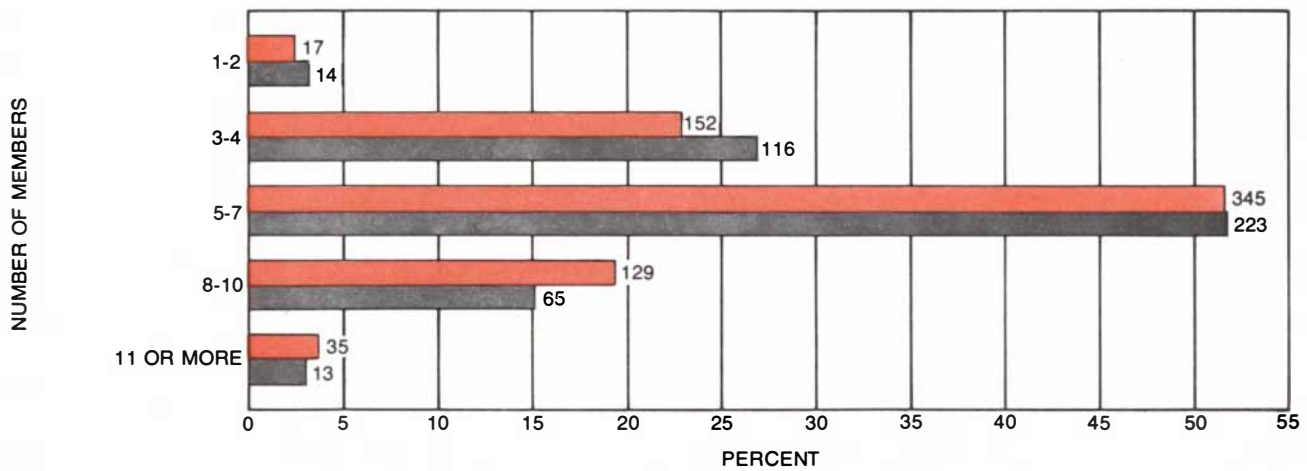
GUARANTEES AND REDUCTIONS are shown on the opposite page in various combinations. For each level of earned income the negative-tax payment (*color*) and the earned income (*gray*) are indicated for three rates of reduction. The problem in arriving at an optimum combination is that a low rate of reduction results in a costly negative-income-tax plan and a high rate tends to make the recipients less inclined to work to increase income.



WEEKLY EARNINGS of the families that received negative-tax payments (*color*) are compared with the weekly earnings of the "control" families (*gray*) at the beginning of the experiment. The control families received no payments but were treated otherwise in the same way as the families receiving negative-tax payments. Numeral at end of each bar shows number of families in the group.



ETHNIC DISTRIBUTION of the families in the experiment is indicated. The colored bars represent families that received negative-tax payments and the gray bars the control families. Until Scranton was added, most of the sample was either black or Puerto Rican.



FAMILY SIZE of participating families is charted. Again the colored bars represent families that received payments, the gray bars represent control families and the numerals give the number of families in each group. A member of a family who left the household after the beginning of the experiment continued to receive his or her proportionate share of the family's negative-tax payment.

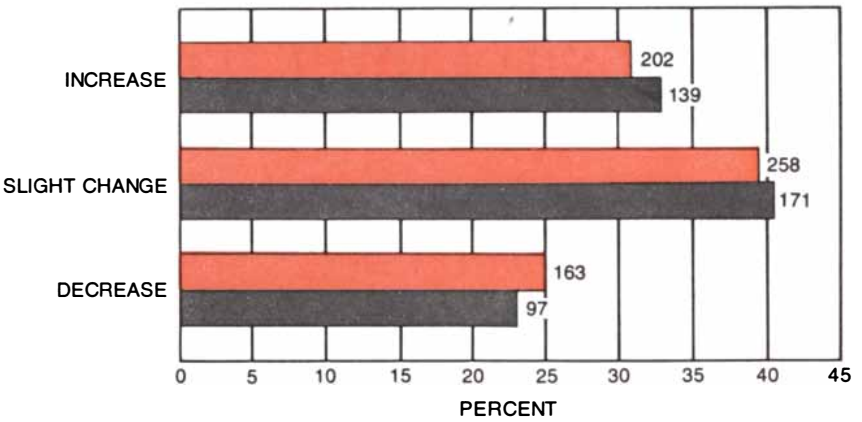
tigator in the experiment, showed that the hours worked by families in the experimental group are about 12 percent fewer than the hours worked by families in the control group. The difference is statistically significant.

Close examination reveals that about 40 percent of the difference is attributable to primary earners in the experimental group who worked less than primary earners in the control group. The reasons appear to be small differences in overtime pay, in periods of unemployment and in time spent on a second job. The remaining 60 percent is attributable to spouses and other adult workers in the family. Interestingly enough, it does not appear that these people are leaving the labor force in comparison to the control group; instead it seems that they are entering the labor force less rapidly. This observation suggests that the reason for the lower number of hours worked in the experimental group may be that people in those families take longer to look for better jobs. The availability of the negative-income-tax payment enables the worker to do that instead of having to accept the first job he finds.

The possibility that recipients spend more time looking for better jobs is a hypothesis; it may not be the actual reason for the reduction in hours worked. Attributing precise causes is a complicated process. Further analysis may provide answers. In any case a reduction of only 12 percent suggests that the introduction of a national negative-income-tax program will not give rise to a tidal wave of voluntary idleness. It certainly would be encouraging if people are reducing their work hours in order to look for better jobs.

We have also obtained information on the attitudes of the people in our experimental and control populations toward work. There would appear to be little reason for low-income workers to adhere to the "Protestant ethic." Why should they consider work a good thing? In the labor market they have met discrimination, low wages, poor working conditions and arbitrary layoffs. For some reason, however, the people we interviewed generally supported the idea of work. This attitude could prove significant if the nation undertakes to develop an income-maintenance system that provides a smooth transition from poverty to reasonable affluence.

It is conceivable that the most important and lasting result of the New Jersey experiment will be the support it provides for the idea of social experimentation. Although the experiment encountered a number of serious unforeseen problems, in general it worked: families were chosen and assigned to experimental or control groups, money was paid, interviews were conducted, data were assembled, analysis was done and results were sent to Washington, where policy makers used them. A more rigorous question is whether social experimentation is a cost-effective way of obtaining answers to policy questions.



CHANGE OF EARNINGS of families that received negative-tax payments (*color*) and of control families (*gray*) is charted for the first two years of the experiment. "Increase" means a rise of more than $25 per week, "slight change" a rise or fall of less than $25 and "decrease" a decline of more than $25. Since the comparisons are so close, there is no statistically valid evidence that the payments curbed the recipients' incentive to work.

The weaknesses of the method are fairly clear: it is an expensive way of gathering information (the cost of the New Jersey experiment will be almost $10 million in the end); it takes a long time to get results, since measuring human behavior with confidence requires at least several years, and it is difficult to control the environment of the experiment. The strengths of social experimentation as a policy tool are also rather clear: it is the only way to obtain information on some kinds of behavioral change before a new program is introduced; it is the best way to collect precise information on specific issues because it is carefully structured and controlled, and it can help to focus the attention of able and imaginative scholars and professionals on new issues. On balance, social experimentation has thus far proved to be an effective new tool.

The New Jersey experiment has given rise to, or at least encouraged, a number of other social experiments. The rural negative-income-tax experiment, sponsored by the Office of Economic Opportunity and conducted by the Institute for Research on Poverty, covers 800 rural families in Iowa and North Carolina. The Department of Health, Education, and Welfare has provided money for income-maintenance experiments in Seattle, Gary, Ind., and Denver and also for the Vermont family-assistance-planning study, which was designed to explore the more important administrative issues in the Family Assistance Plan. The experiments in housing allowance, sponsored by the Department of Housing and Urban Development, give housing vouchers to poor families in several cities with the aim of studying the response of families and landlords, the demand and supply of housing and how a national housing-allowance program might be administered. The Office of Economic Opportunity is sponsoring an education-voucher demonstration and a health-insurance experiment. The education-voucher program seeks to measure the effect on communities and students of giving all parents in a particular area vouchers good for education at a school of their choice. In the health-insurance experiment about 2,000 families will be placed on various health-insurance plans to measure how the utilization of medical services changes in response to differences in the cost of medical care.

Other social experiments are under consideration. They involve such issues as child care, problems of income measurement and administrative techniques in cash-assistance programs. One can anticipate that an increasing number of policy decisions on major social programs will be made with the assistance of information obtained through social experiments undertaken to explore these issues and others yet unforeseen.

Clean Power from Dirty Fuels

Considerations of both efficiency and pollution control suggest that a major effort should be mounted to generate electric power with turbines operated on "power gas" produced from coal or oil

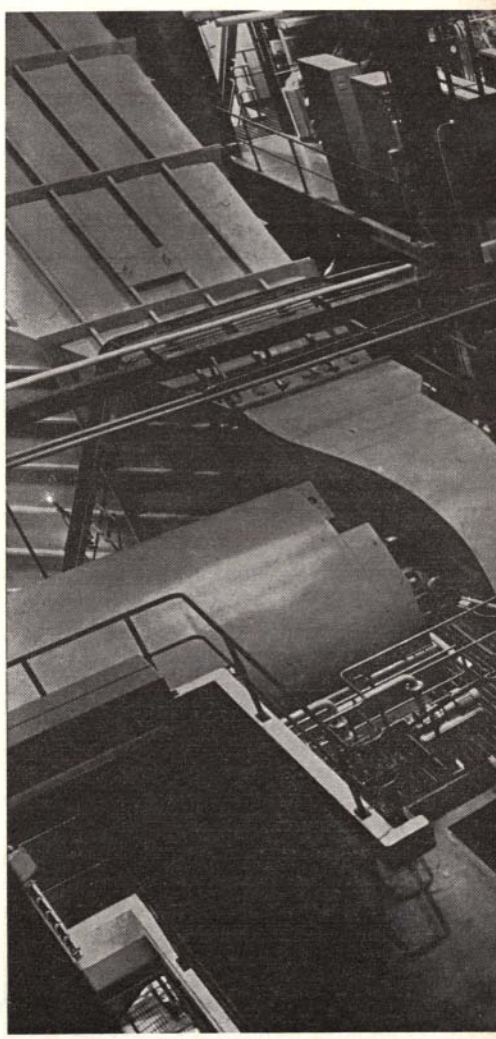
by Arthur M. Squires

Industrial nations face the need to curtail air pollution caused by the burning of dirty fossil fuels to generate electric power and at the same time a scarcity of clean fossil fuels. The main offender, sulfur, can in principle be removed from stack gases after combustion, but that is at best a difficult and expensive process; several once promising techniques intended to accomplish it have had to be abandoned and others are running into trouble. In this situation the question arises: Why not remove the pollutants before the power is generated, at an earlier stage in the combustion process?

A historic approach to clean energy doing just that is emerging as the best hope for dealing with pollutants from power generation with two dirty fossil fuels: coal and residual oil. The 19th-century industrialist sometimes needed to apply clean heat at high temperatures. He could not use the dirty products of coal combustion for such purposes as heat-treating metals or producing ceramics and fine glassware, and so he resorted to a two-step combustion process in order to obtain clean, intense heat. Instead of supplying air to a shallow bed of coal and burning the coal to convert its carbon and hydrogen into carbon dioxide and water vapor, he blew air and steam through a deep bed of coal to obtain a fuel gas composed mainly of carbon monoxide, hydrogen and nitrogen. Cooled and scrubbed with water to remove dust, the clean gas could be burned itself to provide the desired clean heat.

Even at the dawn of the age of electricity power engineers saw the possibilities inherent in two-stage combustion. Ludwig Mond, the great chemist and industrialist who dominated chemical technology in England until his death in 1909, made improvements in the production of what he called "power gas" and used it to fuel the reciprocating gas engines that generated electricity for his electrochemical works. At the time (1890) the reciprocating gas engine's 8 percent efficiency in converting fuel energy to electricity was not much less than that of the newly invented steam turbine, but the steam turbine made rapid progress. Mond worked on turbines that were driven directly by the hot gases of combustion rather than by steam, but he could not get very far because the metals then available could not withstand gas temperatures high enough to make the gas turbine competitive.

It was not until the 1930's that advances in metallurgy made the gas turbine feasible for some stationary power applications. The gas turbines powering military aircraft that appeared during World War II could handle gases at an inlet temperature of about 500 degrees Celsius. Spurred by the desire for improved aircraft performance, metallurgists have formulated a series of materials able to withstand ever higher temperatures. Moreover, techniques have been introduced for cooling turbine blades and other parts exposed to the high temperature of gases entering the turbine. As a result aircraft turbines of the latest design operate at 1,200 degrees C. during takeoff and at temperatures not much below that while cruising. Land-based machines can now be specified for steady operation at around 1,000 degrees or for operation at 1,100



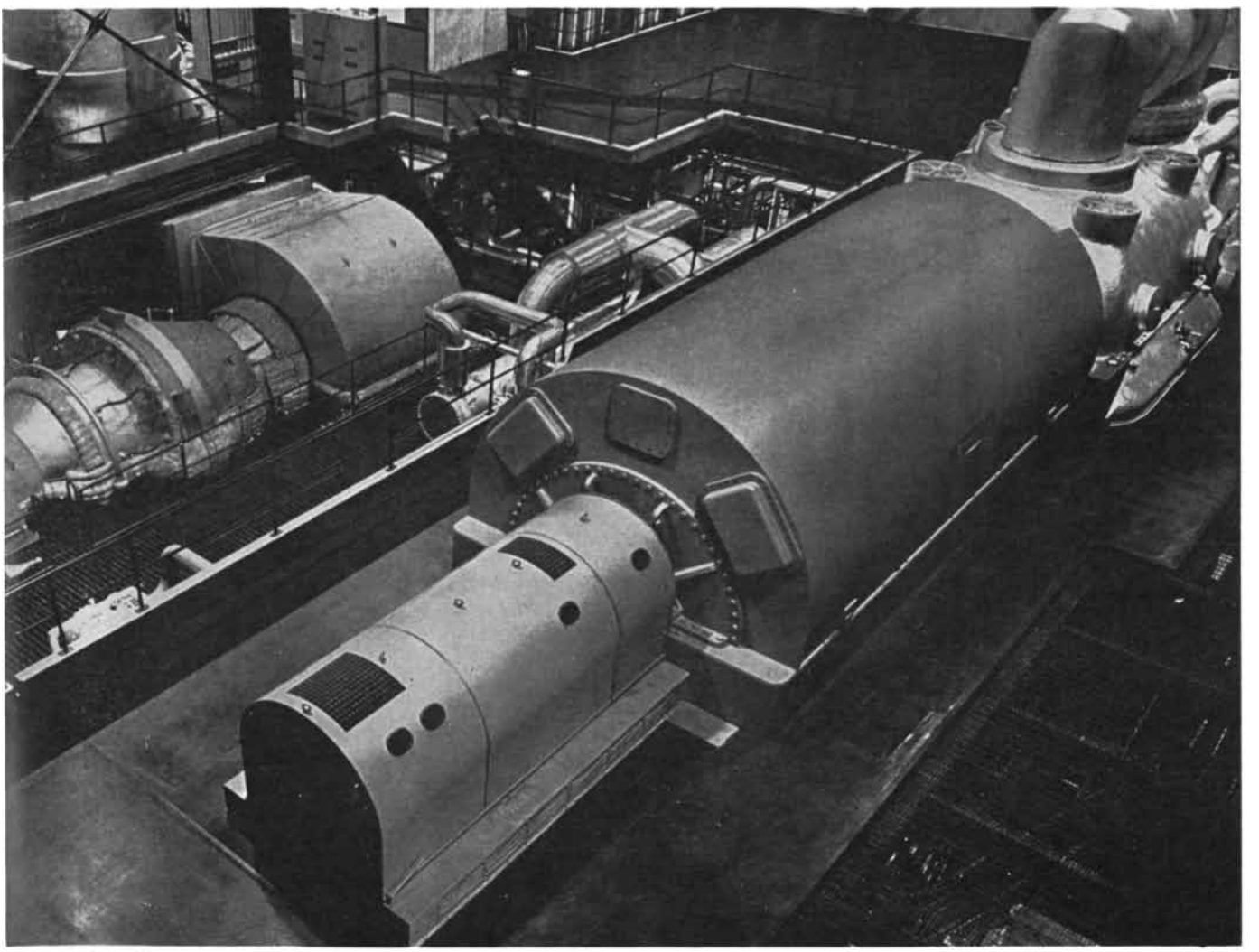
GAS AND STEAM TURBINES, rated respectively at 25 and 85 megawatts, are combined in a high-efficiency power plant operated by West Texas Utilities at Lake Nasworthy in Texas. The turbines and generators were made by the Westinghouse Electric Corporation. The gas turbine is at the upper center, the steam turbine at the top right; the generators are to the left of each turbine. Hot gases exhausted from the gas turbine are piped to a boiler to produce the steam that powers the steam turbine.

degrees if they are run intermittently to meet peaks in the demand for power. The steady advance in gas-turbine inlet temperatures can be expected to continue, according to engineers of the United Aircraft Corporation, who believe a temperature of 1,300 degrees can be attained in land-based machines within 10 years and up to 1,700 degrees by about 1990.

Gas turbines are also growing steadily in size. Units generating 80 megawatts are now available in Europe and the U.S.; the U.S.S.R. has a 100-megawatt unit; the General Electric Company is studying plans for units of 100 megawatts and larger. United Aircraft has proposed designs for 250- and 300-megawatt machines at projected costs of about $25 per kilowatt. This figure compares with not less than $75 per kilowatt for a steam boiler and steam turbine. (These costs exclude electricity generators and other power-station facilities.) Even at today's sizes and inlet temperatures a complete gas-turbine power installation costs only about half as much as a steam plant. As sizes and temperatures increase the advantage of the gas turbine should improve.

In spite of the gas turbine's advantage in capital cost, utility men tend to regard gas-turbine power as expensive because it requires expensive clean fuel, and so they utilize gas turbines primarily to supply peak-load power. If a gas turbine is run only about 1,500 or 2,000 hours a year, its low efficiency in converting fuel energy to electricity—commonly about 25 percent—is not an important negative factor. Moreover, for operation at only about 2,000 hours a year it does not pay to provide a boiler to capture heat from the hot gases leaving the turbine. On the other hand, if such a boiler is provided [*see illustration on next page*], additional power can be recovered with a steam turbine. Even at present gas-turbine temperatures such a gas-steam system has an efficiency beyond the 39 percent attained by the best existing steam-power installations. At the temperatures projected by United Aircraft, system efficiencies that are well over 50 percent appear to be within sight.

Such considerations create a strong economic incentive to find ways of providing gas turbines with a clean power gas made at high pressure from coal or residual oil (the relatively inexpensive dregs of the refining process). Technologies exist today, even though they are not ideal technologies because they were developed for other purposes, that can be exploited to build experimental installations immediately. It is important to realize that an economic incentive would exist for building such installations even in the absence of pollution advantages. In addition, however, gas-steam systems can provide electricity with absolutely no emission of dust. Moreover, they can be fitted at moderate cost with equipment to suppress emission of sulfur dioxide. Most fortunate of all, they will emit far smaller

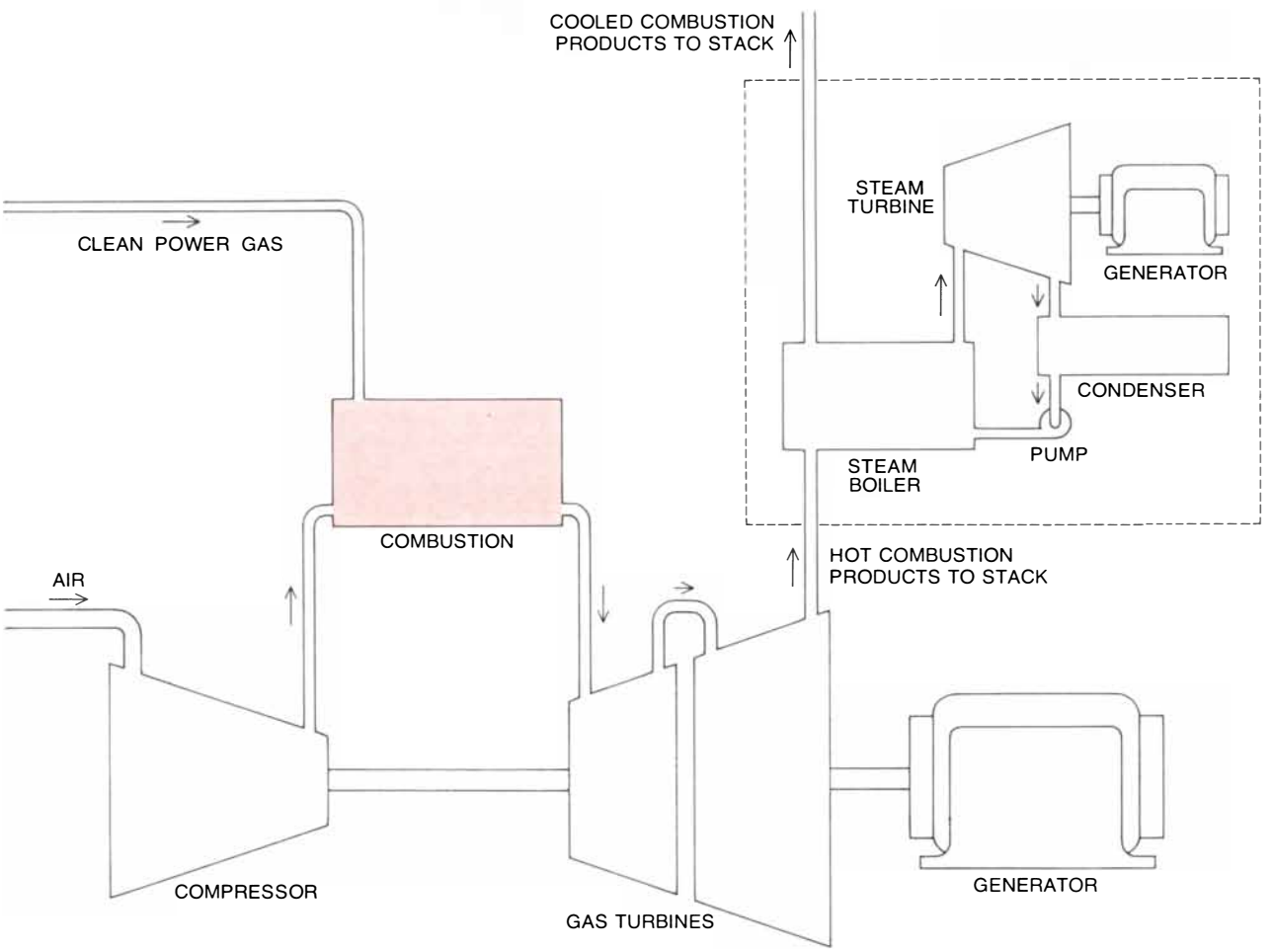


amounts of nitrogen oxides than conventional stations (probably by about two orders of magnitude). Because of their higher efficiency they will discharge less waste heat into the environment.

A feasible but imperfect method for producing power gas from coal already exists: the "gravitating bed" gasifier manufactured by Lurgi Gesellschaft für Mineralöltechnik in West Germany. Lurgi has built more than 50 units to provide town gas (for domestic use) or synthesis gas (for making gasoline) and is now putting into operation in Germany a pioneering installation to supply power gas to a turbine that will generate electricity at a rate of 74 megawatts. A steam turbine for 98 megawatts will operate in conjunction with the gas turbine.

In the Lurgi gasifier as it is adapted for power-gas production coal gravitates downward against a rising flow of air and steam introduced through slots in a rotating grate [*see illustration on opposite page*]. Directly above the grate oxygen in the air is consumed in a shallow combustion zone that converts the last carbon in the descending solid into carbon dioxide. Ash, typically containing a few percent carbon, is discharged below the grate. Hot gases (carbon dioxide, steam and nitrogen) rise upward from the combustion zone through the carbon bed, giving up heat to sustain the endothermic (heat-absorbing) reactions of steam and carbon dioxide with carbon to yield hydrogen and carbon monoxide. When the rising gases have cooled to about 700 degrees C., these reactions effectively cease. Further exchange of heat with the incoming raw coal drives methane and tars from the coal and cools the gases to about 500 degrees. The gases are then quenched with water to reduce their temperature to about 160 degrees.

Sulfur compounds, primarily hydrogen sulfide, can be scrubbed from the crude power gas by any one of several alkaline liquors at a cost far below the cost of scrubbing sulfur dioxide from the stack gases of a conventional power station. There are several reasons for the lower cost. Chemical methods for absorbing hydrogen sulfide are freer of troublesome complications than chemical methods for absorbing sulfur dioxide. Hydrogen sulfide can be converted more readily to elemental sulfur, the by-product a power station can most readily market (or stockpile in the absence of markets). The molecular quantity of power gas from the Lurgi system is only about 40 percent that of stack gas, and because the power gas is under 20 atmospheres of pressure its volume is only 1.7 percent that of stack gas. Rough cost studies indicate that equipment to desulfurize Lurgi power gas can be expected to cost less than $20 per kilowatt, compared with costs of from $40 to $70 for systems now being built to capture sulfur dioxide. Moreover, it should be noted that some of the sulfur dioxide



COMBINATION OF GAS AND STEAM TURBINES promises efficient power production with low pollution. Compressed air and a clean power gas are burned and the hot combustion products expand against the blades of the turbine. One section of the turbine drives the compressor, the other the generator. In most current gas-turbine installations spent combustion products are exhausted, with loss of efficiency. Availability of inexpensive power gas could make it economic to add a steam turbine, increasing the efficiency.

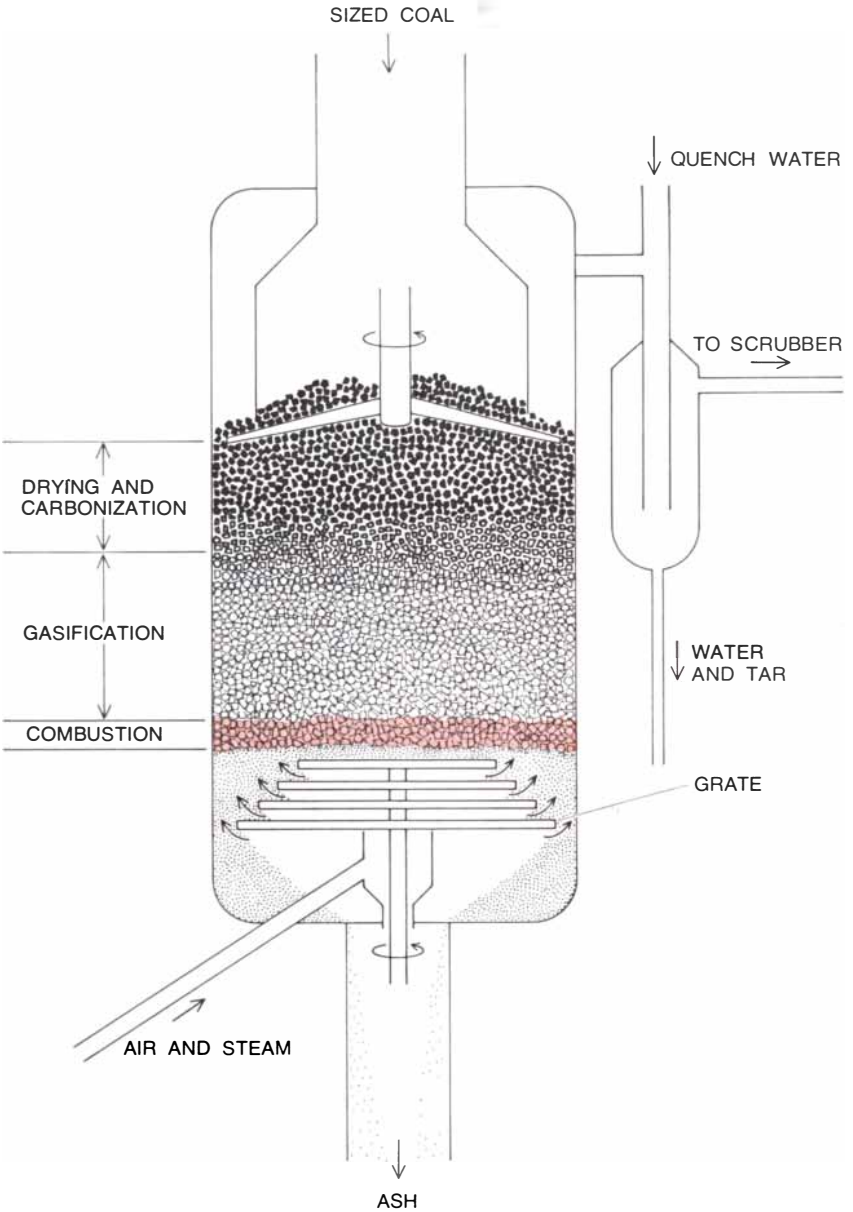
systems do not yield sulfur as a by-product and make it necessary to dispose of calcium sulfate. Others yield an undesirable by-product: sulfuric acid.

Although the Lurgi gasifier has been used on a wide range of coals, it may not be suitable for processing some strongly caking coals mined in the eastern U.S. The Commonwealth Edison Company of Chicago has engaged Lurgi to conduct engineering studies for producing clean power gas from Illinois coal, and one task will be to determine the suitability of moderately caking Illinois coal for use in the Lurgi gasifier. As an immediate stopgap answer to the pollution problem at an existing steam power station Lurgi proposes that clean power gas made at 20 atmospheres be let down in pressure through a turbine generating a relatively small amount of electricity and then be used to fire the station's steam boiler.

The Lurgi gasifier has some major faults. One is that the products of combustion of Lurgi power gas will contain a large amount of water vapor. The Lurgi system discharges ash in the form of a loose, nonagglomerated powder, and the temperature in the shallow combustion zone must be kept below a critical level (generally around 1,100 degrees) at which the ash will agglomerate and form clinkers. A large amount of steam must be supplied with the combustion air to keep down the combustion-zone temperature. Most of this steam is converted to hydrogen in the endothermic gasification zone above the combustion zone. Although hydrogen is a desirable constituent of town gas or synthesis gas, the original Lurgi objectives, it gives rise to an undesirable release of water vapor from the stack of a power station burning Lurgi power gas.

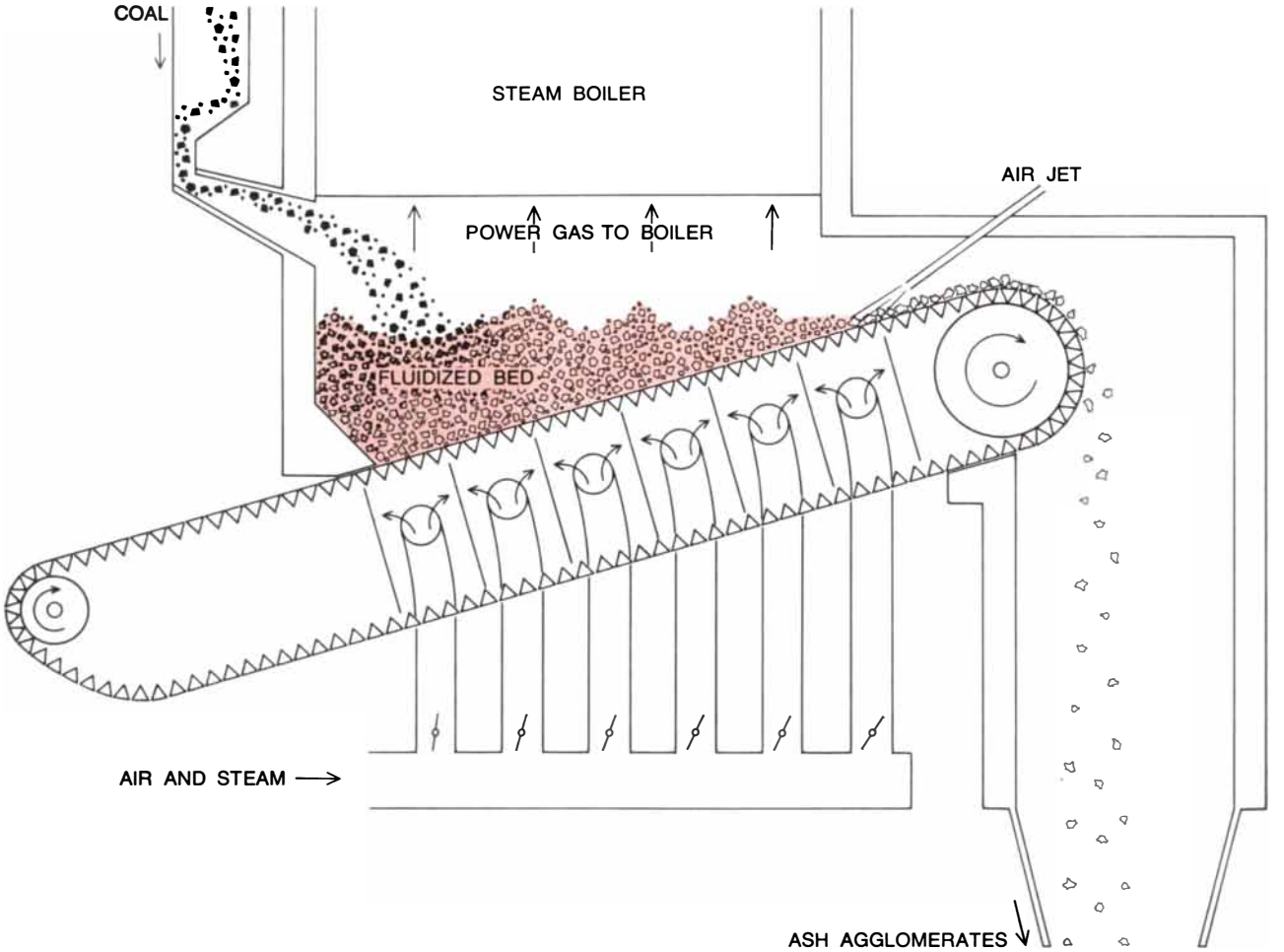
Still another input of water vapor arises from the necessity to quench the crude power gas from 500 degrees to 160. Rapid cooling of the gases is essential because they contain chemically active molecules that would polymerize to form heavy tars if the gases were allowed, for example, to pass slowly through a heat exchanger to raise steam. Such tars would deposit on the heat-exchange surfaces and crack to form coke, ruining the heat exchange and eventually plugging the passageway.

Another problem is that the Lurgi gasifier must be fed with coal from which particles smaller than an eighth of an inch have been removed. Therefore if the Lurgi system is to work on run-of-mine coal, a pelletizing or agglomerating step must be provided to deal with coal fines. Finally, the Lurgi system has a limited coal-processing capacity. The West German installation will require five gasification vessels 13 feet in outside diameter to provide power gas for an electric-generating capacity of 170 megawatts. Scaling up the Lurgi system to larger capacities may be difficult and uncertain.



LURGI GASIFIER can make a power gas from coal at high pressure with which to drive a turbine. The coal is treated in a "gravitating bed." In such a bed the descending coal is first dried and turned into coke by the hot gases rising from lower in the bed; in the next layer down carbon is gasified to yield hydrogen and carbon monoxide; below that the remaining carbon is burned to provide the heat for the reactions above. The gas is cooled and then scrubbed to remove hydrogen sulfide. The ashes are expelled by a rotating grate.

At the City College of the City University of New York, Robert A. Graff, Robert Pfeffer and I have been looking into a fluidized-bed process that offers possibilities for improvement on the Lurgi system. The fluidized bed provides an attractive technique for bringing run-of-mine coal, merely crushed to sizes smaller than about three-quarters of an inch, into intimate contact with air and steam. In a fluidized bed rising gases buoy up granular material, setting it in motion. Large-scale movement of the solid conveys heat from exothermic zones (such as a combustion zone) to endothermic zones (such as a zone for reaction of steam and carbon dioxide



FLUIDIZED BED, in which fuel is buoyed by a rising current of air, is utilized in the Ignifluid boiler developed by Albert Godel and Babcock-Atlantique in France. Coal is gasified with air and a little steam in a fluidized bed. The resulting fuel gas, mainly carbon monoxide and nitrogen, moves into a boiler, where it is burned with additional air to make steam. Godel found that in a bed operated at about 1,100 degrees C. and with air at a velocity of 10 feet per second ashes agglomerate and fall to traveling grate.

with carbon), so that the temperature of a fluidized bed is uniform [see "Fluidization," by H. William Flood and Bernard S. Lee; SCIENTIFIC AMERICAN, July, 1968].

A single fluidized-bed reaction vessel could easily provide power gas for 1,000 megawatts. A fluidized-bed gasifier can deliver gases free of tars or chemically active molecules that would polymerize to tars. No sudden quenching of the gases is required. The amount of steam supplied directly to the gasifier can be a small fraction of the steam needed for the Lurgi system because combustion heat generated near the air inlet is carried away by the motion of the solids. Moreover, there is a good chance that a fluidized-bed gasifier can convert substantially all the steam supplied to it into hydrogen and carbon monoxide, thereby reducing the water-vapor content of the power gas to an absolute minimum. Reducing the water vapor in power gas reduces the loss of latent heat and significantly increases the efficiency of the process [*see illustration on page 33*].

The hope that a fluidized-bed gasifier can thus make full use of its steam supply rests on data shown to me in 1958 by F. J. Dent, who was then director of the British Gas Council's research station at Solihull. Dent had fluidized coke with steam at atmospheric pressure in a small tube that was heated from the outside. He found that as he raised the temperature the utilization of the steam climbed to a value of 99.6 percent at 1,050 degrees C. The gas leaving the tube at that temperature was composed almost entirely of hydrogen and carbon monoxide. This was surprising, because only about 60 percent of the same amount of steam passed through a fixed bed of coke at 1,050 degrees was utilized. In the fixed-bed experiment the steam flowed downward through static granules of coke; in the fluidized-bed experiment the steam flowed upward, buoying the same quantity of coke granules and setting them in rapid motion. Dent explained the difference between fixed-bed and fluidized-bed performance by hypothesizing that each granule of coke in the fluidized bed was reactivated whenever the mixing of the solid in the bed brought the granule near the bottom, into contact with fresh steam. In the fixed bed, on the other hand, the static coke granules near the gas exit, where hydrogen and carbon monoxide left the bed along with unreacted steam, were continuously in contact with hydrogen, which is known to reduce the reactivity of carbon.

I did not see much commercial significance in Dent's data in 1958, because I thought I knew from my earlier participation in a large experiment in gasifying anthracite fines that a fluidized-bed gasifier working at 1,050 degrees

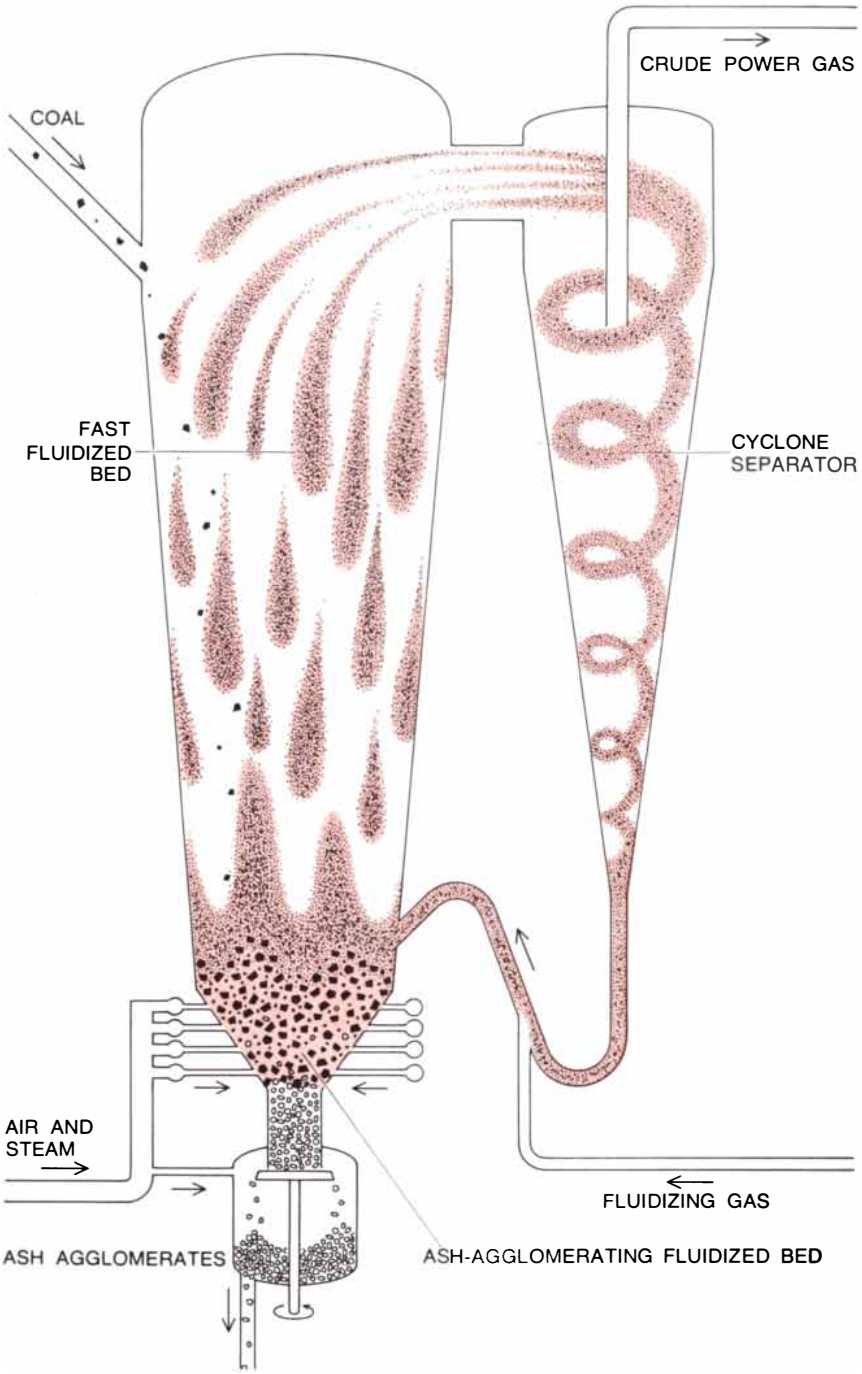
would be impracticable. The reason was that if the formation of ash agglomerates at this temperature was to be avoided, the solid in the bed would need to consist of a high percentage of carbon; I saw no way of removing ash from the bed without removing a large amount of carbon along with it. That would give rise either to a prohibitively large loss of carbon or to the necessity of gasifying or burning the carbon residue in an additional step.

What I did not know was that as early as 1955 Albert Godel of Paris had built an ingenious new boiler in which coal was gasified with air and a little steam in a fluidized bed resting on a traveling grate. Our experiment with anthracite had been at a fluidizing-gas velocity of about a foot per second, and any tendency for ash matter to agglomerate was quickly fatal. Godel, on the other hand, made the marvelous discovery that ash matter of substantially all coals forms agglomerates in a bed of coke at about 1,100 degrees that is fluidized by air at 10 feet per second. The ash agglomerates are roughly spherical and remain in motion until they grow to a size such that they sink to the traveling grate and are carried to an ashpit. Godel had therefore neatly solved the problem of separating ash from a bed of carbon, which had appeared to prevent the application of Dent's favorable levels of steam utilization.

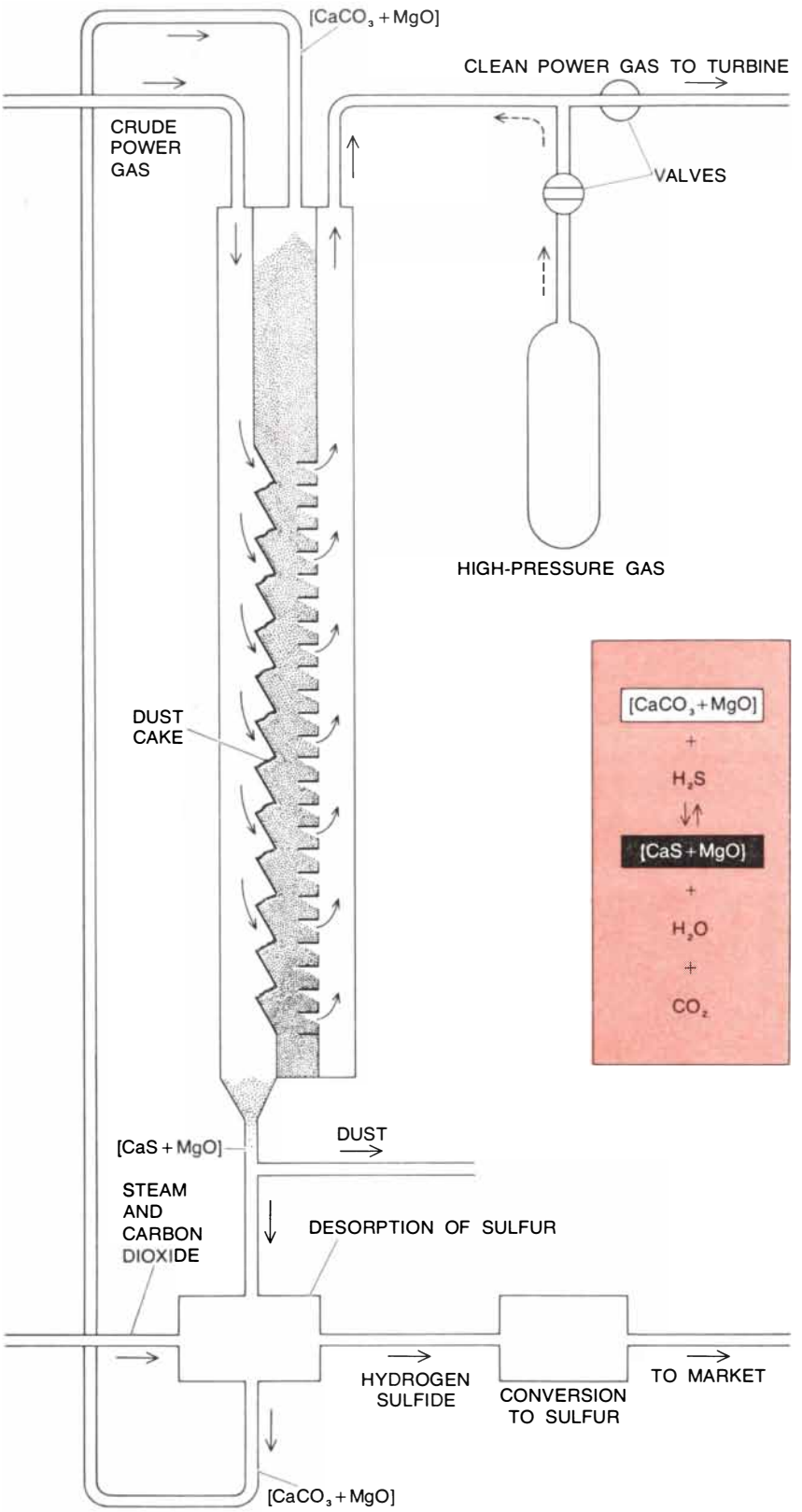
If our projected experiments confirm the hope that a fluidized bed at high pressure and 1,100 degrees can afford comparable steam utilization (or even merely utilization that is high in comparison with other gasification techniques), then the development of hardware to exploit Godel's discovery at high pressure would emerge as a goal of prime importance. In one possible design ash agglomerates would be removed from a shaft blown with air [*see illustration at right*]. Godel has used such a shaft to reduce the carbon level in ashes from relatively nonreactive anthracites with a high ash content. The conical bottom of the fluidized bed, fitted with a large number of horizontal pipes for the introduction of air and steam, has been used successfully by the British National Coal Board in a low-temperature coal-carbonization process.

As fine particles are released by the consumption of carbon a "fast fluidized bed" would be established in the upper part of the coal-gasification vessel. This is our name for a new fluidization technique developed recently by a second Lurgi firm. A fine powder is fluidized at a velocity much higher than would previously have been considered attractive for such a solid. The trick is to provide a large cyclone and a pipe to recirculate powder to the bottom of the bed. Powder flows at a large throughput upward through the region occupied by the fast fluidized bed, which lacks the sharply defined upper surface of the usual fluidized bed.

At City College we are also conducting experiments to determine the feasibility of cleaning power gas from our



FLUIDIZED-BED-GASIFIER DESIGN being studied by the author and his colleagues would exploit Godel's ash-agglomeration principle at high pressure. The clinkers sink through a central shaft into which air is introduced to burn remaining traces of carbon. In the ash-agglomerating bed above the grate, air and steam admitted through numerous spoke-like tubes fluidize and gasify coal, releasing fine carbon particles that are further gasified in a fast fluidized bed above. Particles blown out of the vessel along with the gas are collected in the cyclone separator and are returned, boosted by fluidizing gas, to the gasification vessel.



SULFUR AND DUST can be simultaneously removed from power gas by granules of half-calcined dolomite in a "panel bed" formed by louvers. The crude gas enters at one side of the bed, leaving a deposit of dust at the entry surface; the sulfur in the gas is absorbed by the dolomite and the clean gas leaves the other side of the bed. Sulfur-laden dolomite and the dust deposits are dislodged from time to time by a blast of high-pressure gas (*broken arrows*). The sulfur is removed from the dolomite as hydrogen sulfide and the sulfur-free dolomite is recycled. The equation (*right*) shows the reversible sulfur-dolomite reaction.

proposed ash-agglomerating gasifier at high temperature. Our hope is to find a technique for removing dust and hydrogen sulfide simultaneously by passing the dirty power gas through a bed of a granular solid derived from dolomite rock.

Dolomite is the double carbonate of magnesium and calcium: $CaCO_3 \cdot MgCO_3$. If the rock is heated gently, the magnesium carbonate decomposes to release carbon dioxide and form magnesium oxide. The resulting solid is a half-calcined dolomite, $[CaCO_3 + MgO]$. (The brackets are used to indicate that it is not a true chemical species but an intermingling of microscopic crystallites of calcium carbonate and magnesium oxide.) The solid is porous, so that all the crystallites are accessible to a power gas being treated for the removal of sulfur. We have found that the calcium carbonate crystallites in this solid are extraordinarily reactive to hydrogen sulfide. Since calcium carbonate is almost completely unreactive to hydrogen sulfide, it would appear that it is the porosity of the half-calcined dolomite that accounts for its reactivity. The absorption reaction can readily be conducted in reverse to desorb sulfur (as hydrogen sulfide) from the solid, which can then be used again.

The panel-bed filter we have developed for the desulfurizing reaction can also be highly efficient in removing dust [*see illustration at left*]. If the filter is operated at relatively low velocities, a cake of the filtered dust forms on the surfaces of the bed of granular solid where the gas enters the filter. We have observed efficiencies beyond 99.9 percent for the filtration of an airborne suspension of 1.1-micron particles through a cake of dust resting on sand.

Other techniques for gasifying coal must also be considered. Texaco Incorporated has studied a slagging gasifier in which finely powdered coal is reacted in a chamber with air and steam at high pressure; the company is said to have conducted a large test around 1957, but the results have not been published. The crucial questions have to do with the life of the refractory material lining the chamber and the efficiency of the utilization of carbon. If these are good, the efficiency of the Texaco gasifier can be expected to fall somewhere between the efficiencies of the Lurgi system and the fluidized bed. The City College techniques for cleaning power gas at high temperatures would be applicable to Texaco gas.

The Bureau of Mines and several research organizations under contract to the Office of Coal Research are studying coal-gasification techniques with the objective of producing pipeline gas, which is substantially pure methane. That is a more difficult task, for which one wants a processing scheme that maximizes the quantity of methane made directly from coal. This usually requires several steps in which the coal is brought into contact with gases, the flows of solid and gases being countercurrent. Such schemes are not useful for making power gas, since the exact heating value of power gas does not matter very much; the main objectives, instead, are to achieve simplicity and the lowest possible cost.

Power gas can also be produced from residual oil. In Texaco's "partial oxidation" process oil is reacted with oxygen and steam at high pressure to furnish synthesis gas (hydrogen and carbon monoxide) for conversion to ammonia. The Shell Oil Company licenses a similar process. An experimental installation in which the oxygen is replaced by air could provide early experience in firing a gas turbine with power gas made from oil.

An experiment in which oil is gasified with air at atmospheric pressure in a fluidized bed of lime is in progress at British Esso's research laboratories at Abingdon in England [*see bottom illustration on next page*]. The design of the fluidized bed is unsuitable for operation at high pressure, but the Abingdon chemistry might be conducted in another design, perhaps one incorporating a fast fluidized bed. Esso uses a roasting process to drive sulfur dioxide from sulfided lime; this unfortunately exposes the solid to such a high temperature that reactivity suffers, limiting its usefulness to only a few reaction cycles.

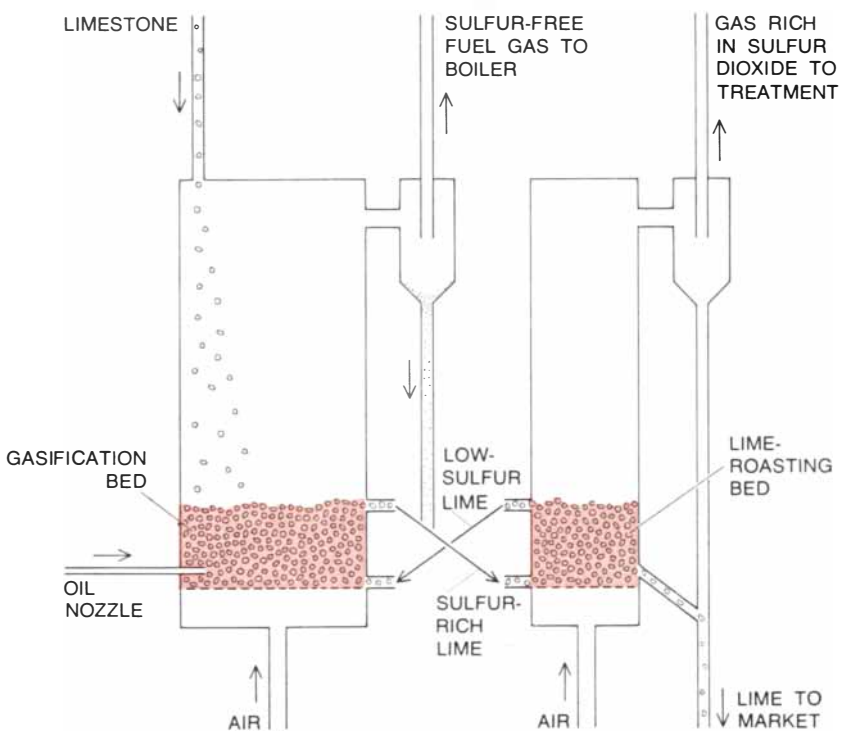
The Abingdon experiment has shown, however, that the hydrocarbons produced by cracking residual oil over lime

ENERGY BALANCE (COAL INPUT=100)	CONVENTIONAL STEAM BOILER AND STEAM TURBINE WITHOUT RECOVERY OF SULFUR	GAS TURBINE AT 1,538 DEGREES CELSIUS FOLLOWED BY CONVENTIONAL STEAM BOILER AND TURBINE WITH SULFUR RECOVERY	
		LURGI GASIFIER (GAS CLEANED BY SCRUBBING)	ASH-AGGLOMERATING FLUIDIZED BED (GAS CLEANED AT HIGH TEMPERATURE)
ELECTRICITY SENT OUT	39.5	45.0	50.5
HEATING VALUE OF SULFUR	0	1.0	1.1
LOSS OF SENSIBLE HEAT IN STACK GASES	5.0	4.6	4.7
LOSS OF LATENT HEAT (WATER VAPOR)	3.8	14.0	4.5
LOSS OF HEAT AT CONDENSER AND OTHER HEAT EXCHANGERS	47.7	28.4	35.2
LOSS OF UNBURNED FUEL AND HEAT LEAKAGE	2.0	5.0	2.0
MECHANICAL LOSSES AND POWER FOR AUXILIARY EQUIPMENT	2.0	2.0	2.0
EFFICIENCY, ALLOWING CREDIT FOR HEATING VALUE OF SULFUR	39.5 PERCENT	45.5 PERCENT	51.1 PERCENT

ENERGY BALANCES calculated for three systems demonstrate the advantage of improved power-generating machinery even with the Lurgi system and the further advantage of a new fuel-conversion system. In the first case the gain is the result of heat conservation; in the second case it is the result of reducing the water vapor in stack gases. The calculation of the final efficiency (*bottom*) of the systems represented by the two right-hand columns allows a credit for the heating value of the sulfur that is recovered.

COMPOSITION (PERCENT BY VOLUME)	LURGI GRAVITATING-BED GASIFIER	ASH-AGGLOMERATING FLUIDIZED-BED GASIFIER
METHANE	4.4	.5
CARBON MONOXIDE	10.7	31.8
HYDROGEN	15.7	15.6
CARBON DIOXIDE	10.7	.5
WATER VAPOR	27.8	.5
NITROGEN	30.2	50.4
HYDROGEN SULFIDE	.5	.7
HEATING VALUE (B.t.u. PER CUBIC FOOT)	129	157

COMPOSITION AND HEATING VALUE of crude power gas from the Lurgi system and a proposed fluidized-bed system are compared. The large water-vapor content of the Lurgi-system gas means a loss of latent heat; the high carbon dioxide content requires a scrubbing liquor that absorbs hydrogen sulfide rapidly but not carbon dioxide. The choice of a liquor is complicated by the fact that some sulfur in the Lurgi gas is in the form of organic compounds. The fluidized-bed gas is easier to clean and has a higher heating value.

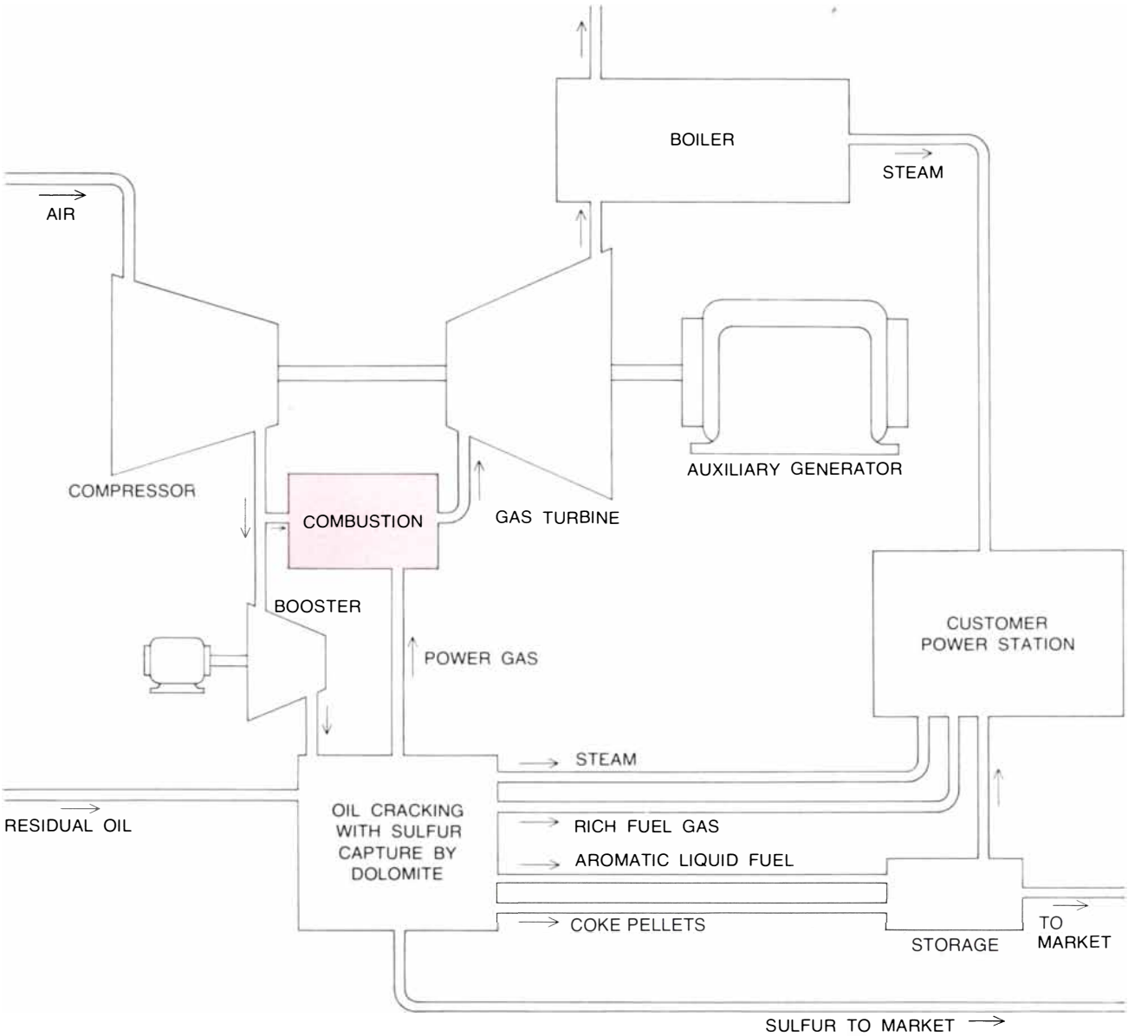


OIL IS GASIFIED at atmospheric pressure in a fluidized bed of lime in a system being developed by British Esso. Sulfur in the oil is removed as calcium sulfide and a clean hydrocarbon fuel gas is produced. The sulfided lime is roasted in a second vessel, releasing a sulfur-rich gas that is subjected to further treatment. The low-sulfur lime produced by the roasting can be recycled a few times but must be supplemented by makeup limestone.

are free of sulfur. This result is encouraging for the potential of a scheme we have studied at City College: a system for cracking residual oil in a coke-agglomerating fluidized bed that has a superposed, contiguous bed of fine dolomite. The process would yield pea-sized coke pellets of low sulfur content, a light aromatic oil and a rich fuel gas, and in addition a power gas that would fire the gas turbine that furnishes air to the process.

We call the system an "Oilplex," and we believe it illustrates an exciting opportunity for the power station of the future [*see illustration on opposite page*]. The station will include both gas-turbine and steam-turbine power cycles. It will be big. It will handle great quantities of fuel. Such a station will provide a new context for chemical processing in which the chemical engineer will play under a new set of rules. First, air at high pressure will be available "free" from the compressor of the gas turbine (or from an axial-flow compressor of the type used in a gas turbine). Second, the gas turbine will constitute a sink for excess gas at high pressure, including a lean fuel gas—even a gas so lean as normally to be considered incombustible. Third, the steam-raising system will constitute a sink for excess heat at temperature levels so high that its discharge would cause a serious loss of efficiency in normal chemical-engineering practice. The availability of such a heat sink will make feasible a broad range of new chemistries. These new rules constitute an invitation to invention, and I have no doubt that the power station of the future will become the scene for chemical operations leading to a greater efficiency in the utilization of fuel. In this context removing dust and sulfur from the power gas that is supplied to the gas turbine will seem to be a mere incidental.

The situation has an ironic aspect. The 19th-century industrial chemist habitually resorted to transformations brought about by the application of intense heat, but after 1900 research on high-temperature chemistry gave way to attempts to achieve chemical transformations with the aid of catalysts at ever lower temperatures. The new rules will revive interest in high-temperature chemistry. Perhaps we shall see a return to some historic technologies: the Brin process used for making oxygen between about 1885 and 1910, in which oxygen was absorbed from air by barium oxide; a pressurized version of the steam-iron process for hydrogen, as proposed by



"OILPLEX" SYSTEM would produce gas-turbine and steam-turbine power and marketable by-products and would be highly efficient. It is based on the cracking of residual oil at about 700 degrees C. and an elevated pressure and would yield three low-sulfur products: pea-size coke pellets, a light aromatic oil and a rich fuel gas. Each of these would be in a quantity equivalent to about a fifth of the oil's heating value. The remaining heating value would be available as high-level heat (steam) and as clean power gas for firing a gas turbine that compresses air for the system and provides auxiliary power. The rich fuel gas and steam would be used promptly to generate power; the light oil and coke could be stored for use during periods of peak demand or be shipped to market.

the Institute of Gas Technology; the shifting of carbon monoxide to hydrogen by the action of steam in the presence of lime, a popular development objective until about 1930.

The new rules will lead naturally to new kinds of fuel-processing complexes serving society's energy needs. Eventually it will become too wasteful to burn raw coal directly in order to generate electricity: the hydrogen chemically bound in raw coal will be too valuable simply to burn to steam and send up a stack as water vapor. In the end power generation must be based on a coke residue from an operation in which fuels of higher value are "creamed off" the raw fossil fuel. For example, a "Coalplex" might produce pipeline gas, a light aromatic liquid such as gasoline, electricity and low-sulfur coke for metallurgy. There might even be roles in such a complex for Mond's dream of a fuel cell that would convert power gas to electricity at an efficiency beyond 50 percent and for a magnetohydrodynamic electric generator operating on power gas made from coke. Such advanced techniques for the production of electricity will have to compete, however, with gas turbines that afford comparable efficiencies.

None of this will happen unless the engineering community devotes much more attention to fuel technology. Higher temperatures for gas turbines are on the way through the efforts of men now engaged in gas-turbine development and design, and will probably be achieved even without additional Government support. But good technologies for providing clean power gas will be developed only if a great deal more talent is recruited for the work, and probably only with a large input of Federal money.

PLEA FOR DIVINE HELP comprises the text scribbled hastily on this clay tablet discovered in the palace ruins at Pylos in the Greek Peloponnese. Only the reverse of the tablet is shown; the syllabic system of writing used for the inscription is the one known as Linear B. The tablet lists sacrifices to 13 gods and goddesses of the Mycenaean pantheon. Each deity will receive a gold vessel; a man will be dedicated (and probably sacrificed) to each of the two chief gods and a woman to each of the eight chief goddesses.

LIFE IN MYCENAEAN GREECE

When Pylos and Knossos were burned some 3,000 years ago, the notes written on clay by palace scribes were preserved by baking. These jottings provide a glimpse of how the Greeks lived before classical times

by John Chadwick

"Rowers bound for Pleuron.... Female slaves of the priestess on account of sacred gold.... Smiths with an allotment of bronze.... Masons who are to build.... Thus the woodcutters will contribute.... Thus Phygepris saw when the King appointed Augeas to be *damokoros*.... The private estate of Amaryntas...." These are some of the more striking phrases we can read on clay tablets written by the earliest literate inhabitants of Greece. What motivated their literacy? Why did the Greeks, long before they borrowed the Phoenician alphabet, adopt a clumsy and complex form of syllabic writing based on the Cretan system? The answer is simple: They needed to keep accounts.

No man willingly keeps accounts. So long as he can, he carries the figures in his head and guesses. A small farm can be run adequately, if not very efficiently, by an illiterate farmer. But if a number of small farms are united in a big one, and even more urgently if a number of tiny principalities are united in a small kingdom, the need for an accounting system arises and an expert who knows how to keep adequate records must be employed.

Although we can only guess at the details, small kingdoms seem to have begun to grow up in Greece around the 16th century B.C. All we can say for certain is that, at some time before the beginning of the 14th century B.C., the growth of these small states created the conditions that require bookkeeping. The requirement was met by borrowing a system of notation from nearby Crete, which was then the home of an alien and more advanced civilization. The Cretan system of writing, which we call Linear A, was crude but it was adequate for keeping rough accounts. The Greeks adopted and modified it. Using some 90 Cretan signs, they wrote down for the first time the sounds of their own language, syllable by syllable. The notation on the tablets these prehistoric Greeks left behind them we call Linear B. It seems safe to assume that by the 14th and 13th centuries B.C. every major Greek palace had a large staff of trained clerks who meticulously recorded in Linear B every transaction that concerned the palace stores.

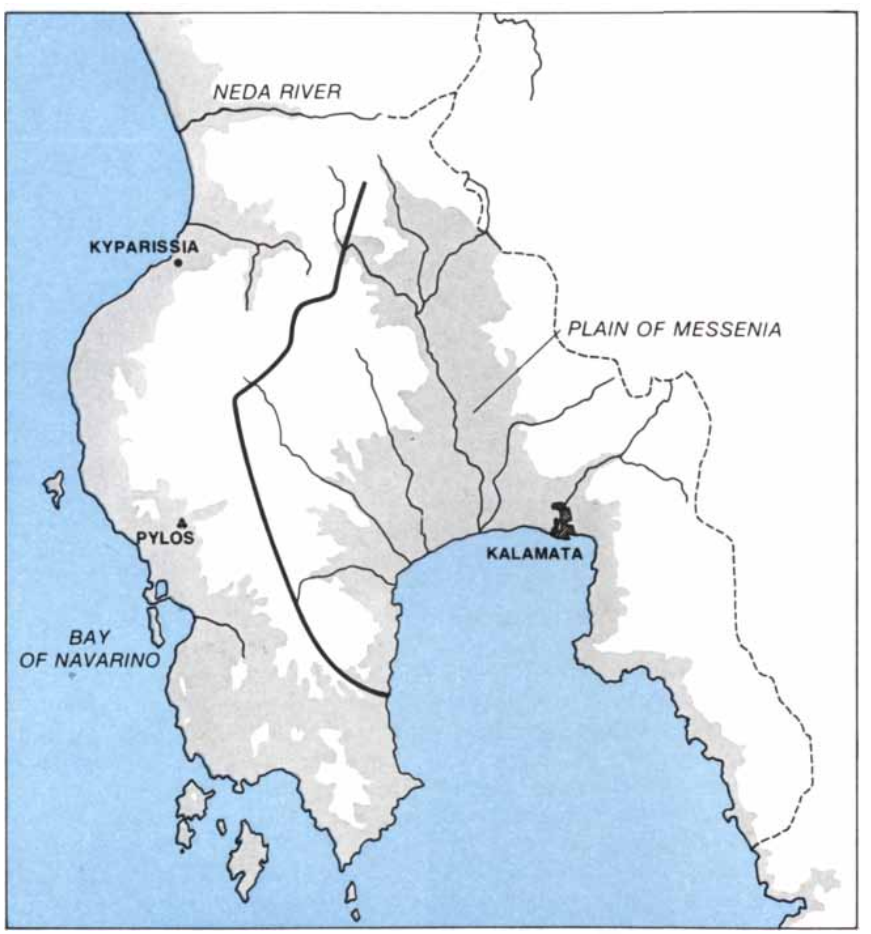
It is an unlucky chance that once a method of recording accounts had been devised its users never chose to employ the system for any other purpose. Indeed, it seems very odd to us who are literate that other literate men never jotted down a private thought, never carved their name on a durable object and never even ordered that their name be engraved on their tomb. The fault lies as much in the script as in its users. The system at their disposal was slow and complicated and its meanings were often ambiguous. It was adequate for the headings of lists, such as the ones quoted above, and it was admirably suited for recording the numbers in a flock of sheep. But it was hardly suitable for a letter, much less a line or two of verse. All things considered, it may be that the attitude of the Greek kings toward their bookkeepers resembled the one attributed, apocryphally no doubt, to the American delegates at an international conference in the far-off days when the language of all such proceedings was French. Asked how, when none of them understood French, they could follow what was going on, one of them replied: "Aw, we've got secretaries."

This much at least is certain. Every Linear B tablet thus far uncovered by the patient work of archaeologists is a piece of the bureaucratic machinery that kept the prehistoric Greek economy operating. So far as the entire corpus of inscriptions is concerned, it is as if we had salvaged the contents of a few wastebaskets at four different state capitals. I call these collections wastebaskets rather than archives advisedly; there is good reason to believe that what we have unearthed are not the permanent palace ledgers at all. Instead they seem to be temporary records, notes written for immediate use and kept on file only until the end of the current year. Moreover, the notes are incomplete; the various series to which they belong have not been preserved intact. To make things harder for us, the individual tablets have not escaped damage, both at the time when the buildings that housed them were destroyed by fire and during the more than 30 centuries they were buried.

Even in those instances where the records happen to be complete, we cannot hope to translate them perfectly. They are not elegantly phrased reports but abbreviated jottings of economic data. To the writers the only matters of importance were the tallies; all the rest consisted of rough headings designed to ensure that the writer, or perhaps another clerk in the same office, remembered what the figures referred to. To those of us who attempt to penetrate the minds of these prehistoric bureaucrats the task is as baffling as it is fascinating. Still, areas of meaning are little by little beginning to appear, and we can already give some account of the facts that underlie the fragmentary records.

Four significant sets of Linear B tablets are known. The first that was found is also the earliest. It was unearthed at Knossos in central Crete in a context that assigns it to the early part of the

MYCENAEAN SITES where tablets with Linear B inscriptions have been unearthed in the greatest numbers are Knossos on the island of Crete and Pylos in southwestern Peloponnese. A few tablets have also been found at Thebes, north of Athens, and at two other sites: the ruins of Mycenae itself and of Tiryns, which may have been seaport for Mycenae.



KINGDOM OF PYLOS consisted of two provinces. The western province, running along the coast, was separated from the eastern province by a mountain chain that probably provided a natural boundary (*heavy line*). The royal palace of Pylos was located in the western province, just north of the Bay of Navarino. The eastern province embraced the rich valley of Messenia; the southern frontier of the kingdom was probably near modern Kalamata. All areas lower than 200 meters in this map and the map on the opposite page are in gray.

14th century B.C. The second set of tablets was discovered at Pylos, in southwestern Greece; they are perhaps the most recent of any known, having been written late in the 13th century. Two very small collections of tablets fall between these extremes. One is from Thebes in Boeotia, about 30 miles northwest of Athens, and the other is from Mycenae in the northeastern part of the Peloponnese. There are now reports of fragments of tablets from Tiryns, which was probably the seaport for Mycenae, and clay jars bearing short, painted inscriptions in Linear B have been discovered at a number of Greek sites. Most of our conclusions concerning the earliest literate civilization in Greece are necessarily based on the relatively large collections of tablets at Pylos and Knossos. Regardless of the scarcity of the finds elsewhere, however, we are doubtless justified in believing that during this period of Greek prehistory a secretariat, busy recording economic statistics, was a fixture of every Greek state. The period itself is called by archaeologists the Mycenaean period after the famous site excavated by Heinrich Schliemann in the 19th century.

One feature common to the tablets from all the sites is the absence of any year date. Moreover, the tablets have an irritating tendency to refer to "this year" and "last year," which makes sense only if one assumes that they were meant to be scrapped at the year's end. An abstract of the rough information they contained was probably transferred to a "permanent" ledger at each year's end. By a fine irony the archives that housed these permanent records, evidently written in pen and ink on perishable material, appear to have been destroyed by the same catastrophic fires that baked the temporary records, jotted on raw clay, into hard pottery and thereby preserved them.

Although year dates are absent, we occasionally find month dates. For example, a month date is almost always present on tablets that record offerings to the gods. A typical superscription might be "In the month of *Diwios*." No day dates within the month are included. The names of five months are found in the collection of tablets at Knossos. Those at Pylos probably bear the names of three months; the identification of one of these, however, is uncertain.

If we knew at what point in the year the Greek calendar of the period began, we should be able to calculate the approximate date when each palace was

KINGDOM OF CRETE embraced the entire island but apparently did not include any overseas possessions. The mountainous interior of Crete minimized all but coastwise communications. Knossos, close to the coast, was thus a good location for the royal palace.

destroyed. The four natural points at which a year may begin are the solstices and the equinoxes, and we know that later Greek calendars favored starting with the autumnal equinox. Actually the Knossos and Pylos tablets do offer some clues to when the year began in Mycenaean times. For example, it cannot have begun with the vernal equinox because the Pylos tablets record nothing about the midsummer grain harvest and the Knossos tablets touch on harvest activities scarcely if at all. At the same time it is quite clear that at Knossos the spring shearing had been done and the wool clip had been gathered. This means that at least the month of April lay behind. Because the name of the current month may not have been recorded before the destruction of Knossos, a date for this event sometime during June appears plausible. This date in turn suggests that the Mycenaean year began with the winter solstice.

The Pylos tablets offer support for this hypothesis, particularly if they do record the names of three months. The third of these months seems to have been named "Sailing." Now, ancient navigators did not sail during the winter. Consequently a month that marked the start of the sailing season would come in early spring. Some confirmation of this conjecture is provided by other Pylos tablets, which contain numerous records of sheep but none of lambing or of shearing. This would accord well with a date in late March or early April for the destruction of Pylos. If the 1,400 tablets we have from Pylos indeed represent a mere three months' work by the palace clerks, we must deplore the fact that the burning of Pylos was not postponed until November.

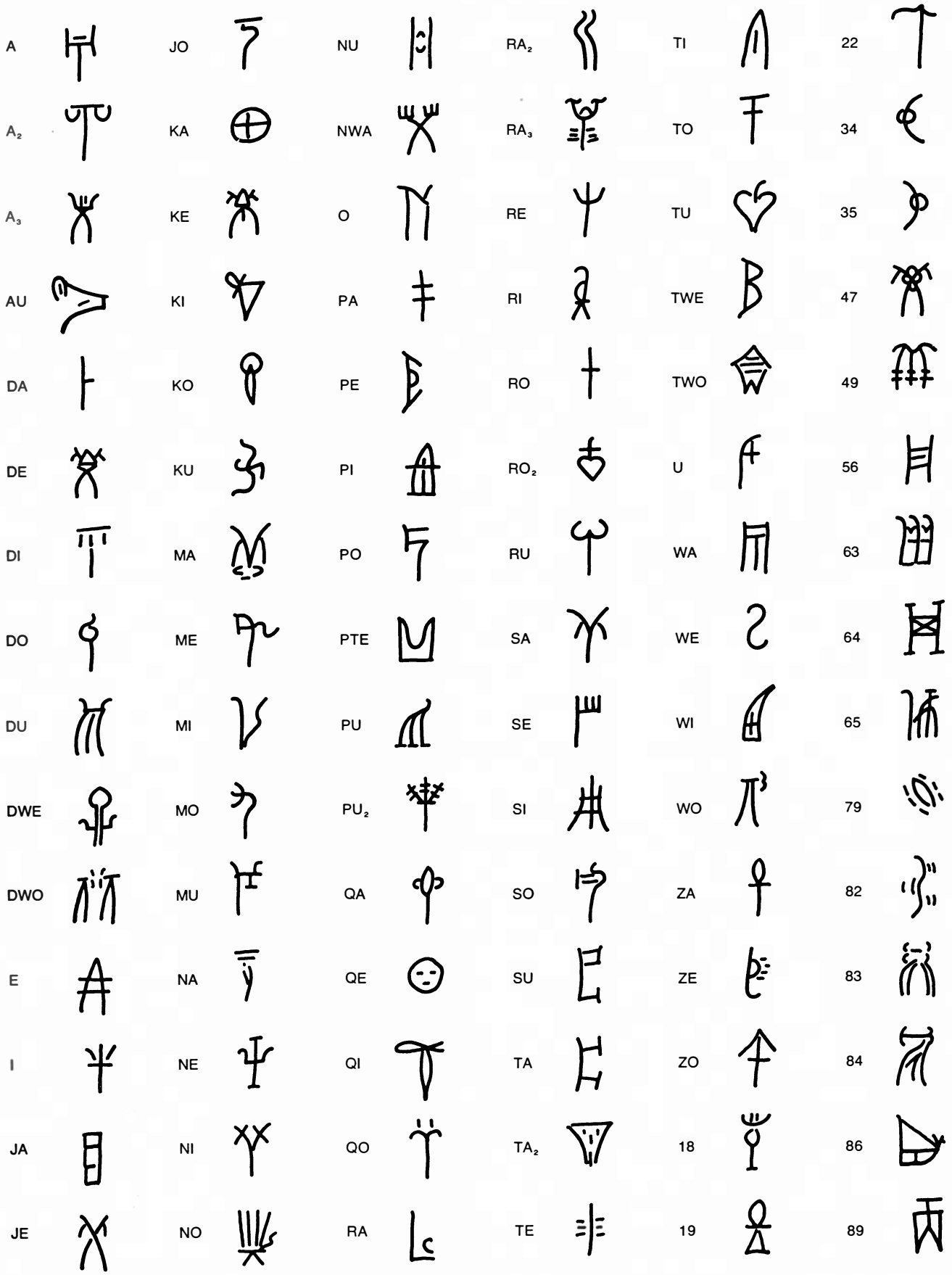
That Knossos and Pylos were the seats of monarchies might be deduced merely from the size of the ruined palaces. The tablets confirm this (the Mycenaean word for "king" was *wanax*), but regrettably they fail to tell us the proper name of either monarch. The king's name was the kind of fact that would have been known to every inhabitant in each capital and therefore was not worth putting down in temporary records.

The tablets do reveal something of the organization below the ruler. There was a class of royal officers called "Followers," a term not unlike the European title "Count" in its original sense of "companion." At the local level there were other officials (and their deputies) who played a more restricted role. For example, these officials are directed to make contributions in bronze and gold. It seems likely that the local authorities were successors to the petty rulers, originally independent, whose principalities had been amalgamated into the royal kingdom.

How large were the kingdoms? In the case of Knossos this question is not hard to answer. Crete is a large island: some 160 miles long and up to 40 miles wide. It is also quite mountainous, with heights exceeding 7,000 feet. Apart from strips along the coast it has only one large level area: the fertile plain of Messará in the south-central part of the island [*see illustration above*]. Knossos was situated a few miles inland from the northern coast, along which the island's lines of communication run, and thus it was well placed to administer the whole of Crete.

The size of the kingdom administered from Knossos is further documented by numerous place-names contained in the tablets. Eleven of the names are easily identifiable. They include Knossos itself; its port, Amnisos; the chief site in the Messará, Phaistos, and various other sites in the central sector. Two place-names belong to towns in the west of Crete: Kydonia (now Khania) and Aptara.

There is now reason to believe that two more names among the several on the Knossos tablets that are not yet geographically identified belong to sites in eastern Crete. This conclusion is the result of a remarkable feat of technology. The story is as follows. Two place-names appear both on the Knossos tablets and on pottery jars that have been unearthed at Thebes, the Boeotian site on the Greek mainland. H. W. Catling and A. Millett of the Ashmolean Museum in Oxford have analyzed the clay of these Theban jars. Its composition is not the same as that of other Theban clays, but it does match the material available from two contemporary sites in eastern Crete now known as Zákros and Palaikastro. The clay-analysis method is too new to give results that are beyond challenge, but the coincidence is at the least remarkable. In any event the general weight of evidence suggests that at this time,



NINETY SIGNS comprise the Linear B syllabary. Seventeen are not yet conclusively deciphered; numerals appear beside them. The vowel or vowel-consonant sounds of the other 73 signs are shown in alphabetical notation. Linear B also has 110 ideograms.

around 1375 B.C., the ruler at Knossos controlled the whole of Crete.

The Knossos tablets are lacking, however, in place-names that can be identified with Mycenaean sites outside the island, which suggests that the kingdom had no major overseas possessions. In this connection the sudden destruction that befell the palace at Knossos does not, in spite of earlier opinion, seem to have been the result of a foreign invasion. It appears increasingly possible that the kingdom was overthrown by a revolt originating on the island itself. Perhaps the rural population grew rebellious because it was weary of filling out endless reports for the benefit of the central administration.

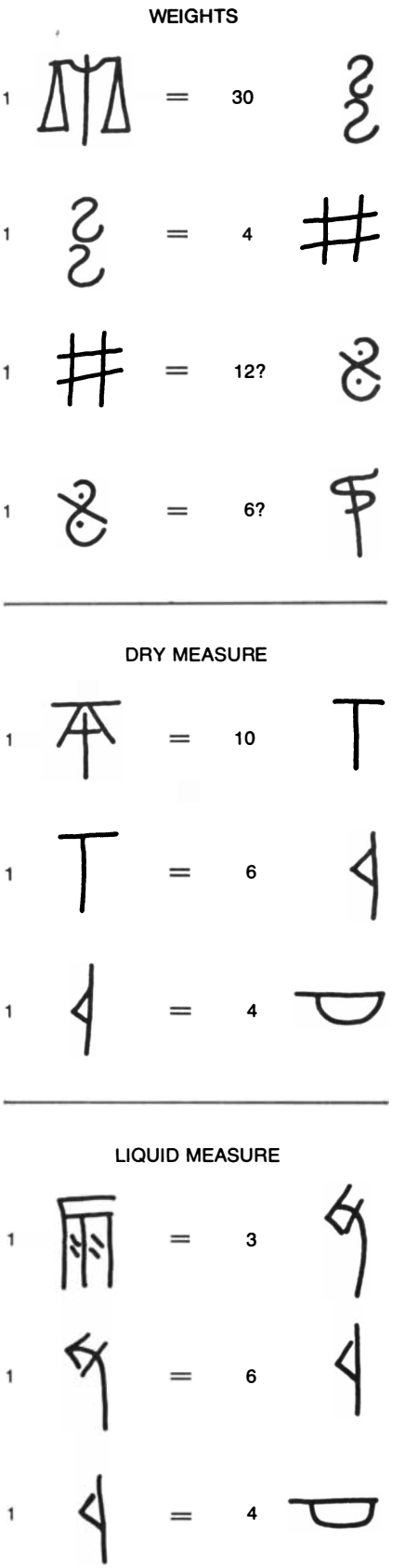
In calculating the size of the domain ruled from Pylos we cannot apply the place-name method with much success. This mainland region seems to have changed more radically with respect to names during the interval separating the Mycenaean period from the classical period that followed it. Apart from Pylos itself, few of the place-names in the Pylos tablets can be located with any certainty. Even Pylos, although the name has been preserved down to the present, has twice been moved to a new location. It was shifted in classical times to a point on the north side of the Bay of Navarino and again in medieval times to its present location at the southern end of the bay.

Mycenaean Pylos was clearly a site well suited to the control of much of southwestern Peloponnese. The question is: How far did the kingdom's control extend to the north and east? We can start to answer this question by building up a picture of the relationships that existed between the place-names listed on the Pylos tablets, even though their locations are not known. This enables us to create a model of the kingdom's political organization and then see if the model can be fitted to the map. For example, we know that the kingdom was divided into two provinces and that the more distant of the two was located beyond some landmark visible from the palace. The outlook from the palace ruins today reveals a very evident mountain barrier that separates the strip of land along the west coast from the rich valley of Messenia to the east [*see bottom illustration on page 38*]. It therefore seems a reasonable assumption that the two provinces of Pylos, broadly speaking, probably corresponded to the western coastal region and to the valley beyond the mountains.

The area we shall call the Hither Province, that is, the coastal region, was subdivided into nine districts; each district included a main town. The tablets always enumerate the nine towns in the same order, and it can be shown that the order of enumeration runs from north to south. Where, then, was the northern boundary of the Hither Province? There are four clues. First, no place-name that can be identified is located more than 25 miles north of Pylos. Second, if the northern frontier had been more than 30 miles to the north, the palace itself would have been eccentrically located within the kingdom. Third, high mountains come close to the sea some 25 miles north of Pylos, providing a good natural line of defense. Fourth, there is archaeological evidence suggesting that this natural line of defense did form the kingdom's northern boundary. Indeed, no one would hesitate to accept this conclusion if it were not that Homer, recording events that had taken place 500 years before his time, placed the frontier of Pylos much farther to the north. Homer's geography, however, was clearly anachronistic if not entirely fictional, so that his evidence need not be taken too seriously.

As for the boundaries of the Further Province, the valley of Messenia is bordered on its eastern flank by another mountain range, the vast Taÿgetos, which includes peaks rising above 7,000 feet. This obstacle establishes a natural eastern frontier for the kingdom. What is less clear is just how far to the south the Further Province ran along the western shore of the Mani Peninsula, the central finger of the three south-pointing fingers of land that comprise the southern Peloponnese. Communications by land along the Mani coast have been notoriously difficult until recently. Adding this fact to the suggestion, contained in the Pylos tablets, that the Further Province had a short coastline, it seems logical to assume that the kingdom's southern boundary on the Mani coast lay somewhere near the modern town of Kalamata. If these frontiers of the Hither and Further provinces are the right ones, Pylos was a tidy kingdom that measured 50 miles at the most from north to south and about 30 miles from east to west.

The economic base of prehistoric Greek kingdoms such as Pylos must of course have been agricultural. In Mycenaean times currency was unknown, and we have no evidence that com-



TABLES OF EQUIVALENTS show signs used to record weights and volumes. The top unit in each table is the largest. For dry and liquid volumes these signs identified the commodity. Shown here are wheat and wine.

BROKEN TABLET seen reassembled here is an example of how contexts help to establish the identity between Mycenaean syllable sequences and words in classical Greek. This is the only tablet from Knossos that records horses in a context unconnected with chariots. A part of the tablet (*right*), obviously a tally, was found by the first excavator of Knossos, Sir Arthur Evans, but the part bearing four syllabic signs (*left*) was not studied until the 1950's. The two syllables on the top line read "i-qo," equivalent to the classical *hippoi*, or "horses." The two syllables on the bottom line read "o-no," which is equivalent to "asses."

modities had their relative value fixed in terms of any common unit. Trade must have been by barter. That exchanges of this kind did take place is suggested by some entries on the tablets.

The agricultural year was not far advanced when Pylos fell. One result of this is that the tablets do not give any clear indication of how the land was farmed. What deductions we can make about the crops in Pylos come from records of the rations issued by the palace. These records make it clear that the chief cereals were wheat and barley. The relative values of the two (rations of barley, a coarser grain, are nearly double those of wheat) suggest that the wheat grown in Pylos was not primitive emmer but the modern form *Triticum vulgare*.

Because no obvious equivalent to the Mycenaean volumetric system exists today it has not been easy to determine the exact quantities of the rations. By reference to similar values in other societies, however, one can estimate a range of magnitudes that ought to include the Mycenaean ones. The estimates can be further refined by a study of the containers the Mycenaeans used, because some of the vessels probably served as measures. For example, eight-tenths of a liter appears to be one standard Mycenaean unit of volume. Exactly which unit this is, however, remains uncertain. It could be twice as much or (less likely) four times as much as the smallest of the Mycenaean units of volume.

One Pylos tablet gives what is apparently an equation between 18 large units of olive oil and 38 storage jars; the figures allow us to cross-check the assumption that the Mycenaean minimum unit of volume was four-tenths of a liter. To judge from the tablet, the average capacity of a storage jar works out to 34 minimum units, or 13.6 liters if the minimum value is .4 liter. This fits nicely with the fact that one kind of jar widely used for liquids in Mycenaean times ranged from 12 to 14 liters in capacity.

Using estimates like this, we reckon that the minimum daily ration for a slave was .64 liter of wheat or 1.2 liters of barley. Larger amounts were often provided, and the basic grain ration was supplemented with foodstuffs such as figs or olives. We know little of how the grain was prepared and cooked. It was evidently ground into meal with stone hand mills; the Pylos tablets refer to women assigned to this task. We do know that spices, among them coriander, fennel and mint, were used to season what must otherwise have been a rather uninteresting cereal diet. Wine was drunk, although in what quantities we cannot tell.

The management of livestock is rather better known. From Crete come very extensive records concerning sheep. J. T. Killen of the University of Cambridge has analyzed these records and deduces that some 100,000 sheep were under the direct control of the palace. There may also have been other flocks under private ownership. The sheep population consisted mainly of castrated males, kept for their wool; smaller breeding flocks served to provide replacements. The annual wool clip was carefully measured against a predicted norm. Any shortfall was duly recorded, but we are not told what the consequences of a deficiency were for the shepherd. The scale of wool production was considerable, although of course the yield per head was much smaller than it is with today's breeds of sheep.

An interesting series of tablets from Crete lists pairs of working oxen by name. The names are the equivalent, in Greek, of the descriptive names commonly given to animals. The important point here is that the names are Greek. This indicates that Greek was the language of the peasantry in Crete and not, as has been suggested, exclusively the language of the palace.

At Pylos oxen are rarely mentioned, but an annual tribute of ox hides suggests that the cattle herds in the kingdom must have totaled at least 1,500 head. There is also evidence for large flocks of sheep and goats at Pylos. Records of pigs are few and list only small numbers.

Deer were hunted, possible for venison and certainly for skins. The hides of oxen, goats and pigs also were made into leather, some of which was used for footwear and some for straps. The native wild goat of Crete was hunted for its large horns. The horns seem to have been used to make composite bows; attaching a layer of horn to the wood gives a bow more power.

We do not read much about the husbandry of horses. At this time the domestic horse in Greece was quite small and not strong enough to make a good mount. Instead horses were used in pairs to draw two-wheeled chariots of light construction. It is most unlikely that the prehistoric Greeks used their chariots in mass military formations as did their contemporaries, the Hittites of Asia Minor. The plains almost everywhere in Greece are rather narrow and are usually intersected by watercourses, if not cluttered with olive trees and vines. As a result the light Mycenaean vehicles would rarely have been able to move freely cross-country except along well-built roads.

There is good archaeological evidence that an extensive Mycenaean road system did in fact exist. The primary function of the chariot must therefore have been road transportation, and indeed this is implied by later Greek tradition. The story of Oedipus' murder of his father is the first recorded instance of a fight developing out of a traffic incident; each driver, it will be remembered, refused to give way to the other. Even in the *Iliad* the chariot was mainly used to carry warriors in and out of battle. They dismounted to fight.

The wool clip of Crete was spun and woven. We have some of the records that enabled the ruler at Knossos to control the output of textile workshops all over Crete, and they suggest that a surplus of wool cloth was available for export. Pylos produced both wool and flax, a crop that is still grown on a considerable scale in this part of Greece. The palace seems to have assessed the local villages for a certain number of bales of

prepared flax fiber; the flax was collected in depots, where a labor force of women made it into linen thread. There is mention of fine linen cloth, no doubt worn by the rich, but much of the linen may have gone into ropes and canvas. The canvas may have been used for sails and perhaps for padded armor. Craftsmen were employed to produce luxury goods other than fine linen. We have descriptions of ornate furniture, richly carved and inlaid with gold and ivory. A favorite material for ornament was a blue glass paste, an inexpensive substitute for lapis lazuli.

The principal metal was bronze. Although iron was known to the Mycenaeans, the techniques of working it were not. Bronze was made not only into tools and weapons but also, at least in the palaces, into cups, cauldrons and other vessels. Ordinary folk no doubt drank from and cooked in pottery. The main weapon was a heavy bronze slashing sword. A series of tablets listing such swords was found at Knossos near the king's private apartments, perhaps in the quarters of the royal bodyguard. Bronze body armor was also known but was not widely used.

There is evidence that at Pylos the working of bronze was a major industry. The ores required to make the alloy are not known to exist in quantity in southwestern Greece. The necessary raw materials must therefore have been imported from overseas, the copper doubtless from Cyprus and the tin probably from central or western Europe. Some of the bronzesmiths in Pylos may have originally been refugees who fled from Crete at the time of the Minoan collapse in the 15th century B.C. This is suggested by Pylos tablets that list tripod cauldrons "of Cretan work." Moreover, some smiths are listed as being "in the service of the Mistress." The Mistress is often mentioned in the tablets; the word must refer to the important female deity who is so often depicted in the religious scenes that appear in murals and vase paintings of the period. We know that in Crete groups of smiths had combined religion with craft, somewhat in the fashion of the guilds of Europe in medieval times. The excavations at Mycenae show that there too groups of craftsmen maintained shrines near their workshops.

The most curious aspect of the bronze metallurgy at Pylos is the large discrepancy between the number of smiths and the quantity of bronze issued to them. Making some allowance for the incomplete preservation of the Pylos tablets, we can estimate that there were nearly 400 smiths in the kingdom. If that number of smiths had been fully occupied, they should have been able to produce bronze objects in large quantities. The amounts of bronze they actually received from palace stores, however, are

TWO TABLETS FROM PYLOS reflect the troubled last days of the kingdom in the late 13th century B.C. The tablet at left is a tally of the bronzesmiths at Akerewa, a town that was probably on the Bay of Navarino. Like the other Pylos bronzesmith tablets, it indicates underemployment, probably because there was a shortage of ores imported from abroad. The tablet at right is the first of a series concerning a coast-watcher force amounting to some five men per kilometer of shoreline, presumably deployed to bring news of any invasion from the sea. Introductory phrase reads "Thus the watchers are guarding the coastal regions." Soon afterward Pylos fell.

remarkably small The total for all the smiths together is only about a ton. Some individuals received as little as 1.5 kilograms, and others are listed as receiving no bronze at all. In other words, the metallurgical labor force must have been partly unemployed and largely underemployed. Finally, there is evidence that the palace was calling on the principal local officials throughout the kingdom for the collection of bronze to be made into armaments (an interesting parallel to the British appeal for aluminum saucepans to be made into fighter planes during World War II).

All of this makes sense if we take two facts into account. First, in order to make bronze, Pylos had to import raw materials from abroad. Second, overseas travel must have been perilous just at this time. We know the second fact from Egyptian historical records that report major attacks on the Nile delta toward the end of the 13th century B.C. and at the beginning of the 12th century. The attackers, called by the Egyptians the "Sea Peoples," seem to have been an alliance of miscellaneous Mediterranean tribes who, by joining together, had assembled a powerful fleet.

A third fact is that Pylos was living in fear of attack from the sea. This is made clear by a remarkable series of tablets that describe a kind of coastal early-warning system: small units of guards spread out along the kingdom's seacoast. There is no reason to doubt that the king of Pylos expected the enemy to come by sea; the kingdom's natural defenses on its land frontiers made any attack from that quarter extremely difficult. The king's fears were fully justified. Soon afterward his palace went up in flames, and the absence of valuable objects among the artifacts unearthed at Pylos strongly suggests that the royal residence was looted before being put to the torch.

The evident shortage of the ores needed to make bronze at Pylos therefore ties in neatly with other evidence that the seas had become unsafe. The reason Mycenaean civilization collapsed is still unknown. The long popular theory that it was caused by a new wave of Greek invaders pressing down from the north is no longer tenable. All we are sure of is that nearly every major Mycenaean site so far excavated shows traces of fire and destruction around this date. Even at Mycenae itself a raid seems to have penetrated as far as the massive fortifications of the citadel, even if it did not actually breach them.

We can well imagine the scene at Pylos as news arrived of raiders scouring the shores of the Aegean. The king hastily organized his coastal-watch system. He must also have disposed his army so as best to block the approaches to the palace; Pylos, unlike Mycenae, had no fortifications. The tablets that speak of the coast-watchers also specify the whereabouts of 11 officers of the royal court. Although one function of these officers was liaison and communication, their disposition strongly suggests that each may have been accompanied by a regiment of the royal army. We can thus deduce that small forces were disposed to protect the north, south and east of the kingdom, while the main weight of defense was concentrated around the Bay of Navarino, by far the most likely place for an enemy landing.

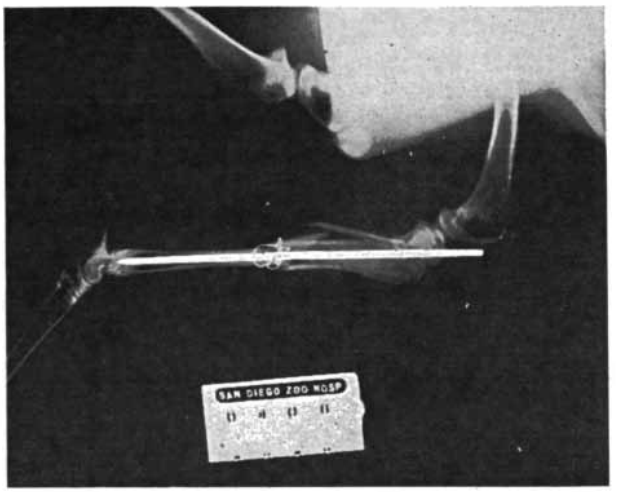
Of course, divine help was also sought. A large, badly written tablet, bearing evidence of several false starts, changes of mind and simple errors, lists an offering to be made to an entire pantheon of deities [*see illustration on page 36*]. Some are the familiar Olympians of classical Greece: Zeus, Poseidon, Hermes and Hera. There are also names that later were entirely forgotten. The offering consists of 13 gold vessels and eight women and two men. This is surely too rich a treasure for any ordinary ceremony. Both the hasty writing and the fact that the tablet was never recopied in a more seemly fashion suggest that it was written only a short time before disaster struck. The ceremony must have been a last desperate attempt to secure the protection of heaven. The men and women were probably destined not to become slaves of the deities named but to be outright human sacrifices. In addition to numerous instances of this practice recorded in classical myth, there is now some archaeological evidence that such offerings were made in Mycenaean Greece under exceptional circumstances. Whether or not these 10 individuals actually fell victim to the priest's knife, the king's cry for help went unanswered. The palace was reduced to ruins and remained forgotten until it was brought to light by American excavators more than 3,000 years later.

FUNERARY MASK made of gold exemplifies the Mycenaean craftsmen's more elaborate work. The mask, presumably that of a chief, was discovered in a shaft grave at Mycenae.

"Photography for Science Fair Contestants," a literature package about how to tell a story with photography, about close-up photography and photomicrography, about films for color or black-and-white, about darkroom work (for those who want or need to do it themselves), and a list of Kodak technical publications that can be purchased if needed—all this we present as a gift to the youthful scientist sufficiently motivated to request it individually from Kodak, Dept. 412-L, Rochester, N.Y. 14650. Included in the package is information about tangible rewards awaiting those contestants who advance beyond motivation to maximum effectiveness in using photography in their projects.

See you in San Diego in May at the International Science and Engineering Fair! While there, let's all go to the zoo (see below).

Interspecific relations



Six-inch pin and all, the subject of this radiograph is now as graceful as a gazelle and in fact is a gazelle, *Gazella subgutturosa.*

As an individual she is lucky the fracture did not occur in her natural habitat, Asian desert and high country shared nowadays with hunters who do not depend on their own or equine legs for speed. As a species the Persian gazelle can scarcely afford loss of even an individual, being perilously near extinction. But riders of the "safari train" through the San Diego zoological society's new Wild Animal Park can shoot all the gazelles they see, using cameras instead of rifles.

Now, as a side effect of giving this breed of hunters their due, a point seems to have been reached where radiological examination can help save the Persian gazelle and other species vanishing from their natural habitats.

As for species that long ago accepted commensality with man, we note that a growing volume of Kodak x-ray materials is going into the service of veterinary medicine.

Pro bono publico

Photography may not be the largest of industries, but it sure excites the inventive mind. This pile of U.S. patents issued in the field in 1971 is not necessarily complete.

Only a small percentage of them belong to us, and a small percentage—not necessarily the same—will turn out to be as useful as the inventors and the framers of the U.S. Constitution had hoped. Patents indeed are a spur to invention. Disclosures in one may provide the spark that kindles the next inventor's flash of brilliance.

Novelty, though essential for patentability, does not guarantee utility. Even if utility is realized in hands ignorant of the existence and disclosures of the patent, the owner of the patent is entitled to a reward, lest it pay to be ignorant. It's a good system that has worked so long and productively that the intellectual complexity of the patented technology in a field like photography is getting to be too much for the mortal mind.

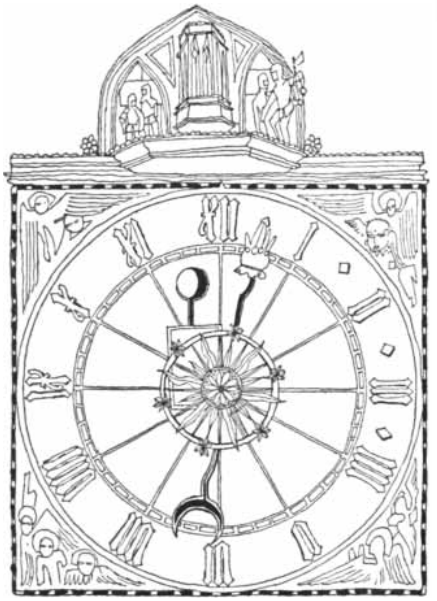
This in itself sounds like a call for invention. The call has been answered by Kodak information scientists who have worked out a microfilm-computer method for organizing and searching the world patent literature in photography and image systems. It handles the extremely difficult organic chemical aspects of photographic technology in an exciting new way. It requires the intellectual analysis of a patent just once, not over and over. It does not assume that the computer can do intellectual work.

Kodak plans to make this technique available on reasonable terms to anyone in the photographic industry and to others who may be interested. We are also inviting others to share in its further development in order to help governments reach sound decisions on what is patentable and what is not.

Correspondence can be initiated through Department 55W, Eastman Kodak Company, Rochester, N.Y. 14650.

Kodak

Let us motivate each other



SCIENCE AND THE CITIZEN

Fertility and Contraception

The modernization of U.S. contraceptive practices, dramatized by a 36 percent decline in the rate of unwanted childbearing between the five-year periods ending in 1965 and 1970, has been a major factor in the remarkable decrease in the U.S. birthrate during the past decade. The birthrate dropped from 23.7 per 1,000 of population in 1960 to 17.3 in 1971 and was below 16 per 1,000 in each of the first five months of this year. The "total fertility rate" (in effect the projected average number of children per completed family based on current age-specific fertility rates) dropped from 3.62 in 1961 to 2.46 in 1968. According to Charles F. Westoff of Princeton University, codirector of the 1970 National Fertility Study, a significant increase in the use by married couples of the most effective means of contraception was "undoubtedly the main explanation" for the decline in unwanted births.

The study, which paralleled one that was made in 1965, was based on extensive interviews with a national sample population of women under 45 who were married and living with their husbands. Westoff describes the result in *Family Planning Perspectives,* a publication of the Planned Parenthood Federation of America. There was little change, he writes, in the proportion of couples who were currently using contraception: 63.9 percent in 1965 and 65 percent in 1970. (Most of those who were not using contraception were either pregnant, sterile, subfecund or seeking a pregnancy.) The important change, he points out, was in the methods used. In 1965 only 37.2 percent of the couples practicing contraception were using one of the three most effective methods: the oral contraceptive pill, sterilization or the intrauterine device. In 1970, 57.9 percent of such couples were using one of these most effective methods. Adding those who were using other effective methods, Westoff writes, about four out of five couples practicing contraception in 1970 were "highly protected from the risk of unintentional conception." This high level was being experienced by blacks and whites and generally by couples of widely varying educational level, "probably in substantial part due to the efforts of public and private family planning programs."

Westoff terms the adoption of the oral contraceptive pill by American women "an amazing phenomenon." First available to the public in 1960, the pill was being used in 1965 by 23.9 percent of the married women currently practicing contraception; by 1970 the proportion had increased to 34.2 percent. The pill was most popular among wives less than 30 years old, almost half of whom were using the oral contraceptive in 1970. The intrauterine device (IUD) is still much less popular than the pill, but its use grew sixfold, from 1.2 percent of the wives practicing contraception in 1965 to 7.4 percent in 1970.

Voluntary sterilization (usually a tubal ligation for women and a vasectomy for men) was the method selected by 12.1 percent of the couples using contraception in 1965 and by 16.3 percent in 1970. The acceptance of these surgical procedures by older couples (those in which the wife is between 30 and 44 years old) was particularly striking: in 1970 a fourth of all older couples who were currently practicing contraception had been surgically sterilized, with the operations about evenly divided between men and women.

The Advance of Nuclear Power

At the end of July the U.S. had 25 nuclear power reactors of commercial size that were operable, 48 under construction and 63 on order. The count is presented by the Atomic Industrial Forum, Inc., in its most recent periodic tabulation of reactors. The operable plants (five in Illinois, three in New York, two each in California, Connecticut, Massachusetts, Michigan and Wisconsin and one each in Florida, Minnesota, New Jersey, Pennsylvania, South Carolina, Vermont and Virginia) plus four others that are semicommercial or demonstration reactors have an aggregate electric-generating capacity of 13,250 megawatts (13,250,000 kilowatts), representing about 3.5 percent of the nation's generating capacity. When the plants under construction and on order are contributing (most of them are due to be in operation by 1980), 31 states and Puerto Rico will have at least one nuclear power plant each and the total capacity will be about 122,000 megawatts.

The tabulation includes commercial nuclear plants with capacities greater than 50 megawatts. "Already this year," the report says, "more nuclear plants—eight—have become operable than in any previous calendar year." Taking note of estimates by the Government and the industry that nuclear power will account for up to 150,000 megawatts (24 percent) of the nation's total electrical capacity by the end of 1980, the report says: "This means that about 130 nuclear plants must be completed and licensed in the next 8½ years—an ambitious schedule indeed."

Supermicroscopy

The resolving power of an electron microscope is related to the energy of the electrons that illuminate the microscope specimen: the higher the energy of the electrons, the finer the detail that can be seen. The electrons not only illuminate the specimen, however; they also damage it. In organic materials the damage decreases slowly with increasing electron energy up to one million electron volts (MeV). It has been thought that above 1 MeV the damage would increase again, destroying the specimen and therefore placing an upper limit on the resolution of the electron microscope. Now experiments conducted by Gareth Thomas and Robert Glaeser of the University of California at Berkeley demonstrate a completely opposite effect: as the energy of the electrons increases above 1 MeV, the damage to the

specimen rapidly decreases. The observation may open up new prospects for direct exploration of the world of the very small.

Thomas performed the experiments with a 3-MeV French electron microscope at the Centre National du Recherche Scientifique in Toulouse, using specimens of amino acids prepared by Glaeser. At conventional electron energies of .1 MeV to 1 MeV a biological specimen must be very thin, and it must be stained or coated with metal to keep it intact while it is being examined. Thomas found that at energies above 1 MeV, however, the electrons of the beam begin acting rather like X rays, passing through the specimen before they have a chance to do any damage. At these energies the specimen does not need to be stained or coated with metal nor does it need to be as thin as it does at lower energies. At a given electron-beam current Thomas could examine a specimen at 2.5 MeV 10 times longer than he could examine it with the same amount of damage at 1 MeV. The experiments indicate that a decrease in the damage from 1 MeV to 2.5 MeV should continue through 5 MeV.

At these higher energies the electron microscope should be able to resolve some remarkably small structures. Because of the limitations presented by specimen damage the resolution of a .1-MeV electron microscope is about 25 angstroms. A 2.5-MeV microscope should reveal structures as small as two angstroms: the diameter of the sulfur atom. With a 5-MeV microscope it should be possible to obtain a true molecular picture of DNA, RNA, enzymes, viruses, cell membranes and other fine-spun biological structures.

Some of the surprising phenomena observed by Thomas cannot be explained by existing theory. An electron microscope capable of energies of between 3 and 5 MeV is needed to continue the investigation.

Rural Earth

Although the fraction of human beings who live in cities has been increasing at an accelerating rate since about 1850, some 61 percent of the human population is still in rural areas. "Clearly, by the standards of a highly industrial nation, the world is not yet extremely urbanized," writes Kingsley Davis of the University of California at Berkeley in *World Urbanization 1950–1970,* the second volume of his two-volume study of the subject. "Yet it is worth noting," he adds, "that the present degree of world urbanization is both very recent and totally unprecedented. Prior to 1850 no country, no matter how advanced, was as urbanized as the world is today. It was not until just after 1850 that the United Kingdom, the first country to industrialize, became as urbanized as the world was in 1970, and not until around 1900 that urbanization reached this level in the United States. In other words, although the world as a whole is just entering the twentieth century with respect to urbanization, it is not far behind the most advanced countries and is certainly a long way from the Middle Ages. Furthermore... the global level of urbanization is rising rapidly.... Barring some great reversal in the process of change, it will not be long before the world as a whole is as urbanized as even the most advanced nations are today."

About 2.2 billion people live in places classified as rural and about 1.4 billion in urban places. Since most of the rural people depend on agriculture for a living, Davis notes, the figures show "the extent to which the human species, for all its vaunted science and technology, is still devoting its labor to meeting the elementary needs for food and natural fibers." Even so, he says, the rate of growth of urbanization has been so rapid in recent decades that "if [it] continues in the future, the world will be 100 percent urban in the year 2031." Davis concludes that the recent trend in urbanization "certainly will not endure long in the future." He also points out that although the rate of growth of urbanization has been rapid, "when the shift in the world's *level* of urbanization between 1950 and 1970 is compared to the change during the previous century and a half, it does not seem particularly spectacular or even unprecedented."

A Bad Shaking

One mild and commonplace form of parental discipline, a good shaking, has now been declared more dangerous to the health of the child involved than most of the more violent assaults that befall "battered" children. This is the conclusion reached by John Caffey, a Pittsburgh pediatrician who recently reported the results of a 25-year study in *American Journal of Diseases of Children.* The reason is painfully simple. Brain hemorrhage is by far the most common cause of accidental death in infants; the "whiplash" that accompanies even a mild shaking (and can even occur in the course of a vigorous "burping") tends to induce bleeding within the pliable skull of the young. The less-than-fatal damage that can be done by shaking includes injuries of the limb bones, particularly at the joints, and chronic brain hemorrhages that prevent normal growth of the cortex and induce mental retardation.

Caffey notes that most instances of shaking are without malicious intent. The pervasive practice, he writes, "can be observed wherever parents, parent-substitutes, infants and small children congregate: in the home, on the street, in buses, nurseries, kindergartens, day-care centers, orphanages, 'preschool' schools, in parks, playgrounds, shopping centers and even in the waiting-rooms of pediatric clinics."

How Interferon Interferes

Interferon is a protein, manufactured in cells infected by viruses, that subsequently protects other cells of the same animal species against virus infection. Interferon is apparently the cell's own first line of defense against viruses and efforts are under way to induce it in human cells in an effort to control virus diseases, but its mode of action is not known. Does interferon (or, more likely, another protein that it causes cells to produce) interfere with transcription: the synthesis of viral messenger RNA from the viral genetic material? Or does it interfere with translation: the synthesis of viral protein from the messenger RNA? Investigators have reported evidence for both possibilities. The latest findings, reported in *Nature* by D. H. Metz and M. Esteban of the National Institute for Medical Research unit at Mill Hill in London, support inhibition at the level of protein synthesis, not RNA synthesis.

Metz and Esteban first established the rate of messenger-RNA synthesis and protein synthesis in a suspension of mouse cells infected by the vaccinia virus. Soon after infection there was a burst of RNA synthesis, which they followed by measuring the rate of incorporation of radioactively labeled uridine, a component of RNA. They could identify the RNA as viral because the synthesis was resistant to actinomycin, which inhibited cellular-RNA synthesis but not viral-RNA synthesis, because the viral RNA is temporarily protected by the core of the virus. The manufacture of proteins from the new viral DNA was followed by labeling the cells with radioactive methionine, an amino acid, and noting its incorporation in bits of viral protein that were visualized by gel electrophoresis.

The investigators then treated mouse

cells with mouse interferon and repeated their measurements. They found that the interferon did not inhibit RNA synthesis but rather stimulated it. They had previously learned that such stimulation of RNA synthesis can be caused by various drugs that inhibit protein synthesis, and so this first result was an indication that translation was being inhibited by the interferon. Metz and Esteban confirmed this directly by examining the incorporation of radioactive methionine into protein. The electrophoresis pattern was very different from that of the cells not treated with interferon: there was almost no labeled protein, indicating that the effect of the interferon was to inhibit protein synthesis by vaccinia RNA.

Last Adam

There are only two members of the genus *Homo: Homo sapiens* and the extinct *Homo erectus.* (Neanderthal man, who was once regarded as being a separate species, is now generally classified as *Homo sapiens neanderthalensis.*) The heavy-boned *Homo erectus* flourished in Java at least 700,000 years ago (where it was named Pithecanthropus when it was first discovered in 1891); the fossil remains unearthed since then both in China ("Sinanthropus" and "Lantian man") and in Africa ("Swartkrans man" and "Olduvai Bed II hominid") are of almost equal age. Skulls that were buried a scant 10,000 years ago now suggest that at a time when elsewhere in the Old World the successor species *Homo sapiens* was turning from hunting and gathering to agriculture, some *Homo erectus* genes lingered on in Australia.

The place of burial is Kow Swamp, a reservoir in the state of Victoria some 120 miles north of Melbourne. Since 1968 the heavily mineralized bones of some 40 adult, juvenile and infant human beings have been unearthed there along with grave goods that include stone tools, animal teeth, shells and lumps of ocher. Writing in *Nature,* A. G. Thorne of the Australian National University and P. G. Macumber of the Geological Survey of Victoria note that 15 of the adult skulls were sufficiently preserved to allow detailed study.

The bones of the skulls are thick, the browridges are massive and prominent and the back of the skull is bun-shaped and marked by a clearly defined horizontal ridge for the attachment of neck muscles. The lower jaws are unusually large and the teeth are severely worn. Similar features are rarely seen in the skulls of other prehistoric inhabitants of Australia. Thorne and Macumber suggest that the overall skull form includes archaic features that preserve almost unmodified the morphology typical of *Homo erectus* fossils from Java, combined with elements reminiscent of early representatives of *Homo sapiens.* Because later *Homo sapiens* strains were present in Australia some 15,000 years before the time of the Kow Swamp burials, the two investigators conclude that the archaic skulls represent isolated remnants of an even earlier population.

Trimming the Lean

The notorious eccentricity of the medieval campanile, or bell tower, at Pisa in central Italy, first noticed during the construction of the tower between 1174 and 1350, has recently been the cause of more than the usual concern. Measurements indicating that the angle of lean is steadily increasing have given rise to fears that the tower may be in danger of imminent collapse. In response to widely publicized reports stressing the urgency of the situation an ingenious plan to solve the problem of the leaning tower "once and for all" has emerged from an unexpected source. Yao Tzu Li, an aerospace engineer at the Massachusetts Institute of Technology, has analyzed the "static and dynamic stability conditions" of the Pisa tower and has come up with two alternative schemes—both "quite unconventional"—to stabilize the structure at its present leaning angle.

Basically, Li explains, the tilting of the tower results from "a deviation of the vertical projection of the center of gravity from the center of pressure of the base area." Since the net vertical sinking rate of the base of the tower is currently "quite tolerable," he concludes that the present base area is large enough to carry the load of the tower and hence there is no need to disturb the existing foundation. What is needed, in his view, is the introduction of "some additional stabilizing surface" to shift the tower's center of pressure to be directly under its center of gravity.

As Li puts it, "this modification is in effect equivalent to the use of a tail surface to stabilize an airplane while the main load is carried by the wing." Like many high-performance airplanes, he adds, the tower is "an inherently unstable system as a passive element but can be stabilized with some suitable feedback arrangement in an active manner. In the case of the tower this only means a periodic readjustment of the structure, say once every few decades." Thus the only lasting solution to the problem of the Pisa tower would be one that provided a "convenient means... to facilitate future adjustments."

Li outlines two "practical dynamic stabilizing systems" that meet all the desired design criteria. One of the schemes calls for a group of outlying "pads" placed around an arc with its center located near the low side of the circular base of the tower. The area of these pads would be such that the center of pressure of the total area, including the tower, would coincide with the vertical projection of the center of gravity of the tower and the supporting structure while maintaining the present leaning angle. A "rough calculation" indicates the need for 11 such pads, each with a diameter of about eight feet.

The underground structure used to connect each pad with the tower is described by Li as a "deep inverse truss arrangement." Essentially the excessive load at the low side of the base introduced by the tilting of the tower would be redistributed partly to the pad and partly to the uplifting side of the tower through the use of a compression member (extending downward parallel to the side of the tower from the low side of the base) and two tension members (extending from the uplifting side of the base to the lower tip of the compression member and from there to the outlying pad). One possibility would be to use cables as the two tension members in each supporting structure. In this case, Li estimates, a dozen or so two-inch cables could be pulled through holes bored under the tower and bent over the lower tip of the compression member "in much the same way as the construction of the tower of a suspension bridge viewed upside down." After each structure has been safely installed the cables could be tightened to their prescribed tension.

The same general principle embodied in this system could also be accomplished in a second scheme put forward by Li. In this design two larger pads are used as the stabilizing surfaces, and prestressed concrete is used to couple the pads with the base of the tower. In comparison with the first scheme the design lacks the rigidity achieved by the use of the deep compression member. This disadvantage, however, "can be compensated in part by the bulky structure of the cement, plus the use of much heavier cross section for the steel. Other than this the choice between the two would have to be determined by a detailed cost analysis."

Premise:
Pollution control begins with effective sensing and measurement.

Honeywell offers a practical way to detect harmful chemical vapors.

The job of cleaning up air pollution involves far more than control of smokestacks and auto engines. Many industrial processes are the source of other potentially toxic gases and vapors.

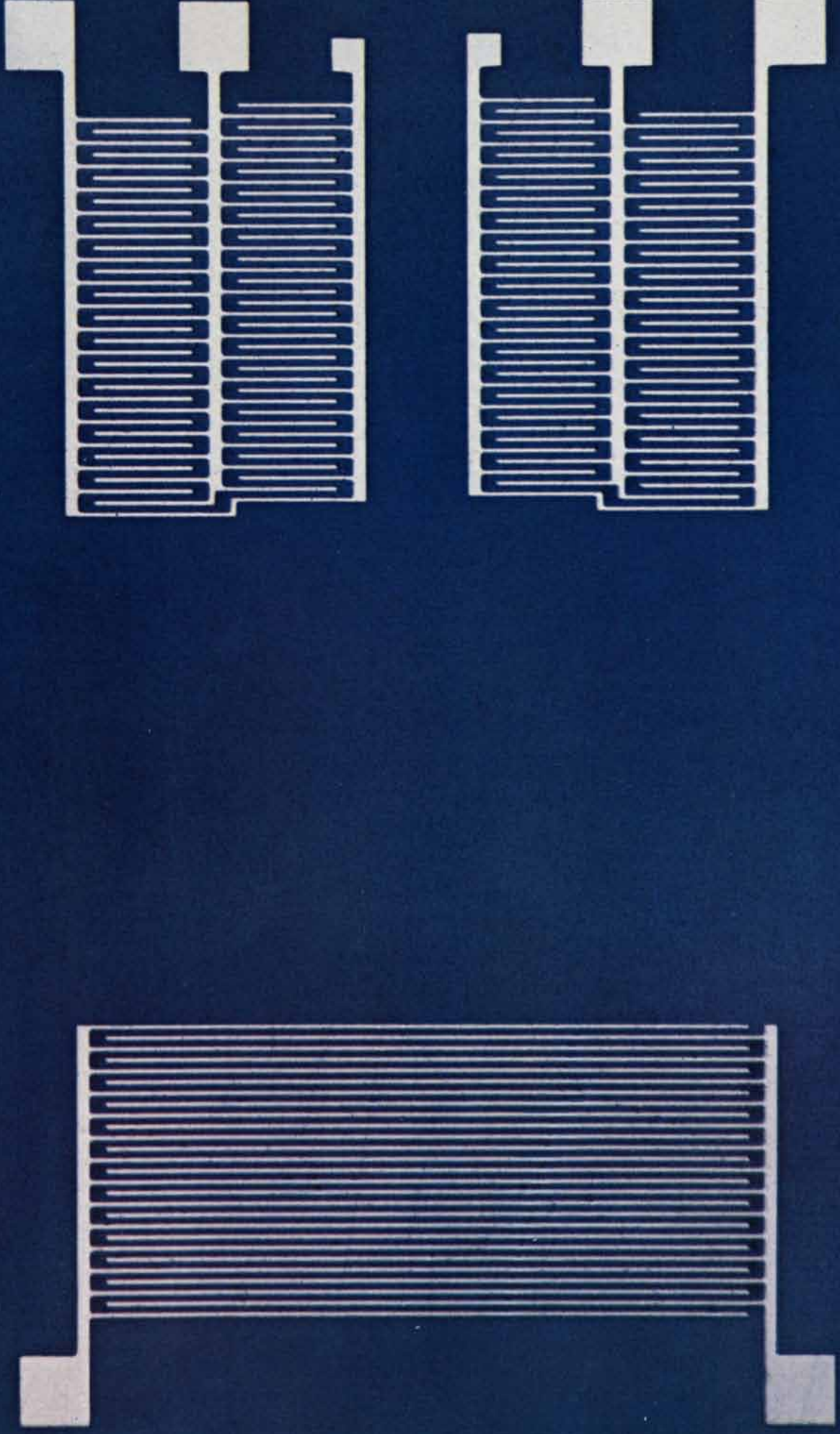
For example, the use of paint products results in concentrations of vapors such as toluene or benzene. Degreasing operations produce vapors of other hydrocarbons. Dry cleaning and refrigeration plants must control perchloroethylene and ammonia.

Charcoal filters, after-burners or scrubbers neutralize such pollutants. However, an effective control system requires dependable sensors to detect harmful vapor levels and provide for alarm control functions. Thus far, most common methods of sensing and measuring have been less than satisfactory or too costly.

Honeywell technology has developed simple, reliable detectors for many noxious gases and vapors. One such instrument, using the principle of ultra-violet absorption, can be calibrated to sense such pollutants as ammonia, benzene, hydrogen sulfide, perchloroethylene, trichloroethylene and sulfur dioxide. For a wide range of applications, Honeywell sensors can provide an economical, practical means of monitoring industrial atmosphere.

Honeywell fully recognizes that pollution control is a difficult and complex task. We'd like to help by sharing our specialized knowledge in the field of sensing and measurement. For details on the subject above, or other information, please write Mr. Richard Boyle, Director of Environmental Services, Honeywell, 2701 Fourth Ave. So., Minneapolis, Minn. 55408.

Honeywell



ACOUSTIC SURFACE WAVES

A new family of electronic devices employs ultrasonic waves to store electronic signals, to recognize signals, to separate one signal from another and to perform operations that usually require a computer

by Gordon S. Kino and John Shaw

The acoustic waves that travel along the earth's surface after an earthquake were first described in 1885 in a theoretical investigation by Lord Rayleigh. Recently they have been studied for a different purpose: to process signals in communication systems. In this application electrical signals are used to excite Rayleigh waves, as they are now called, on the surface of a crystal a few centimeters long and one or two millimeters thick. The acoustic surface waves excited in this manner can be employed to filter one signal from another, to amplify weak signals and to store signals for use at a later time. It is also possible to do certain things with acoustic surface waves that are difficult to do with simple electronic components, such as recognize a signal of known form.

We are familiar with audible sound waves in the frequency range from 50 hertz (cycles per second) to 15,000 hertz. Sound waves of still higher frequency can readily be generated; moreover, these ultrasonic waves travel through liquids and solids the same way that audible sound waves normally do. Ultrasonic waves with frequencies of up to a few million hertz are used for such purposes as detecting objects under water by sonar and revealing structures inside the body (as an alternative to X rays). It was only some 10 years ago that Hans Bömmel and Klaus Dransfeld of the Bell Telephone Laboratories first demonstrated that ultrasonic waves with frequencies of a billion hertz and up are capable of traveling several centimeters through a solid medium. It had been thought that because sound induces a crystal to vibrate mechanically, frictional forces would tend to dissipate the sound when the rate of vibration became too high. If the crystal is a very hard material such as sapphire, however, the attenuation remains fairly low even when the sound waves have frequencies of up to 10^{10} hertz. Such frequencies are now routinely employed in acoustic devices.

The first acoustic devices for frequencies above 10^7 hertz were delay lines that could store signals to be recalled later. In the past few years very-high-frequency sound waves have been studied for many other purposes. These applications include the use of acoustic surface waves for signal processing and signal recognition, for the scanning of visual information in a picture and for the amplification of electrical signals.

Acoustic waves are well suited for a delay line because their velocity is typically five orders of magnitude lower than the velocity of light. If an electrical signal is sent down a cable one kilometer long, it is delayed by three millionths of a second, the time required for the signal to travel from one end of the cable to the other. If the same signal is sent along the surface of an acoustic delay line consisting of a small crystal of quartz in which the wave velocity is only three kilometers per second, the same delay can be obtained in a structure one centimeter long.

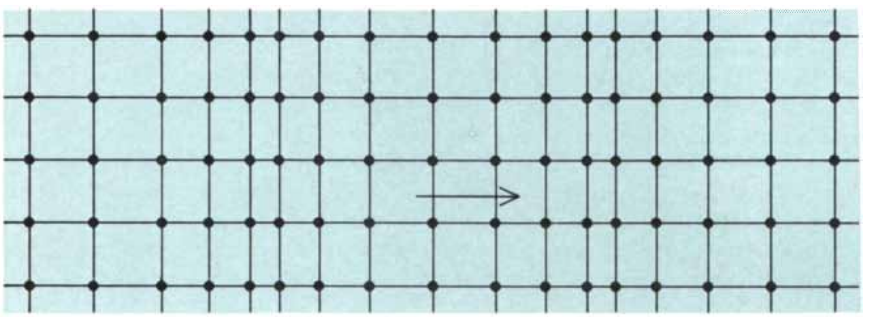
A teletype machine connected to a telegraph line is an old-fashioned example of the need for the kind of information-processing to which acoustic-surface-wave devices are well suited. As signals come in over a telegraph line, the machine "delays" until all the dots and dashes representing a particular letter or number have arrived before making a decision and typing the appropriate character on a piece of paper. There is a further delay until a message has been typed before someone can read it and make a simple decision based on it. In a modern data-processing system the rate at which information comes into the receiver is multiplied 100 million times or so. The train of data arrives in a form not unlike that of the dots and dashes of the teletype machine, except that the individual "bits" are very much shorter and are coded differently. Such a train of data can contain some 10,000 such bits of information in a thousandth of a second, and from these 10,000 bits a decision of the yes or no type must be made electronically within a thousandth of a second. For such a task a mechanical typewriter would be hopelessly inadequate, and so would the human mind. What is needed is an electronic reader capable of taking appropriate action in a thousandth of a second. It must have all 10,000 bits of information available so that it can compare the pattern formed by those 10,000 bits with a reference pattern. Only then does it make a decision and provide a yes or no out-

TELEVISION-SIGNAL FILTER in the photograph on the opposite page uses acoustic surface waves, also known as Rayleigh waves, to allow the passage of a desired television signal and to eliminate the signals on neighboring channels. The long, thin structures with finger-like projections are metallic transducers deposited on a piezoelectric base material. The interdigital transducers are designed to generate and detect acoustic surface waves having a narrow range of frequencies. In this particular device the spacing between fingers is about 20 microns, or .020 millimeter, corresponding to the wavelength of acoustic waves with a frequency of about 45 million hertz (cycles per second). The device shown here is an experimental filter developed by a group under Adrian DeVries of Zenith Radio Corporation.

put signal signifying that the signal does or does not match the reference. In the next thousandth of a second it makes another decision based on another 10,000 bits of information, and so on. To make such a feat possible it is necessary to delay and store the signal until all 10,000 bits of information have arrived. Here is where the acoustic-surface-wave delay line excels. Not only can it be used to store the signal; it can also be coded to recognize certain signals and to compare one signal with another.

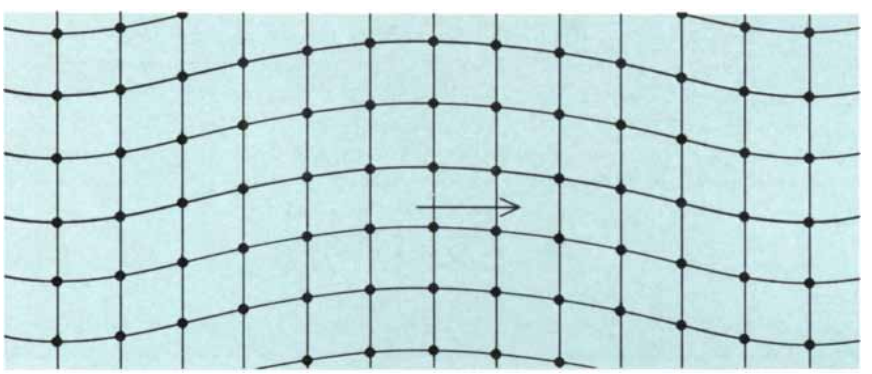
Let us now consider the properties of some of the more important types of elastic wave that can travel through a solid. The simplest type of elastic wave is the longitudinal wave, in which the material is alternately compressed and expanded. A second type of acoustic wave is the transverse, or shear, wave, in which material particles oscillate from side to side at right angles to the direction of the acoustic signal. The third principal type of wave, the Rayleigh wave, exists only near the free surface of a solid. The Rayleigh wave is a composite wave incorporating both shear and longitudinal components (which are required to satisfy the boundary conditions) and the force normal to the surface is zero. This wave travels along the surface of the solid much like ripples on the surface of a pond [*see illustrations on this page*].

a



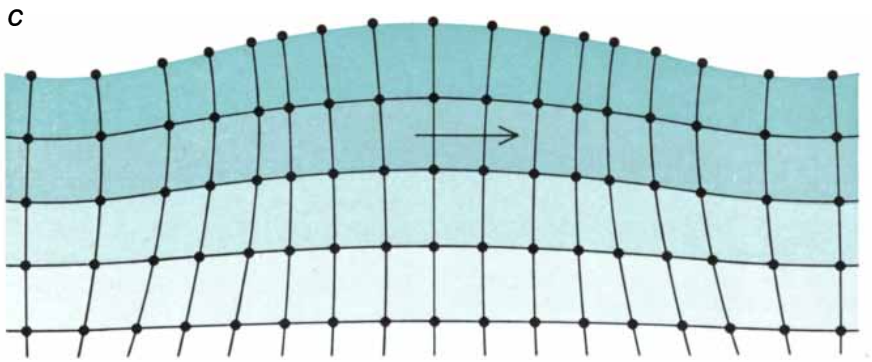
LONGITUDINAL WAVE is the simplest kind of acoustic wave that can travel through an elastic material. The material is alternately compressed and expanded as the wave passes.

b



TRANSVERSE WAVE, also known as a shear wave, provides a second way for acoustic energy to travel through a solid. Oscillations are at right angles to the direction of the signal.

c



RAYLEIGH WAVE, or acoustic surface wave, is a more complex wave that is found only near the free surface of a solid. Wave has both longitudinal and transverse components.

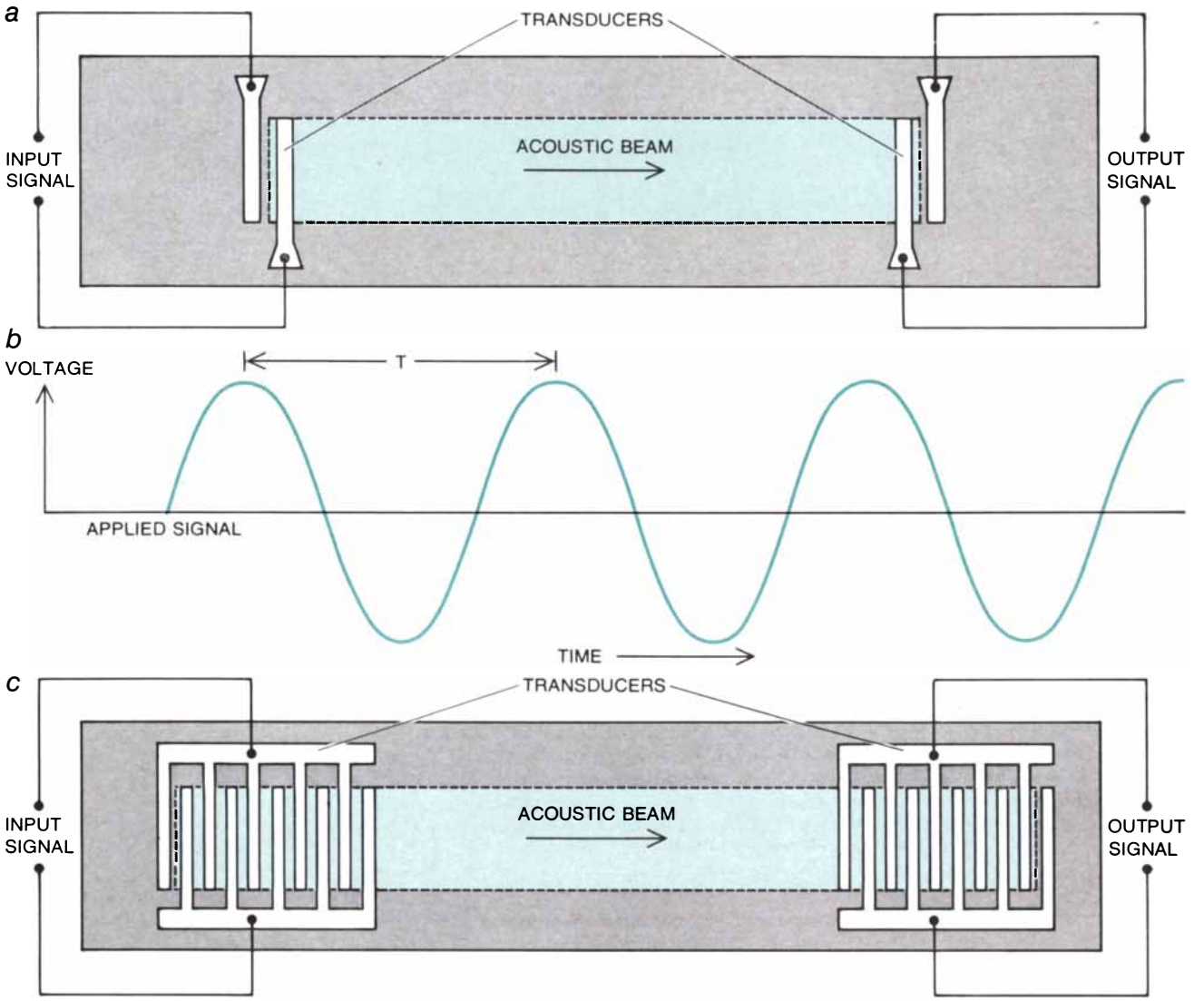
Waves in a Solid

The first acoustic devices employed in electronic applications made use of either longitudinal or shear waves that passed through the interior of a solid material. They were called volume-wave devices. The big advantage provided by Rayleigh waves is simply that the waves are accessible at the surface and thus are well adapted to the technology developed for creating microcircuits in thin, flat structures. In typical applications most of the acoustic energy is contained within a distance of a few hundredths of a millimeter of the crystal surface. The waves can be easily excited anywhere on the surface and can be readily collected elsewhere on the same "chip." As a result it is easy to construct a delay line in which an acoustic wave travels along the surface of the crystal rather than through its interior. Moreover, because the wave is so easily accessible, signals with different delay times can be picked up at various points along their path. Hence the delay line can be tapped at intermediate points.

In the early days it was not at all clear that very-high-frequency acoustic surface waves would be worth studying. At the outset there were not even any efficient transducers for converting electrical signals into acoustic surface waves. Furthermore, it was feared that the wave energy would be excessively dissipated by irregularities on the surface and by the presence of air adjacent to the surface. Fortunately the dissipation proved to be quite manageable.

In recent years the technology of acoustic waves has expanded rapidly with the development of the interdigital transducer, an efficient type of transducer for converting the electrical signal into an acoustic surface wave and reconverting the acoustic wave back into an electrical signal. An interdigital transducer is normally placed on a piezoelectric material. When such materials are compressed, they generate an internal electric field. Conversely, when an electric field is applied to such materials, they expand or contract. Thus if a rapidly changing electrical signal is applied to a piezoelectric material, the material will vibrate in unison with the electrical signal, generating a sound wave.

The required electric field can be produced at the surface of a piezoelectric crystal by applying an electric po-

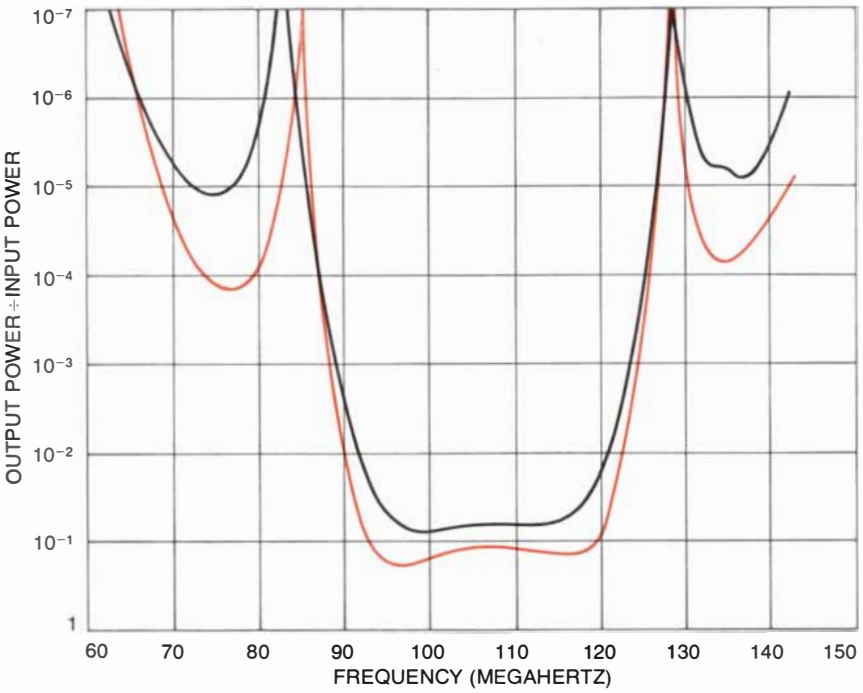


EXCITATION AND DETECTION OF RAYLEIGH WAVES can be accomplished by a simple transducer consisting of two metal electrodes deposited on a piezoelectric crystal (*a*). When a sinusoidal electrical signal (*b*), which repeats itself in time *T*, is applied to the input electrodes, the alternating electric field sets up alternating vibrations in the piezoelectric material that give rise to Rayleigh waves. When the waves reach the output electrodes, they generate an alternating voltage between the two metal fingers. If the input electrodes have a uniform interdigital pattern (*c*), the separate waves excited by each pair of fingers will reinforce one another if the time required for the Rayleigh wave to travel between electrode pairs corresponds to the frequency of the electrical signal. If the output electrodes have the same spacing as the input electrodes, they will be "tuned" to receive the passing acoustic waves.

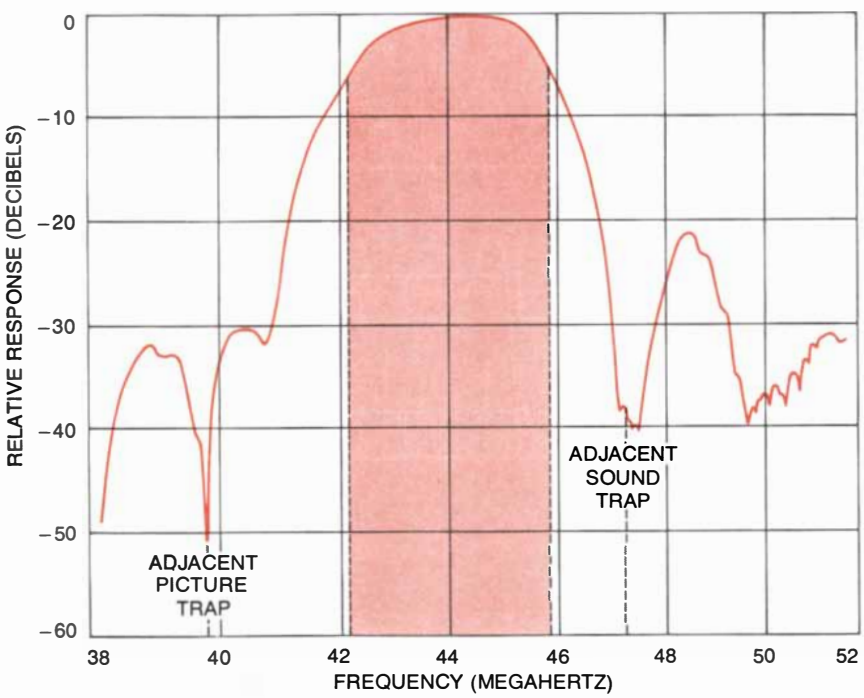
tential to two parallel metal electrodes that are deposited on the surface of the crystal. The application of an oscillating electrical signal to the two electrodes excites an acoustic surface wave that can be reconverted to an electrical signal at a second pair of similar electrodes. Because a single pair of electrodes is not very efficient in producing acoustic waves it is customary to use several pairs of electrodes, placed one after the other in an interdigitating pattern [*see illustration above*]. Each pair of electrodes excites a Rayleigh wave, and the transducer is designed so that these separately excited waves reinforce one another and give rise to a usefully large acoustic signal. This is accomplished by choosing the spacing between each pair of "fingers" so that a Rayleigh wave travels that distance in exactly the time required for the exciting signal to repeat itself.

One can appreciate that if the repetition rate of the wave—its frequency—is altered from the ideal value, the individual excitations due to each pair of fingers will have a tendency to cancel one another. The longer the transducer is, and hence the larger the number of fingers, the more easily a slight change in frequency will cause the signal from one end of the transducer to cancel the signal excited at the other end. Thus a long transducer tends to be efficient for exciting and receiving signals over only a narrow frequency range, and can therefore act as a filter to sort out signals of one frequency from signals of another frequency. Conversely, a short transducer with only a few fingers can be used to excite signals over a wider frequency range.

Filters of this kind are commonly required in communication systems. For example, in a television receiver provision must be made to switch among several channels, each of which is at a different frequency. Several individual filters corresponding to the frequency of each channel are therefore required. The signal from the chosen channel is then shifted to an "intermediate" frequency and passed through another filter that separates the picture and sound information in addition to strongly rejecting signals from the adjacent chan-



OUTPUT-INPUT RATIO is plotted for a lithium niobate delay line incorporating interdigital input and output transducers, each with five pairs of fingers. Experimental values (*black*) are compared with theory (*color*). Since acoustic surface waves are normally generated in two directions at the input transducer, only half of the signal can reach the output. Similarly only half of the acoustic energy reaching the output transducer can be converted to an electrical signal. Thus the maximum signal that can normally be transmitted through the delay line is a quarter of the input. More efficient transducers can be designed, however.



FREQUENCY-RESPONSE CURVE is plotted for the prototype television-signal filter shown in the photograph on page 50. When a television set is tuned to a particular channel, the signal is converted to an "intermediate" signal of a different frequency in the vicinity of 45 megahertz. The intermediate signal is then put through a filter that excludes signals from adjacent channels. The curve shows how an experimental filter using acoustic surface waves produces a "pass band" (*color*) about four megahertz in width, with a sharp cutoff.

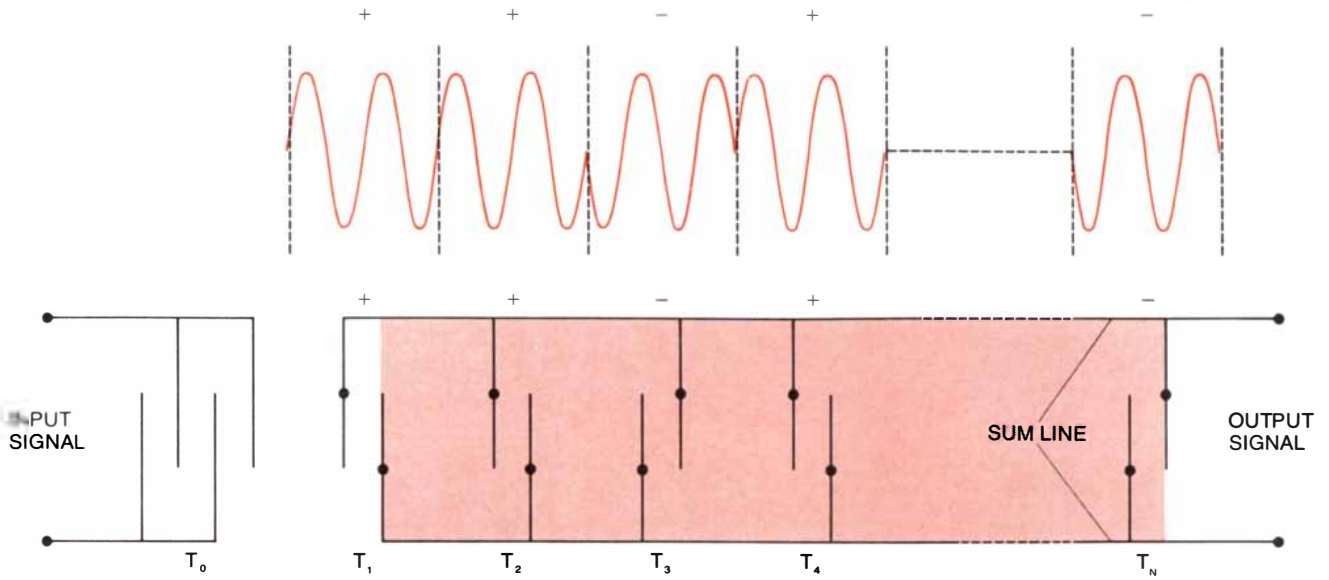
nels [*see bottom illustration at left*].

The interdigital transducers used to generate and detect acoustic surface waves are extremely small. For example, if waves with a frequency of 40 million cycles per second are to be excited, each finger must be no more than about 20 microns wide and the spacing between the fingers must be of comparable dimensions. (A micron is a thousandth of a millimeter.) A frequency near 40 million hertz is a common intermediate frequency in television applications. Fingers a twenty-fifth of this distance apart (.8 micron) are needed to excite waves with a frequency of 10^9 hertz. Structures of these dimensions can be produced by the well-developed photolithographic techniques commonly used in the transistor industry. In practice the metal fingers are deposited on the crystal by evaporating in a high vacuum a metal such as gold or aluminum through a mask. The mask itself is made by photographically reducing a large-scale reproduction of the interdigital transducer by a factor of the order of 100. Thus many identical filters can be reproduced by relatively simple and cheap photographic techniques.

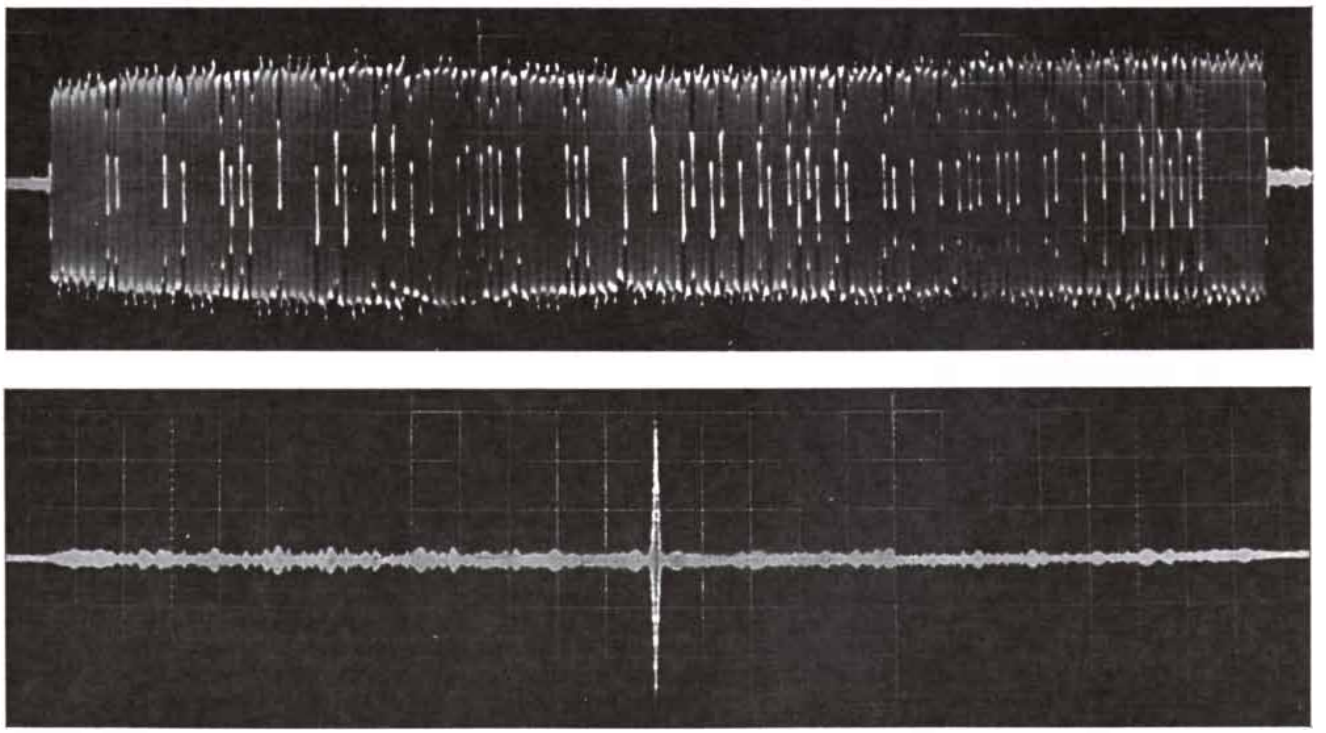
Crystals for Wave Generation

The use of interdigital transducers to excite surface acoustic waves was first demonstrated by a group at Bell Laboratories and by R. M. White of the University of California at Berkeley. In the early experiments the piezoelectric material was quartz. The acoustic-wave output was low, however, because in quartz the piezoelectric coupling coefficient, the factor relating the coupling between the electrical and the acoustic signals, is rather weak. W. Campbell and W. R. Jones of the Hughes Aircraft Company then calculated that lithium niobate, a new piezoelectric crystal grown at Bell Laboratories, should be very efficient in exciting Rayleigh waves. We grew samples of this material in our laboratories at Stanford University and undertook a series of experiments with it. We also developed a theory for predicting the electrical characteristics of transducers. This made it possible to design efficient electrical circuits to couple to the acoustic wave. We were thus able to make efficient transducers with losses close to the theoretical values [*see top illustration at left*].

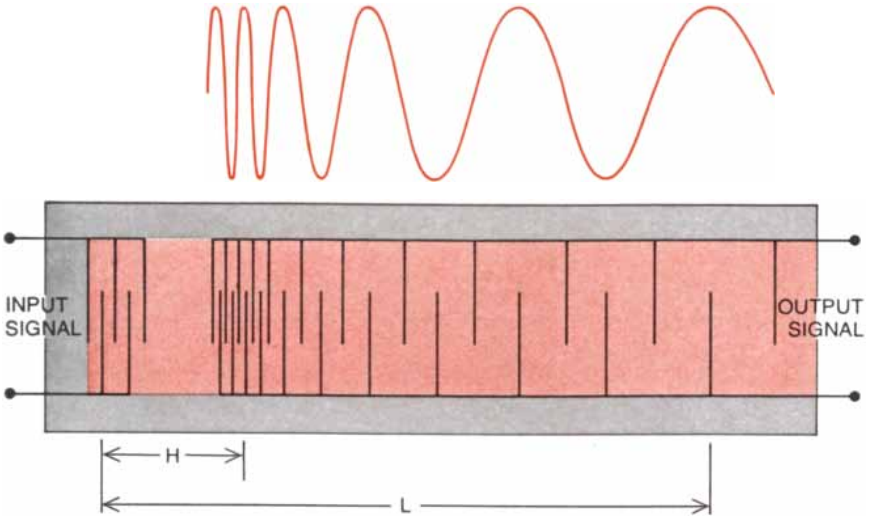
As might be expected, fewer fingers can be used for efficient coupling when a material such as lithium niobate is used rather than quartz. As a result the



TAPPED DELAY LINE (*bottom*) employs acoustic surface waves to recognize a particular digital signal of the biphase type (*top*). When the signal is fed into the transducer T_0, it forms a pattern in space and moves to the right along the axis of the delay line. In this example the signal contains two cycles per pulse. Sudden reversals in polarity divide the signal into "plus" and "minus" segments capable of representing 1 and 0 in a binary code. Transducers $T_1 \ldots T_n$ sample the signal and deliver their electrical output to the sum line. Transducers can have either plus or minus connections to the sum line, as indicated. When the polarity of the signal matches that of a transducer, the individual output is maximal; otherwise it is minimal. At the instant shown all the signal polarities match all the transducer polarities, so that the summed output pulse is at a maximum. The ratio of the maximum output amplitude to the amplitude of the input signal is the signal-processing gain. Processing gains of 1,000 should be achievable in the near future.



OUTPUT SIGNAL FROM TAPPED DELAY LINE of the type illustrated at the top of the page yields the top oscilloscope trace when a short radiofrequency pulse is fed into the input transducer. Phase reversals, corresponding to polarity reversals of individual taps, look like slots cut into the envelope of the wave. The time duration of the signal is 25.4 microseconds, which is the total delay time of the delay line. The delay line, constructed on lithium niobate, has 127 interdigital taps. The trace at the bottom shows what happens when the entire output signal, 25.4 microseconds in duration, is applied to the input transducer. There is essentially no output for 25.4 microseconds and then there is a sudden strong pulse, indicating that the polarity reversals in the input signal exactly match the polarity reversals of individual taps. At that instant the signal is "recognized." The recognition pulse lasts for only about .25 microsecond, corresponding to a compression of about 100 to one. The signal is also increased in amplitude by a factor of about 100. This experiment in signal recognition was performed by Thomas W. Bristol and his group at the Hughes Aircraft Company.



"CHIRP" SIGNAL (*top*) is a wave form whose instantaneous frequency varies linearly across the length of the pulse. If the signal were audible, one would hear a short chirp, rising in pitch. By appropriate spacing of taps one can design a delay line (*bottom*) that will compress the extended chirp signal into a sharp, intense pulse. The small finger-spacing at the left-hand end of the array corresponds to the higher frequencies at the left end of the signal. There is a similar correspondence between finger-spacing and signal frequency at the right end of the array. Thus at the instant depicted here the signal matches the array and an intense output signal results. The delay-line configuration enables the trailing edge of the long input pulse to catch up with the leading edge, thereby collapsing the pulse and piling up its energy into a single compressed output pulse. The acoustic path length for the high-frequency end of the chirp signal corresponds to *H*; the path length for the low-frequency end of the signal corresponds to *L*. Chirp signals often appear in radar systems.

theoretical frequency band over which efficient coupling can be obtained is much larger with lithium niobate than it is with quartz. By tapering the distance between the fingers and the length of the fingers, the coupling of any particular pair of fingers to the acoustic wave can be varied, and coupling as a function of frequency can be controlled. If only the spacing between the fingers is tapered, the fingers with small spacings will tend to excite waves of higher frequency and the fingers with larger spacings to excite waves of lower frequency. Thus a tapered transducer of this kind can excite signals over a wide range of frequencies and the bandwidth can be made quite large.

The design of acoustic filters with a specified frequency response has now reached a high level of sophistication. In radio receivers and television receivers such filtering functions are usually mediated by tuned circuits consisting of inductance coils and capacitors. Recently television manufacturers have begun to examine acoustic-surface-wave filters for replacing some of the tuned circuits in television receivers. The reason is that the coils normally used must be manually adjusted to the right values after the receiver has been assembled. Acoustic-surface-wave devices, on the other hand, can be made precisely and uniformly by photolithographic reproduction techniques, the same techniques that are used for making the transistors and integrated circuits in modern television receivers. Several manufacturers are now developing devices of this kind and are obtaining results that appear to be close to the requirements for television receivers [*see illustration on page 50*].

Signal-processing Functions

Much of the industrial interest in acoustic-surface-wave devices arises from their potential value in signal processing, a function that goes considerably beyond simple filtering. The signal-processing function depends on interdigital transducers in which the fingers' geometry and their spacing along the path of the acoustic beam are specially tailored in such a way as to tap, or sample, the signal at desired points. By the appropriate choice of finger design or finger-spacing the interdigital transducer can be matched to a particular signal. Let us now consider two important examples of such applications: the tapped delay line, which responds to particular digital codes, and the tapered transducer, which responds to a particular form of analogue signal.

A typical tapped delay line consists of an array of transducers uniformly spaced along the path of the signal [*see upper illustration on preceding page*]. A signal in the form of a short pulse introduced into a transducer at one end of the delay line generates electrical output pulses at all the transducers of the array as it travels past them one at a time. If one connects the electrical outputs of all these transducers together in the same fashion, one will obtain a train of successive pulses corresponding to 1's in a binary code. In order to produce a series of pulses in which some pulses have a reversed polarity (thus corresponding to 0's in a binary code) one simply reverses the connections of the appropriate transducers.

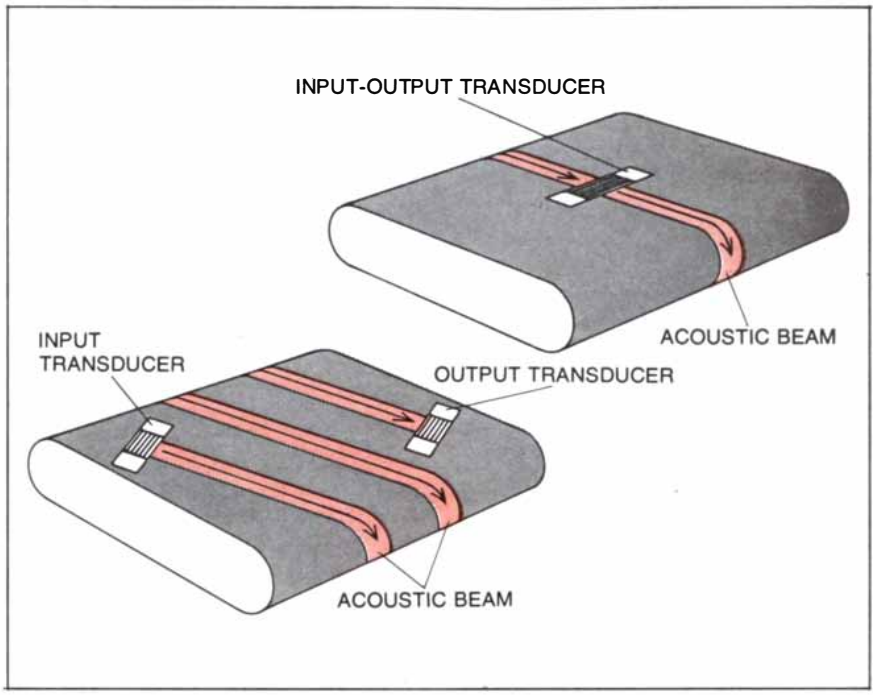
In this way one can generate a coded digital signal composed of discrete pulses following one after the other, whose polarity can vary from pulse to pulse in an arbitrary way. Conversely, if the same coded digital signal is introduced into the delay line as the input signal, a large output signal will result when the polarities of the input train correspond exactly to the polarities of the transducers at one particular time (in other words, when the code of the signal matches the code built into the device). When the input code does not match, the output will be small. The increase in signal amplitude over the amplitude obtained from a single transducer is known as the processing gain; processing gains of the order of 1,000 are within the grasp of the present state of the art. In mathematical terms the output is the cross-correlation of the input signal with the geometric pattern formed by the transducer taps [*see lower illustration on preceding page*].

The entire device can be made programmable by changing the polarities of the individual transducers with switches inserted between them and the output line. The switches are constructed as a semiconductor microcircuit array that is no larger than the delay line itself. It is therefore potentially possible to build high-speed signal processors, incorporating hundreds or thousands of taps, that can be rapidly switched to respond with high gain to arbitrary and complex signal patterns. Such a device could "recognize" any desired code from among other digital codes, even in the presence of considerable "noise," responding strongly to the desired signal and weakly to all others. When the desired signal comes in, the device registers yes, whereas to all other signals it registers no, thereby reducing signals of many pulses, or bits, to a single bit that is the desired output information.

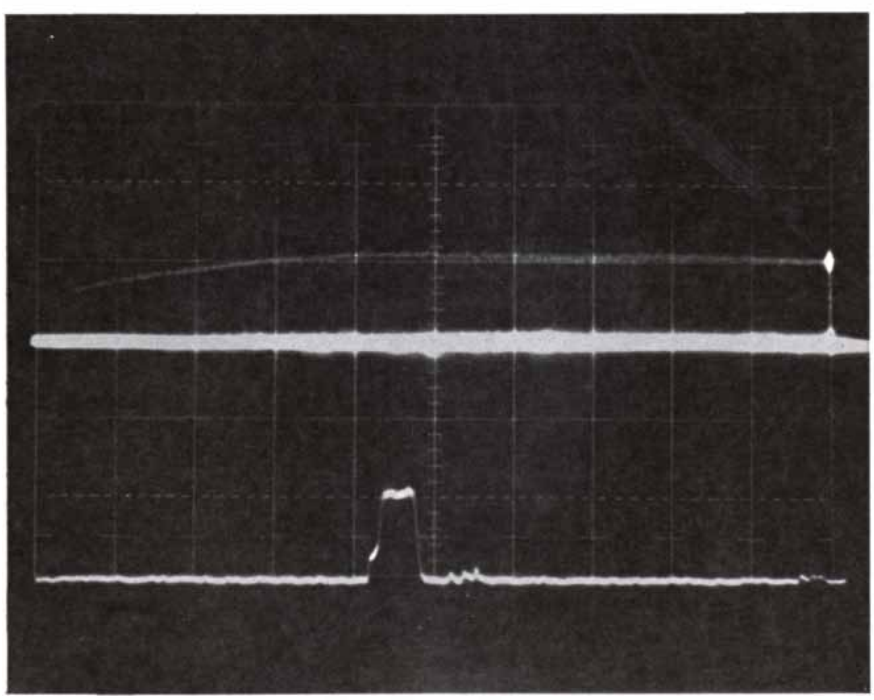
Possible applications of such devices are numerous because they fit into the general category of devices that can recognize particular patterns. Devices of this kind are already in service in radar technology. For example, when several radar sets are transmitting simultaneously, each sending out a pulse of a distinctive pattern, each radar can respond only to its own signal and also discriminate against natural noise. One of the obvious applications is in air-traffic control. An air-traffic controller needs a device that can swiftly and accurately pick out the unique identification signal assigned to each aircraft as it comes under his control. The principles of pattern recognition could be used in the same way to recognize the letters of the alphabet in an electronic reading device.

The second important example of signal processing with acoustic surface waves involves detection of an analogue signal of constant amplitude whose frequency varies linearly with time [*see illustration on opposite page*]. If the frequency rises with time, the signal resembles the chirping of a bird and is therefore called a chirped pulse. Such pulses are frequently encountered in the radio echoes received by radar systems. To improve the resolution of a radar system it is desirable to compress the chirped pulse into a single sharp pulse whose time of arrival can be accurately measured. This compression can be accomplished by building an acoustic-surface-wave transducer in which the finger-spacing is varied along its length so that the left end of the array responds to the highest frequencies in the signal and the right end to the lowest frequencies (assuming that the chirped pulse moves from the left). In other words, the spacing is tapered to match the frequency variation of the acoustic wave corresponding to the chirped signal as it travels across the delay line. The result is that when the input signal passes the position where it exactly lines up with the transducer array, a short, intense electrical output signal is generated, just as in the digital decoding device. This is another example of cross-correlation between the pattern of the input signal and the geometric pattern of the transducer array; again it is the general property of such correlations that the relatively long input signal is collapsed into a very short output signal. The device is said to yield pulse-compression.

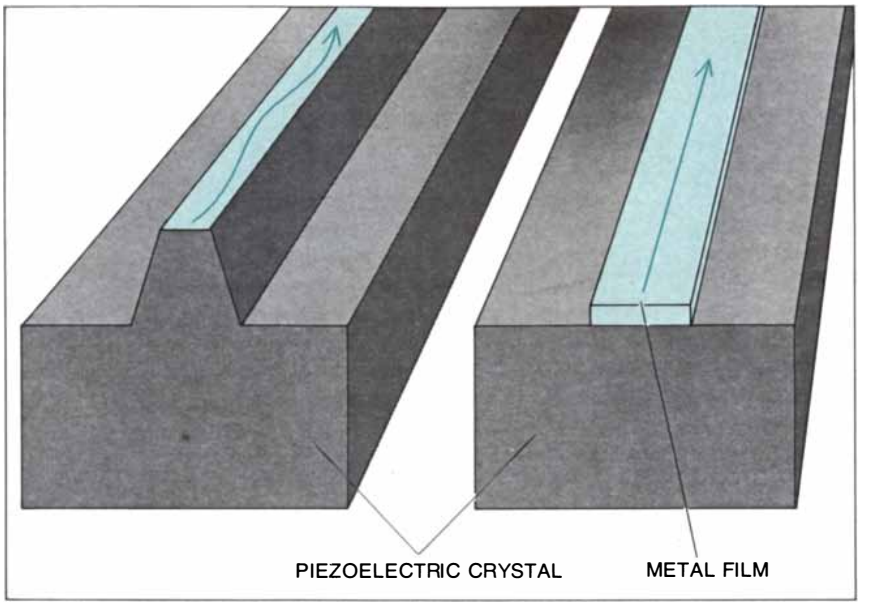
One can appreciate the value of pulse-compression techniques in radar and sonar systems where the precise timing of echoes is needed to provide an accurate



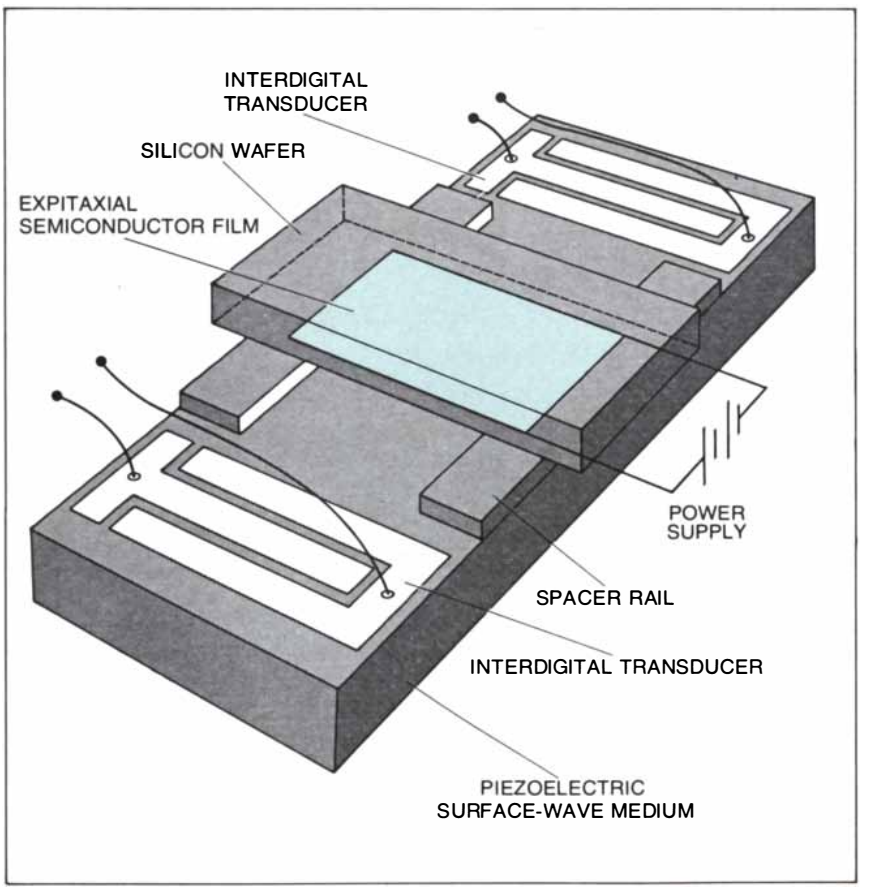
WRAPAROUND DELAY LINES provide acoustic surface waves with extended paths. If the path is in the form of a closed loop (*top*), the wave can make multiple transits, passing the transducer on each round trip. For maximum information storage on a given crystal area the input transducer is angled so that the wave path becomes helical (*bottom*) and the wave is eventually captured by an output transducer located elsewhere on the plate.



CLOSED-LOOP DELAY LINE of lithium niobate produced these two oscilloscope traces. The initial pulse fed into the delay line has a rectangular shape and is a microsecond long. One trip around the loop takes 25 microseconds. On each round trip the pulse is amplified and detected by a transducer, producing a sharp vertical "pip" at the far right in the top trace. The thin line that rises at the left and levels off represents the upper envelope of hundreds of individual pips, adding up to a total delay of about .01 second. The fact that the envelope levels off indicates that the amplifier is just compensating for acoustic losses in the delay line. In the bottom trace an individual pip is magnified to show that the rectangular shape of the initial pulse is well preserved after a delay of .01 second involving hundreds of trips through the amplifier. Delays of up to .02 second have been achieved.



WAVEGUIDES are often desirable in acoustic-wave devices to keep the waves from spreading by diffraction. One type of guide (*left*) is made by machining or chemically etching a ridge on the piezoelectric crystal. The acoustic surface wave then propagates along the "roadway" formed by the ridge. A second type of waveguide (*right*) is made by depositing a dense material such as gold on the surface of the crystal to decrease the velocity of the wave. The wave can also be slowed by deposition of a thin metal film, which short-circuits the electric fields associated with the wave. The film acts as a medium with a higher refractive index than the surrounding medium, thus tending to focus and to confine the wave.



ACOUSTIC-WAVE AMPLIFIER can be constructed by mounting a silicon crystal close to a piezoelectric one. The acoustic surface wave interacts with drifting electrons in the silicon.

measurement of an object's distance or, in more advanced systems, to distinguish and resolve the geometric details of an object. Early radars worked with very short pulses so that the arrival time could be accurately measured, and in order to override natural and man-made noise the pulses had to be very intense. Now, with signal-processing systems such as the chirp system, it is possible to use a much longer and less intense signal, and to reassemble it at the receiver into a short, intense signal with the pulse-compression filter. The compression ratio, defined as the ratio between the width of the input pulse and the width of the output pulse, can reach about 1,000 in the present state of the art. Such compression can extend both the distance resolution and the maximum range of a radar system.

For example, if one must deal with very weak return signals, as in making a radar map of the moon, pulse-compression techniques can be helpful in discriminating between the signal and the background noise. Similarly, if an ultrasonic "radar" is used to probe objects in living tissues, pulse-compression enables one to limit the power to nondestructive levels and still obtain accurate distance resolution and discrimination against interfering signals. The technique also has great advantages when it is applied with modern transistor power sources, where a long, relatively weak signal is often easier and cheaper to generate than a short, intense signal.

Increasing Delay Times

The typical delays easily obtainable at the present time with surface-wave devices are of the order of a few tens of millionths of a second, corresponding to a delay path perhaps 10 or 20 centimeters long. There are applications in which delays many orders of magnitude longer are needed. A potentially important example is the economical transmission of television signals. The complete television picture, or "frame," is reproduced by an electron beam that sweeps from the top of the picture tube to the bottom twice in a thirtieth of a second, creating a raster pattern of 525 horizontal lines. If it were required, for instance, in an educational cable-television system to transmit a still picture of a page of a book every few minutes, it would only be necessary to transmit the single desired picture in a thirtieth of a second and then repeat the same frame over and over for as long as it is wanted. This performance could be achieved by

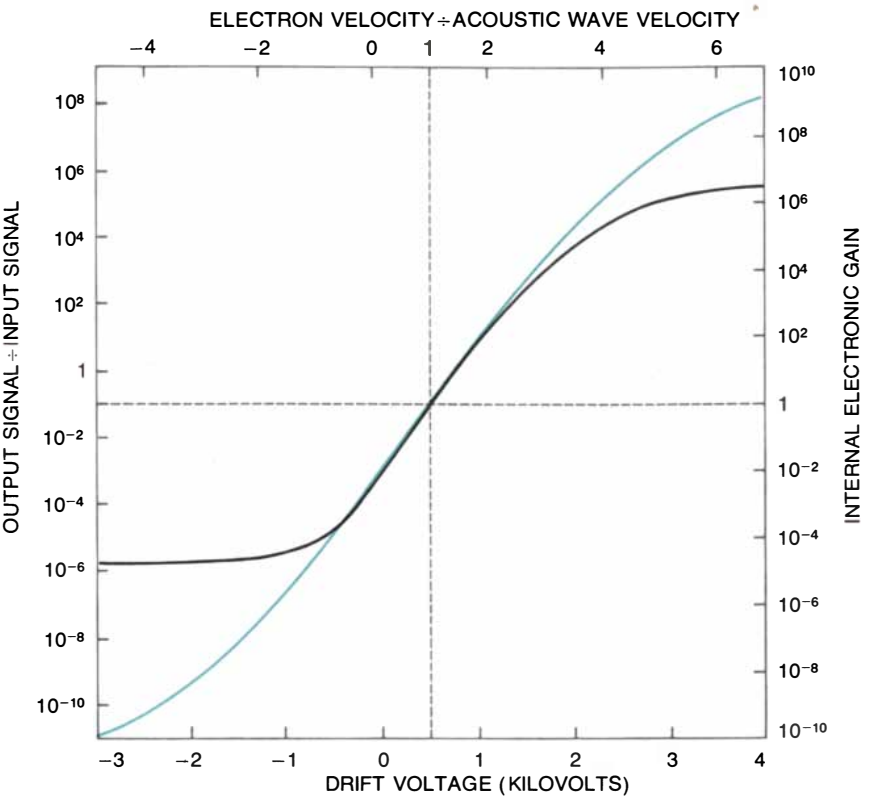
repeatedly circulating the signal around a delay line with a thirtieth-of-a-second delay, so that the information corresponding to a given point on the picture would be available every thirtieth of a second. Thus the cable could transmit other information during the time that the still picture was required, and the communication system could be utilized far more efficiently.

In principle even a "moving" television picture could be transmitted on narrower and cheaper channels than are now required by comparing each new frame with the preceding one, which has been stored in a delay line. Only the differences between the two frames would then be transmitted.

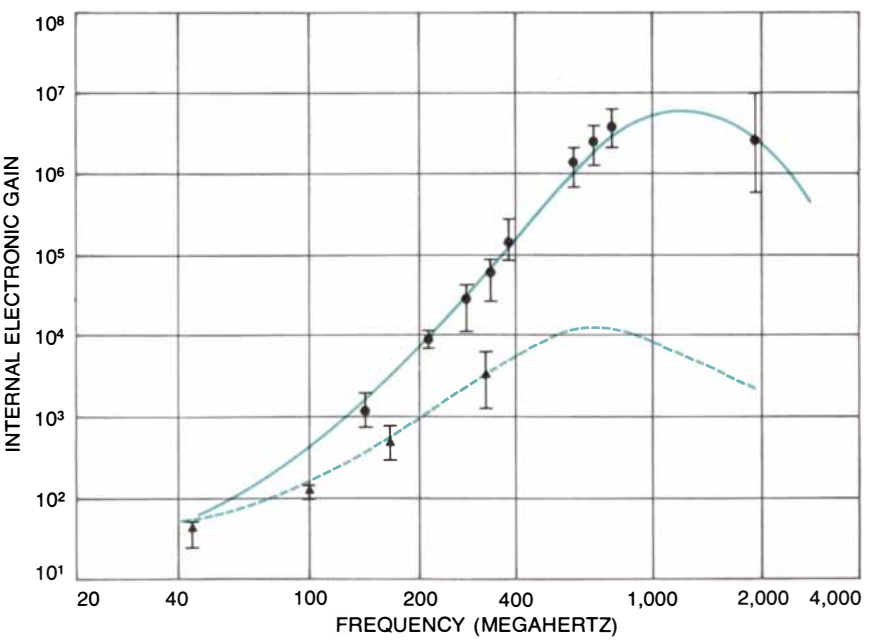
Recently delay times of the order of several thousandths of a second have been achieved in our laboratory and others by circulating the surface wave many times around the outside surface of a crystal with rounded ends. If the input transducer is correctly located, the wave will either continuously retrace a single-loop closed path or follow a helical path [*see top illustration on page 57*]. If the corners and end faces of such delay lines are lapped and polished to optical tolerances, the waves circulate with little loss in energy.

We have conducted a series of experiments with crystals of bismuth germanium oxide, a piezoelectric material that provides roughly twice as much delay time per unit length as lithium niobate. We have worked with samples of bismuth germanium oxide as long as 20 centimeters, which we fabricated from bulk crystals supplied to us by the Autonetics Division of North American Aviation. With such samples the delay time around a complete loop is of the order of 200 millionths of a second.

In our experiments we have been able to pass a signal in a closed loop or helical path around the crystal about 15 times, corresponding to a delay of 2.5 thousandths of a second (.0025 second), before the losses caused by errors in the end surfaces, by diffraction spreading of the acoustic beam and by friction in the material make the signal too weak to detect. By using special acoustic-wave amplifiers to restore the signal to its original level after each turn of a loop we have been able to achieve as many as 120 round trips on bismuth germanium oxide and up to 400 round trips on small crystals of lithium niobate [*see bottom illustration on page 57*]. In this way we have been able to get delays of as much as two hundredths of a second (.02 second), which is nearly sufficient to store



MEASURED PERFORMANCE OF AMPLIFIER (*black curve*) of the type shown in the bottom illustration on the opposite page closely matches the performance predicted by theory (*color*). The actual signal gain from input terminal to output terminal is shown by the vertical scale at the left. The internal gain is shown by the scale at the right. The terminal-to-terminal gain is less than the internal gain because power is lost in converting from an electrical signal to an acoustic wave and back again. Amplification occurs when the electron velocity exceeds the acoustic-wave velocity. The gain is negative when the electron velocity is less than the wave velocity or when the electrons are moving counter to the wave.

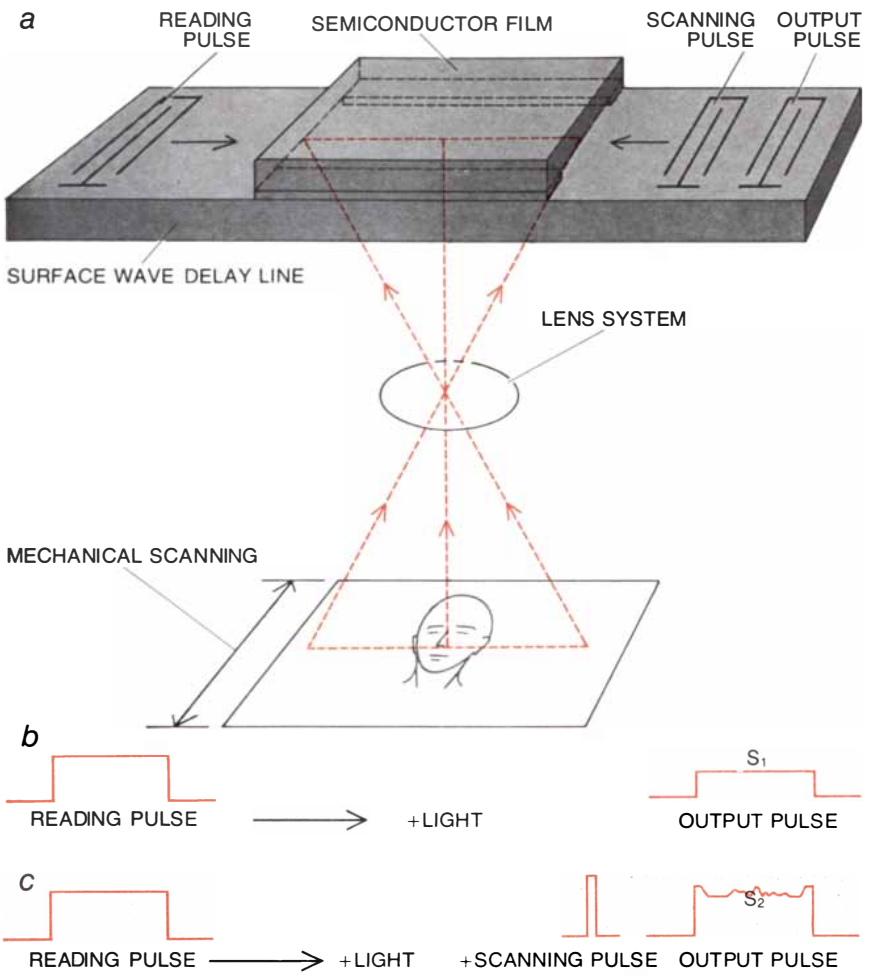


INTERNAL ELECTRONIC GAINS are plotted for two monolithic acoustic-wave amplifiers. The solid curve in color shows the theoretically calculated gain for a lithium niobate amplifier; the measured values are represented by black dots. The broken curve in color is the theoretically calculated gain for a bismuth germanium oxide amplifier; the black triangles are measured values. The vertical bars represent confidence limits in each case.

all the information in a complete television frame.

A delay of two hundredths of a second is comparable to the delay in a coast-to-coast telephone line. In such a line repeater amplifiers are required every 30 kilometers or so to boost the signal back to its starting level. The limit on the total delay obtainable in an acoustic delay line is set by the repeated amplification of the natural noise in the system at frequencies different from the frequency of the signal; this amplification eventually causes the noise to build up to an unacceptable level.

An acoustic-surface-wave beam tends to spread out because of diffraction effects as it propagates along the surface of a crystal, in the same way that a searchlight beam spreads out along its axis. This spreading would be a serious problem in a simple helical delay line, because intermediate turns of the helical beam could excite the output transducer. Some years ago, however, E. A. Ash and his co-workers at University College London demonstrated that an acoustic surface wave can be confined to a narrow path and the spreading can be eliminated by propagating the wave along a narrow ridge, or in a region where a metal strip is deposited on the surface of the crystal [*see top illustration on page 58*]. Ultimately such "waveguides" will be required for very long delay lines. They are now being actively examined for this purpose in a number of laboratories, with encouraging results.



ADDITION OF LIGHT PATTERN to an acoustic-surface-wave device alters the signal output. The schematic arrangement shown in *a* represents a device designed by Calvin F. Quate for scanning an optical image with an acoustic surface wave. A signal of relatively long duration (the reading pulse) and a signal of shorter duration (the scanning pulse) are fed into the transducers at opposite ends of the device. The two signals excite surface waves traveling in opposite directions that pass through each other in the vicinity of a silicon semiconductor film spaced a short distance above the surface. Light from an object is focused by a lens system onto the semiconductor film. With light present (*b*) the reading pulse emerges from the delay line as a signal, S_1, unchanged except for a slight decrease in amplitude. When the scanning pulse is introduced (*c*), it moves the photoelectrons farther from the surface of the delay line in the region where the pulse is present, thereby reducing the absorption in the localized region where the scanning pulse overlaps the reading pulse as it moves along the surface of the delay line. The output signal is then S_2, whose amplitude variations reproduce the variations in light amplitude along the semiconductor film.

Amplification Techniques

Let us now consider how acoustic surface waves can be amplified. An internal amplifier not only is needed to maintain the signal level in a long-delay-line system but also can be used to eliminate unwanted "echoes": waves reflected from the output transducer and various taps in the system. In the performance of these functions internal amplifiers have distinct advantages over external ones (for example transistor amplifiers).

One way of obtaining amplification is to allow the electric field associated with the acoustic surface wave to interact with moving electrons. If an electron is traveling faster than the wave, there is a tendency for it to slow down and deliver some of its energy to the wave and hence increase the amplitude of the wave. If, on the other hand, the electron is moving more slowly than the wave, the reverse is true: the wave speeds up the electrons and in the process of delivering energy to them decreases in amplitude. Both effects are useful, the first for an amplifier and the second for eliminating unwanted interfering signals.

The easiest way to get acoustic surface waves to interact with electrons is to use a piezoelectric material (such as cadmium sulfide) that is also a semiconductor, that is, a material containing some conduction electrons. R. M. White, who was among the first to design interdigital transducers, was also the first to demonstrate the amplification of Rayleigh waves by the application of a direct-current potential to force electrons to drift through a crystal of cadmium sulfide.

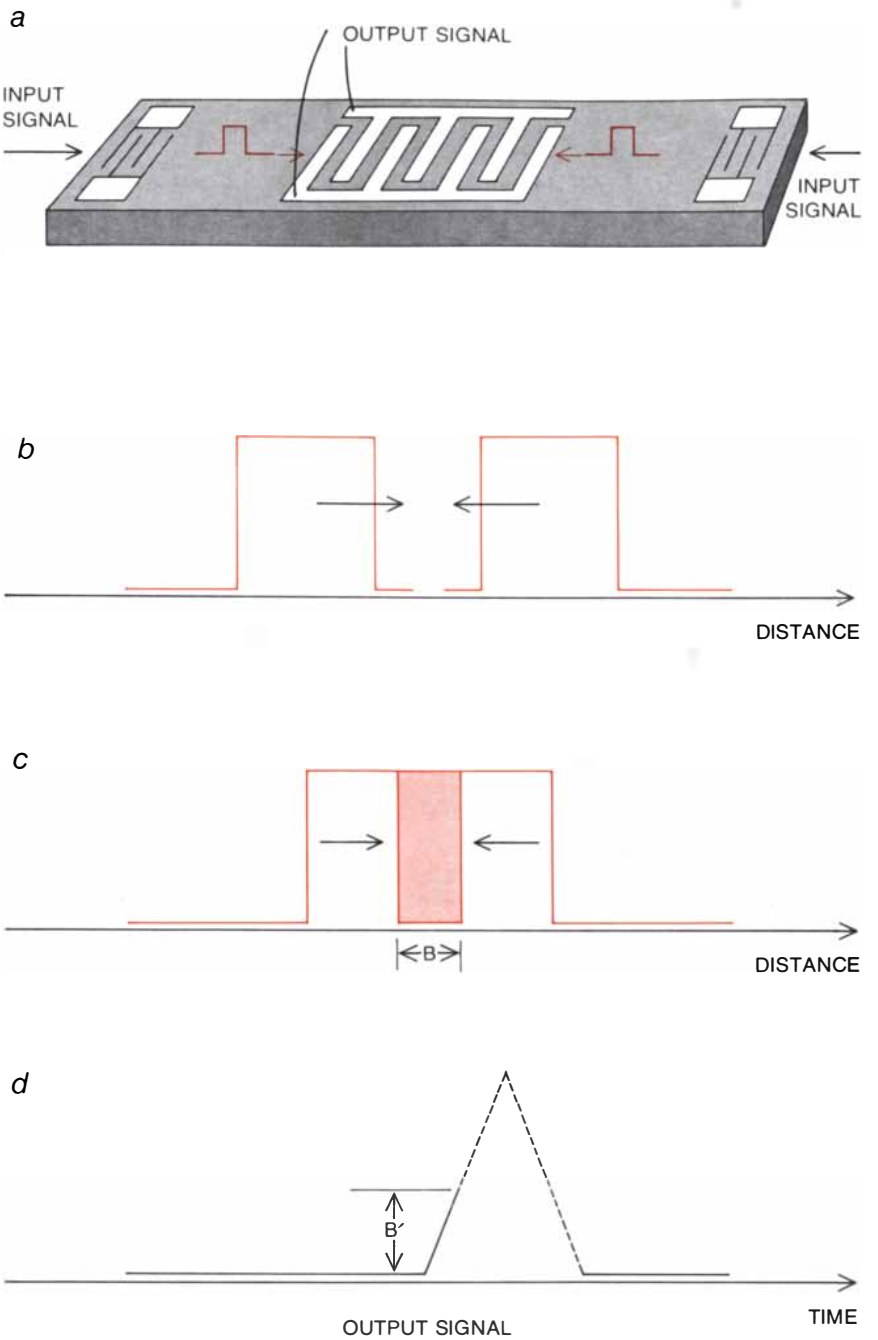
In our laboratory we had had considerable experience with similar acoustic amplifiers made of cadmium sulfide and other piezoelectric semiconductors, in which the wave passed through the interior of the medium rather than along its surface. We knew that cadmium sulfide had the disadvantages of poor reproducibility and poor semiconductor properties; a large amount of power is needed to make the electrons drift at a high enough velocity to obtain amplification. We realized that it would be necessary to use a semiconductor of better quality. Materials that combine a

strong piezoelectric coupling coefficient with good semiconducting properties, however, are not easy to find. Perhaps we could have the best of both worlds and make an amplifier by choosing a good semiconductor such as silicon and combining it with a good piezoelectric material such as lithium niobate.

We did this by placing the semiconductor very close to the surface of a piece of lithium niobate along which the Rayleigh wave was passing. In order to obtain interactions between the semiconductor and the wave that are strong enough it is necessary to keep the spacing between the two materials very small (of the order of .05 micron) and preferably uniform. These tolerances are of the same order as those normally required for high-quality optical "flats." In our first experiments we used optically polished plates of silicon and lithium niobate. We were able to observe for the first time an amplification sufficient to overcome the transducer losses and propagation losses and provide a net amplification between the electrical input and output signals.

In succeeding experiments we deposited spacer rails of silicon monoxide approximately .05 micron thick on the lithium niobate, and we devised a small press to push on the semiconductor in order to keep the spacing between the semiconductor and the lithium niobate uniform. We worked with a film of crystalline silicon about one micron thick (grown for us by Autonetics) on a sapphire wafer .5 millimeter thick. The wafer was sufficiently flexible so that it could be pushed down hard against the spacer rails all along its length [*see bottom illustration on page 58*]. The device produced a very large net amplification over broad bands of frequencies. In order to predict the behavior of the device, we developed a new theory that takes into account the various spacings encountered, the different types of material involved and the fact that the materials are piezoelectric. The predictions of the theory are in gratifying agreement with the experimental results [*see illustrations on page 59*].

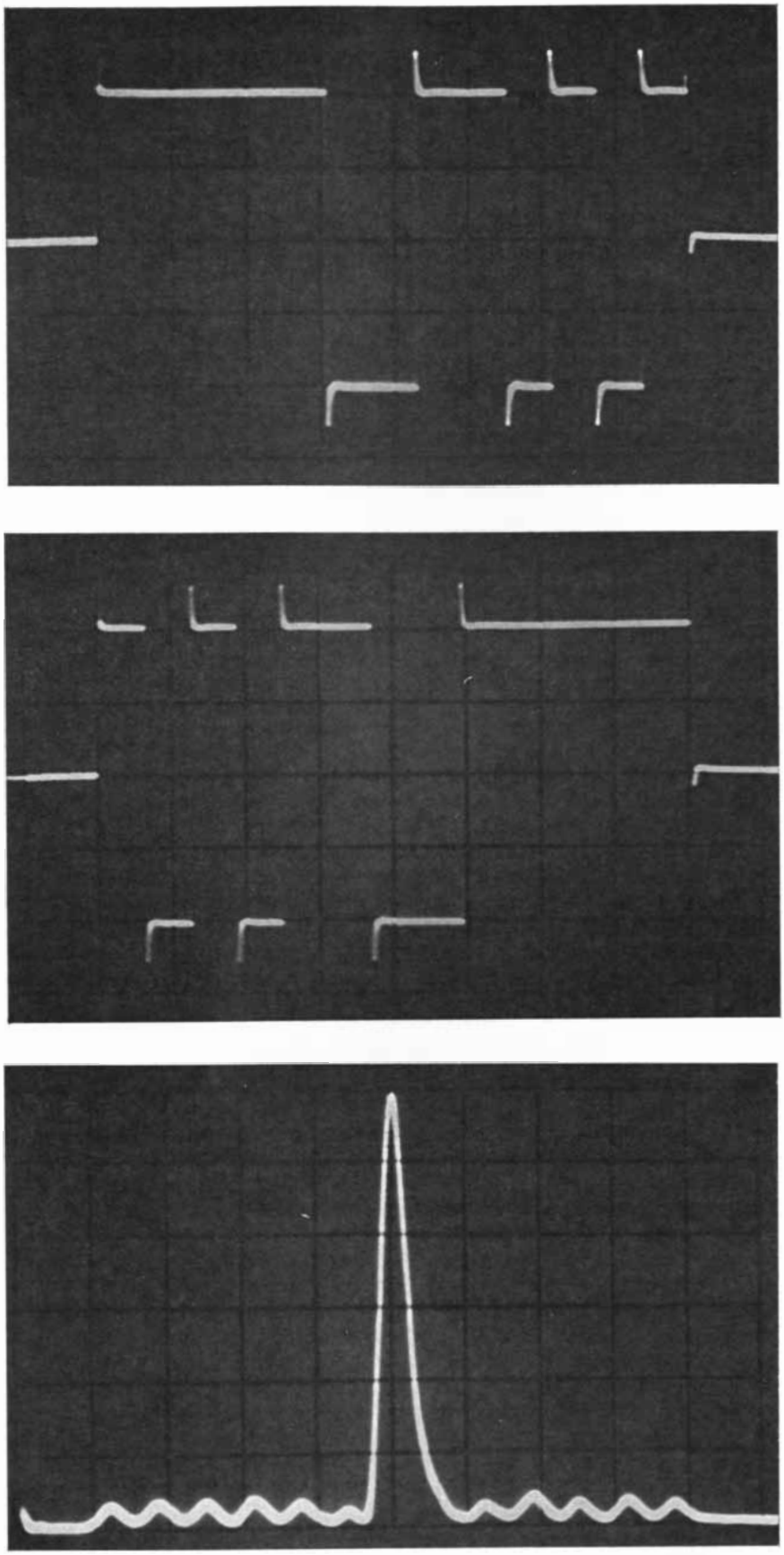
As the work progressed we found that working with a semiconductor physically separated by spacers from the piezoelectric medium was not convenient; it required very careful polishing and very fine control of the tolerances. It would be far better if we could deposit the semiconductor directly on the lithium niobate by evaporating the semiconductor material in a vacuum, just as we were already doing with the transducers.



NONLINEAR SIGNAL PROCESSING is accomplished by introducing two signals at opposite ends of an acoustic-wave device (*a*) and extracting the mathematical result from transducers in the middle. The acoustic-wave representations of two rectangular pulses approach each other (*b*) and begin to overlap (*c*). When the acoustic signals first touch, the output signal (*d*) begins to rise. When the overlapping signals have proceeded to *B*, the output signal has risen to *B′*. The output signal reaches a peak when the two acoustic signals are exactly superposed, and then begins to fall again. Thus the output signal is proportional to the shaded area in *c*. The output is termed the convolution of the two input signals.

A considerable body of work existed in the technical literature on the vacuum evaporation of the semiconductor indium antimonide. The work had been done for other purposes and the material had properties other than those we were seeking, but we had reason to believe it could be suitably altered.

Our initial experiments were quite discouraging. Indium antimonide had more electrons per unit volume than we wanted, and it also tended to be contaminated by the lithium niobate. As a consequence our results were highly nonuniform from sample to sample. The acoustic interactions that we did manage



NONLINEAR PROCESSING OF DIGITAL CODES provides a means for recognizing a coded input signal. Here the two input signals, known as Barker codes, are mirror images (*top and middle*). When the input codes overlap, a sharp pulse appears at the output (*bottom*). In this way one can establish whether or not a code signal matches a reference code.

to observe were only barely perceptible.

Our skill finally improved. We found, for example, that we could protect the indium antimonide by laying down a third layer of silicon monoxide .03 micron thick between the antimonide and the lithium niobate. With this refinement and others we were able to make reproducible films of indium antimonide .05 micron thick (only about 100 atoms thick) in which we could get strong interactions with acoustic waves. Today, two years later, we can make amplifiers with a large gain, as much as 10^8 per centimeter at frequencies of up to 1.3×10^9 hertz, and with results in excellent agreement with the theory. These amplifiers appear to be the forerunners of practical devices. They have also given us an important tool for measuring the properties of semiconductors, since the acoustic-wave gain depends directly on the drift velocity of the electrons.

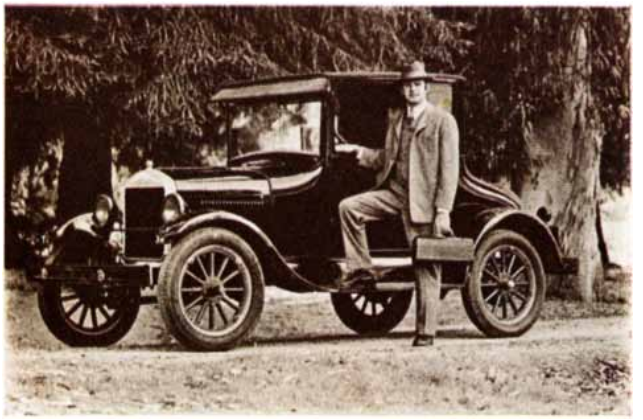
Reactions with Light

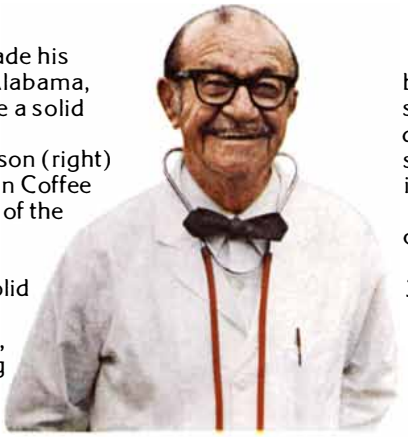
It seemed likely that interactions of acoustic surface waves with semiconductors could provide useful effects in addition to amplification. Our colleague Calvin F. Quate suggested that it might be possible to utilize the photoconductive effect already known in the thin-film semiconductors. If the electrical conductivity of a semiconductor were changed by shining a light on it, one should observe a concomitant change in the interaction between an acoustic surface wave and the electrons in the semiconductor.

In one experiment Quate and his students applied patterns of light to the silicon film in an acoustic-wave amplifier and changed its conductivity at will. They reasoned that when a short acoustic-wave pulse moved along the delay line at the acoustic velocity, it would sense changes in conductivity caused by local variations in the intensity of the light. In Quate's system a "reading wave" consisting of a second surface wave was sent in the opposite direction through the delay line; the electrical output of the delay line contained the visual information. The amplitude of the reading wave is modulated by the scanning pulse at the point where the two pass each other. This mechanism, termed the transverse acoustoelectric effect, was first discovered by Yuri Gulyaev and his collaborators in the U.S.S.R.

In order to test his hypothesis Quate and his co-workers conducted an experiment in which the semiconductor was illuminated with optical images [*see il-*

We built Ford Pinto to live up to Dr. Gibson's indestructible Model T.





When Dr. E. L. Gibson made his rounds in Coffee County, Alabama, a half century ago, he drove a solid reliable Ford Model T.

Today, at age 83, Dr. Gibson (right) is still practicing medicine in Coffee County. Still treating some of the same patients he treated a generation ago.

And he's still driving a solid reliable car: the Ford Pinto.

Which isn't so surprising, when you know something about how Pinto is built.

Unitized body. Pinto's body is welded into one solid piece of steel. Side doors are reinforced with steel guard rails. The roof has inner reinforcements of solid steel.

We built Ford Pinto to be a basic, durable, economical car... just like the one Dr. Gibson started out with.

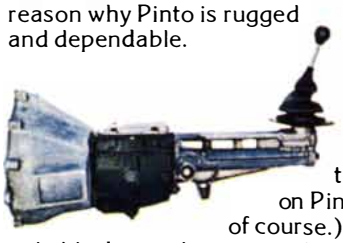
See the 1973 Pinto at your Ford Dealer's: 2-door sedan, 3-door Runabout, and the popular Pinto Wagon.

Better idea for safety... buckle up!

The Pinto engine was developed and perfected in over 10 years of actual driving in small Ford-built cars all over the world. It's rugged and durable.

Shown here is a 1973 Pinto Runabout with optional whitewall tires, luxury decor and protection groups.

In addition, Pinto uses extra strength parts (ball and universal joints, starter motor, rear wheel bearings) where you need them most. Another reason why Pinto is rugged and dependable.



A four-speed full synchromesh transmission is standard on Pinto. (You can also get automatic, of course.) The transmission is sturdy and reliable. It was designed to be lubed for life, so it needs inspection only during routine maintenance.

When you get back to basics, you get back to Ford.

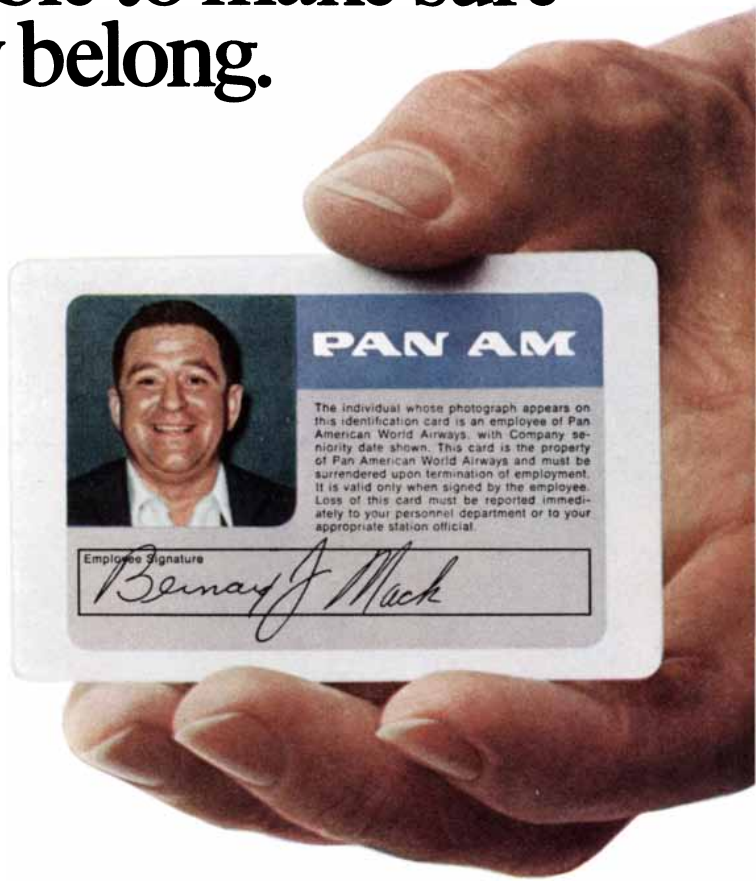
FORD PINTO

FORD DIVISION Ford

All 1973 cars must meet Federal Emissions Standards before sale. See your Ford Dealer for details.

It's impossible to know everybody in a big company.

But it is possible to make sure they belong.



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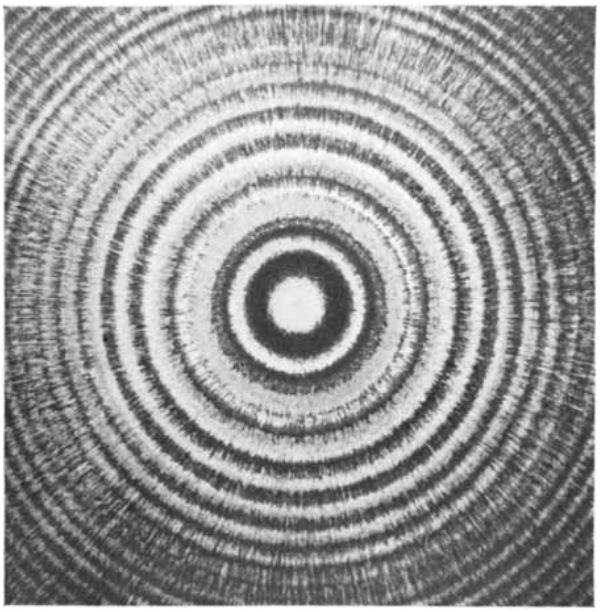
"LASER LIGHT"

A SCIENTIFIC AMERICAN FILM



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

A few highlights of the film are:

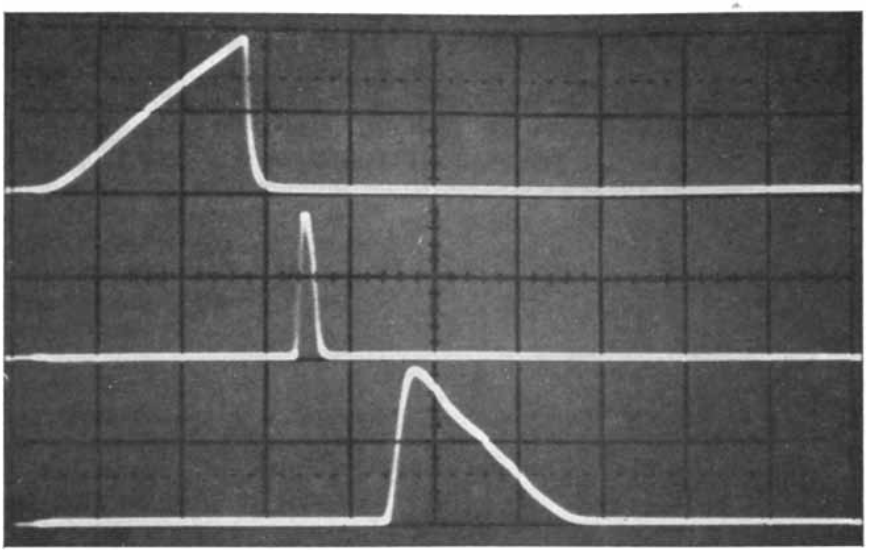
- **Computer-generated animation explaining stimulated emission and resonant optical cavities.**
- **Ripple-tank and oscilloscope demonstrations explaining the wave principles underlying laser action and holography.**
- **Holograms, their three-dimensionality dramatically evoked by the moving camera.**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

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

Rental: $37.50 for 3 days. For purchase and preview write **MOTION PICTURE DEPT., SCIENTIFIC AMERICAN**, 415 Madison Ave., New York, N.Y. 10017. (201) 891-7727. **IN CANADA:** International Tele-Film Enterprises, 221 Victoria St., Toronto 205. (416) 362-2321.

lustration on page 60]. Using a large short pulse and a uniform "reading" signal, they obtained a signal output as a function of time. By reading this signal into an oscilloscope to reconvert it into a light signal, they were able to display the electrical output, clearly demonstrating the principle.

The importance of this result is that a simple acoustic pulse moving at the acoustic-wave velocity can sweep along one line of a picture, just as a scanning electron beam does in the present television-camera systems. In both cases the variations in light intensity across a picture are translated into an electrical signal. This is one possible mechanism for a solid-state replacement of the electron-tube scanner in television systems. It is not difficult to see how the method could be generalized to sweep several parallel lines one after the other, as is needed for television. Thus it appears that there may be far-ranging new applications for acoustic surface waves, applications that were not apparent at the time of the first development of acoustic delay lines.



INVERSION OF ELECTRONIC SIGNAL can also be accomplished by nonlinear signal processing using, for example, the acoustic-wave device illustrated on page 61. A signal (*top oscilloscope trace*) is introduced at the transducer located at the left-hand side of the device. A short pip (*middle trace*) is inserted by way of the transducer located in the center of the device. A time-inverted signal (*bottom trace*) then appears at the original input transducer.

Nonlinear Effects

In the optical scanner the acoustic waves interact in a nonlinear manner, in contrast to the linear way they interact in the other devices described above. Linearity normally means that if two signals are put into the device, the output is proportional to the simple sum of the two signals. At low signal levels that is what happens. As the signal level is increased, however, other effects begin to show up. An output begins to appear that is proportional to the product of the two signals, so that the output of one signal is altered by the presence of the other signal. Such an interaction is called nonlinear.

Nonlinearities of this kind are observed in piezoelectric materials. They are enhanced if the piezoelectric material is coupled to a semiconductor, as in Quate's optical scanning device. The first demonstration of this type of interaction, using two acoustic surface waves in a piezoelectric crystal, was achieved by L. O. Svaasand of the Technical University of Norway. The application of these nonlinear effects to signal processing had previously been proposed by Quate, who demonstrated signal-processing functions with acoustic waves passing through the interior of a lithium niobate delay line rather than along its surface. He showed that nonlinear processes make it unnecessary to design a specially coded transducer to recognize a particular signal. Instead one simply feeds a coded reference signal into an uncoded delay line. In this way one can vary the code at will and perform a wide range of signal-processing operations.

We subsequently demonstrated such processing techniques with acoustic surface waves traveling in opposite directions that are excited by signals through transducers at each end of the device [*see illustration on page 61*]. Because of the nonlinear properties of the material a signal will be generated that is proportional to the product of the two input signals at each point. This signal can be detected on a fairly long transducer located between the two input transducers. The actual amplitude observed on the output transducer will depend not only on the amplitude of the product signal but also on the length of material in which the two signals overlap as they pass each other. Thus for two identical signals the output amplitude increases as their overlap increases, reaching a maximum when they overlap each other completely and then decreasing again. Therefore if the input consists of two square pulses, the output should consist of a triangular pulse that rises and falls steeply with time. The output formed in this way, by what is essentially the mathematical process of taking the product and then integrating it, is called the convolution of the two signals. It turns out that the output is strongest when the two signals are mirror images of each other in time. It is as if one signal were acting as a reference code for the other.

In our experiments we have worked with digital codes known as Barker codes that are designed so that if one code is a mirror image in time of the other and the two sets of pulses of each code overlap, a large output signal results [*see illustration on page 62*]. At other times, when the codes do not overlap completely, the output is a series of small peaks with an equal but low amplitude. In this way it is possible to recognize the arrival of any particular Barker code group by repeatedly feeding into the device as a reference signal the mirror image of the coded signal sought. When the device gives a large output signal, one knows that the desired input signal has arrived.

We often have some given signal at our disposal and are concerned with determining the extent to which an unknown signal is identical with it, a process known as calculating the cross-correlation. To calculate such a cross-correlation we need the mirror image of the given signal to use as a reference signal in the device, which means that we must be able to reverse the time sequence of the given signal before using it. Reversing the pulse in this way would seem to be violating the principles of causality. If, however, we can store the signal for a certain time and have it all available before trying to reverse its time sequence, it is possible to get a time-inverted signal.

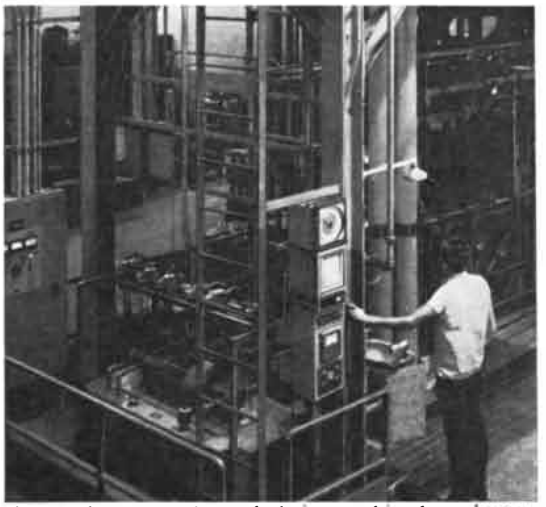
We have achieved this result by putting the signal into one transducer and placing a very short time signal (an im-

pulse, or "pip") on the middle transducer. When the input signal passes under the middle transducer, the short impulse is turned on and one gets the integral of the product of the two signals, which has the same form as the original signal. The product signals are generated in the form of an acoustic surface wave that can travel in either direction. We designed a system that would respond to waves traveling in the backward direction, that is, back toward the input transducer. Here the part of the signal that originally came last now reaches the input transducers first, and the part at the beginning of the signal now comes last, so that a time-inverted signal is obtained [*see illustration on preceding page*].

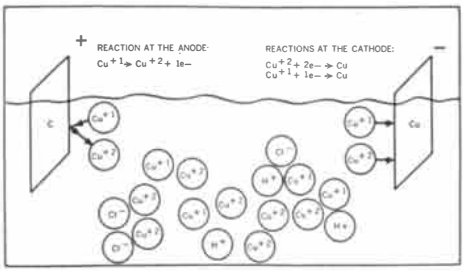
We are therefore able to take various input signals and recognize them by using nonlinear processes. We can also invert arbitrary signals in time. In fact, we can carry out many functions that are normally very difficult to achieve except by storing the signal in a computer and elaborately processing it by a series of mathematical manipulations. Now the entire procedure, which is mathematically equivalent to multiplication and integration, can be accomplished in a small crystal in a period of time comparable to the length of the signal.

Hence the application of acoustic surface waves has led not only to better methods of performing operations now carried out in other devices but also to methods of performing operations that were either difficult or impossible to accomplish in the past. There are many types of acoustic-wave interaction still to be investigated. For example, research is currently being undertaken on methods of exciting surface waves on nonpiezoelectric materials such as glass or silicon. For this purpose a thin film of a piezoelectric material such as zinc oxide is typically laid on top of an interdigital transducer that has been deposited on the nonpiezoelectric material. With the realization of such techniques it should be possible to make extremely cheap devices out of glass and similar materials. Alternatively, with the use of silicon it should be possible to combine acoustic devices with a broad range of semiconductor devices normally made in silicon integrated circuits and thus investigate a wider class of interactions between semiconductors and acoustic surface waves. It is clear that methods of processing acoustic and visual information and displaying the information with the help of acoustic techniques are only in their infancy.

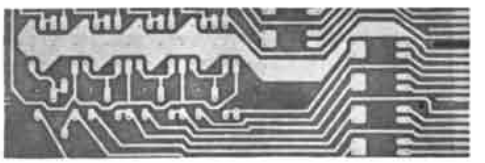
ACOUSTIC-WAVE PICTURE produced by an experimental version of the device depicted in the illustration on page 60 is shown on an oscilloscope screen. The picture is created by moving the scanning pulse horizontally across the original photograph while the lens system is moved at right angles to the scanning pulse from top to bottom of the photograph.



Automatic regeneration and plating machine has a heavy, rubber-lined tank with 22 stationary graphite anodes and 57 rod-like copper cathodes moving at the rate of 90 transfers an hour.



The action at the cathode. Electrochemical reversal of the etching reaction effecting etchant regeneration and copper recovery.



Typical printed wiring board consists of copper (only 0.0028 inch thick) laminated to a phenolic-resin panel. With the new process, unwanted metal is etched away with cupric chloride.

Creating an entirely new way to etch printed circuits.

One of the most common methods of printed circuit manufacturing is by batch-etching with ferric chloride. However, while batch-etching produces circuits of high quality, it also has some processing disadvantages.

For instance, it takes more and more etching time as the etchant is used. Then, to replace the spent etchant means considerable downtime. And the etching of 100,000 circuit boards produces 2000 pounds of copper in a non-recoverable form.

Engineers at our Columbus, Ohio plant set out to discover a better way to etch that would eliminate all of these inherent problems.

Their new process is the first closed-loop, spray-etching system that electrolytically reverses the chemical reaction of etching. It continuously recycles cupric chloride and has reduced the cost of etching wiring boards by over 90%.

Virtually all the problems of the old method have been overcome. No more machine downtime is required to change etchant. No more costly ferric chloride is needed. Etchant strength does not diminish. The etching rate is now constant and faster than the average ferric chloride rate. There's no more waste of etched copper. It is now recovered, about 20 pounds per hour, and resold.

Conclusion: The first completely closed-loop cupric chloride etching system in the printed circuit industry is a major innovation that has improved efficiency and quality, eliminated downtime and decreased costs by more than 90%. Furthermore, it has helped conserve a valuable natural resource.

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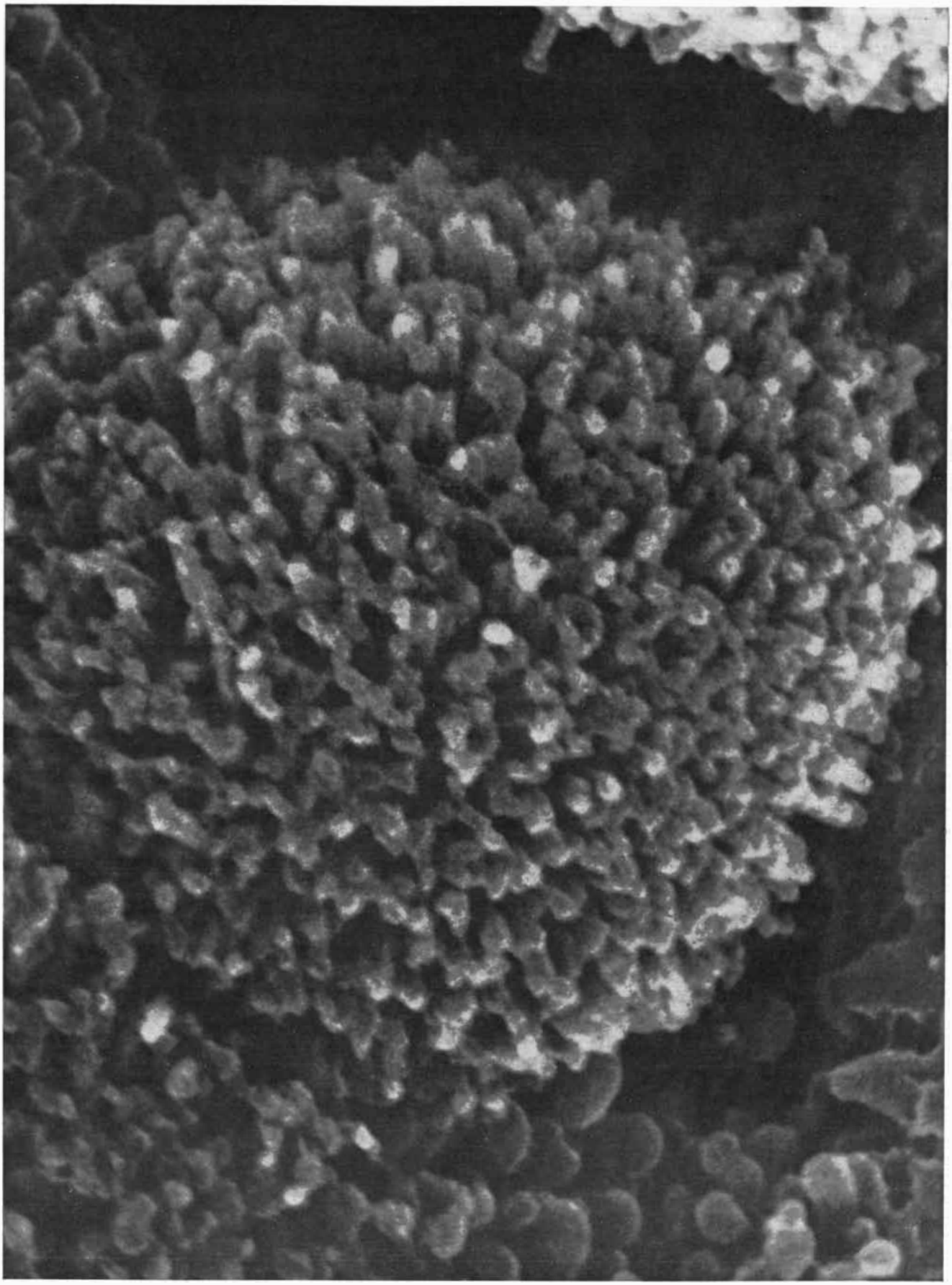
We make things that bring people closer.



LACTOSE IS DIGESTED BY LACTASE in the intestine, a single epithelial cell of which is enlarged 37,500 diameters in this scanning electron micrograph made by Jeanne M. Riddle of the Wayne State University School of Medicine. The cell, on the surface of one of the finger-like villi that stud the lining of the intestine, is in turn covered by innumerable fine processes called microvilli.

LACTOSE AND LACTASE

Lactose is milk sugar; the enzyme lactase breaks it down. For want of lactase most adults cannot digest milk. In populations that drink milk the adults have more lactase, perhaps through natural selection

by Norman Kretchmer

Milk is the universal food of newborn mammals, but some human infants cannot digest it because they lack sufficient quantities of lactase, the enzyme that breaks down lactose, or milk sugar. Adults of all animal species other than man also lack the enzyme—and so, it is now clear, do most human beings after between two and four years of age. That this general adult deficiency in lactase has come as a surprise to physiologists and nutritionists can perhaps be attributed to a kind of ethnic chauvinism, since the few human populations in which tolerance of lactose has been found to exceed intolerance include most northern European and white American ethnic groups.

Milk is a nearly complete human food, and in powdered form it can be conveniently stored and shipped long distances. Hence it is a popular source of protein and other nutrients in many programs of aid to nutritionally impoverished children, including American blacks. The discovery that many of these children are physiologically intolerant to lactose is therefore a matter of concern and its implications are currently being examined by such agencies as the U.S. Office of Child Development and the Protein Advisory Group of the United Nations System.

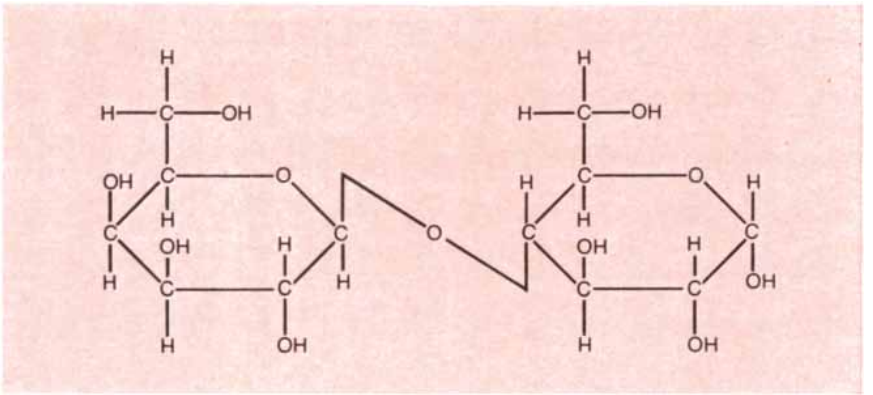
Lactose is one of the three major solid components of milk and its only carbohydrate; the other components are fats and proteins. Lactose is a disaccharide composed of the monosaccharides glucose and galactose. It is synthesized only by the cells of the lactating mammary gland, through the reaction of glucose with the compound uridine diphosphate galactose [*see illustrations on next page*]. One of the proteins found in milk, alpha-lactalbumin, is required for the synthesis of lactose. This protein apparently does not actually enter into the reaction; what it does is "specify" the action of the enzyme galactosyl transferase, modifying the enzyme so that in the presence of alpha-lactalbumin and glucose it catalyzes the synthesis of lactose.

In the nonlactating mammary gland, where alpha-lactalbumin is not present, the enzyme synthesizes instead of lactose a more complicated carbohydrate, N-acetyl lactosamine. Test-tube studies have shown that alpha-lactalbumin is manufactured only in the presence of certain hormones: insulin, cortisone, estrogen and prolactin; its synthesis is inhibited by the hormone progesterone. It is when progesterone levels decrease late in pregnancy that the manufacture of alpha-lactalbumin, and thus of lactose, is initiated [see "Milk," by Stuart Patton; SCIENTIFIC AMERICAN, July, 1969].

The concentration of lactose in milk from different sources varies considerably. Human milk is the sweetest, with 7.5 grams of lactose per 100 milliliters of milk. Cow's milk has 4.5 grams per 100 milliliters. The only mammals that do not have any lactose—or any other carbohydrate—in their milk are certain of the Pinnipedia: the seals, sea lions and walruses of the Pacific basin. If these animals are given lactose in any form, they become sick. (In 1933 there was a report of a baby walrus that was fed cow's milk while being shipped from Alaska to California. The animal suffered from severe diarrhea throughout the voyage and was very sick by the time it arrived in San Diego.) Of these pinnipeds the California sea lion has been the most intensively studied. No alpha-lactalbumin is synthesized by its mammary gland. When alpha-lactalbumin from either rat's milk or cow's milk is added to a preparation of sea lion mammary gland in a test tube, however, the glandular tissue does manufacture lactose.

In general, low concentrations of lactose are associated with high concentrations of milk fat (which is particularly useful to marine mammals). The Pacific pinnipeds have more than 35 grams of fat per 100 milliliters of milk, compared with less than four grams in the cow. In the whale and the bear (an ancient ancestor of which may also be an ancestor of the Pacific pinnipeds) the lactose in milk is low and the fat content is high.

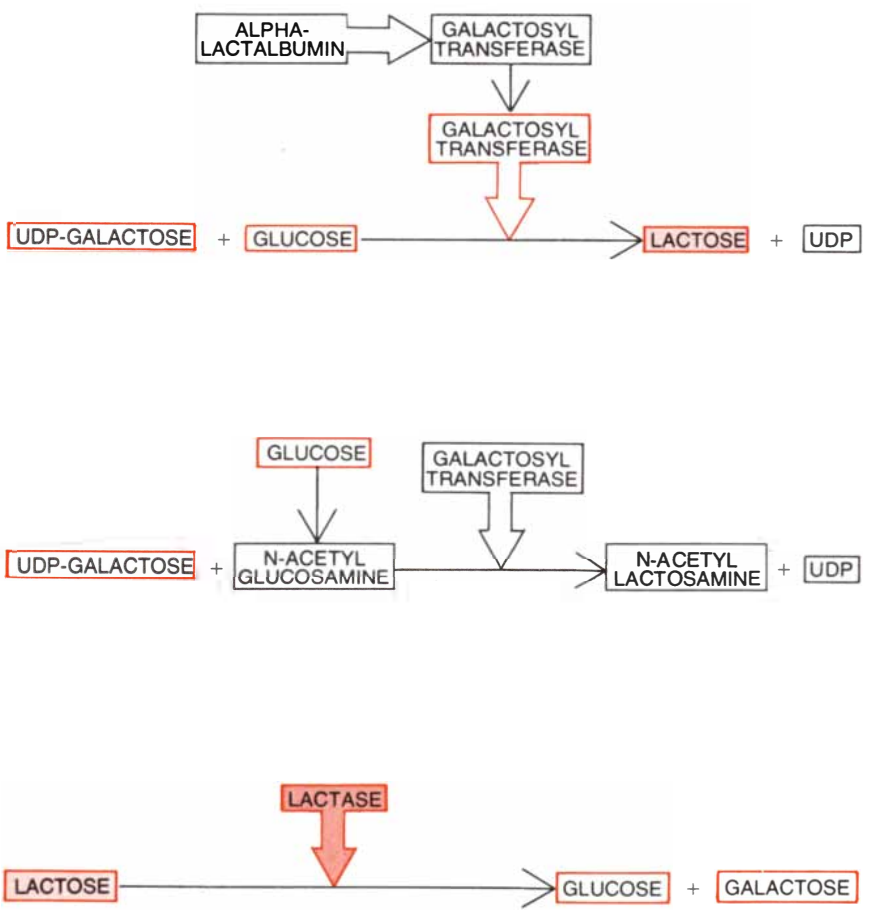
Lactase, the enzyme that breaks down lactose ingested in milk or a milk product, is a specific intestinal beta-galactosidase that acts only on lactose, primarily in the jejunum, the second of the small intestine's three main segments. The functional units of the wall of the small intestine are the villus (composed of metabolically active, differentiated, nondividing cells) and the crypt (a set of dividing cells from which those of the villus are derived). Lactase is not present in the dividing cells. It appears in the differentiated cells, specifically within the brush border of the cells at the surface of the villus [*see illustrations on page 74*]. Lactase splits the disaccharide lactose into its two component monosaccharides, glucose and galactose. Some of the released glucose can be utilized directly by the cells of the villus; the remainder, along with the galactose, enters the bloodstream, and both sugars are metabolized by the liver. Neither Gary Gray of the Stanford University School of Medicine nor other investigators have been able to distinguish any qualitative biochemical or physical difference among the lactases isolated from the intestine of infants, tolerant adults and intolerant adults. The difference appears to be



LACTOSE, a disaccharide composed of the monosaccharides glucose and galactose, is the carbohydrate of milk, the other major components of which are fats, proteins and water.

merely quantitative; there is simply very little lactase in the intestine of a lactose-intolerant person. In the intestine of Pacific pinnipeds, Philip Sunshine of the Stanford School of Medicine found, there is no lactase at all, even in infancy.

Lactase is not present in the intestine of the embryo or the fetus until the middle of the last stage of gestation. Its activity attains a maximum immediately after birth. Thereafter it decreases, reaching a low level, for example, immediately after weaning in the rat and after one and a half to three years in most children. The exact mechanism involved in the appearance and disappearance of the lactase is not known, but such a pattern of waxing and waning activity is common in the course of development; in general terms, one can say that it results from differential action of the gene or genes concerned.



SYNTHESIS OF LACTOSE in the mammary gland begins late in pregnancy when specific hormones and the protein alpha-lactalbumin are present. The latter modifies the enzyme galactosyl transferase, "specifying" it so that it catalyzes the synthesis of lactose from glucose and galactose (*top*). In the nonlactating gland the glucose takes part in a different reaction (*middle*). In intestine lactase breaks down lactose to glucose and galactose (*bottom*).

Soon after the turn of the century the distinguished American pediatrician Abraham Jacobi pointed out that diarrhea in babies could be associated with the ingestion of carbohydrates. In 1921 another pediatrician, John Howland, said that "there is with many patients an abnormal response on the part of the intestinal tract to carbohydrates, which expresses itself in the form of diarrhea and excessive fermentation." He suggested as the cause a deficiency in the hydrolysis, or enzymatic breakdown, of lactose.

The physiology is now well established. If the amount of lactose presented to the intestinal cells exceeds the hydrolytic capacity of the available lactase (whether because the lactase level is low or because an unusually large amount of lactose is ingested), a portion of the lactose remains undigested. Some of it passes into the blood and is eventually excreted in the urine. The remainder moves on into the large intestine, where two processes ensue. One is physical: the lactose molecules increase the particle content of the intestinal fluid compared with the fluid in cells outside the intestine and therefore by osmotic action draw water out of the tissues into the intestine. The other is biochemical: the glucose is fermented by the bacteria in the colon. Organic acids and carbon dioxide are generated and the symptoms can be those of any fermentative diarrhea, including a bloated feeling, flatulence, belching, cramps and a watery, explosive diarrhea.

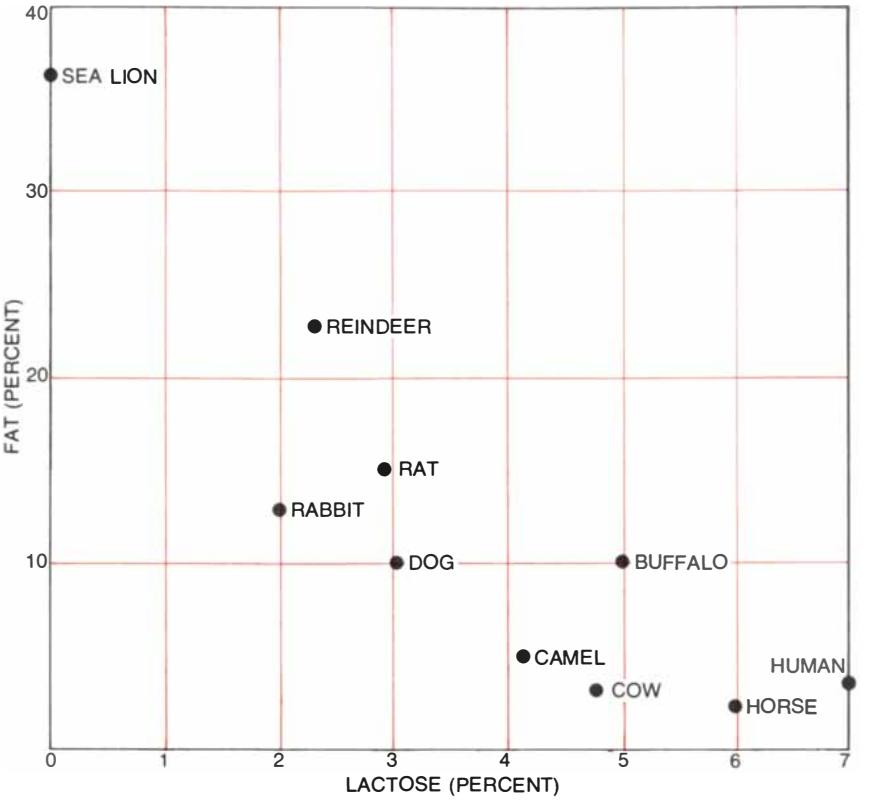
At the end of the 1950's Paolo Durand of the University of Genoa and Aaron Holzel and his colleagues at the University of Manchester reported detailed studies of infants who were unable to digest lactose and who reacted to milk sugar with severe diarrhea, malnutrition and even death. This work stimulated a revival of interest in lactose and lactase, and there followed a period of active investigation of lactose intolerance. Many cases were reported, including some in which lactase inactivity could be demonstrated in tissue taken from the patient's intestine by biopsy. It became clear that intolerance in infants could be a congenital condition (as in Holzel's two patients, who were siblings) or, more frequently, could be secondary to various diseases and other stresses: cystic fibrosis, celiac disease, malnutrition, the ingestion of certain drugs, surgery and even non-

specific diarrhea. During this period of investigation, it should be noted, intolerance to lactose was generally assumed to be the unusual condition and the condition worthy of study.

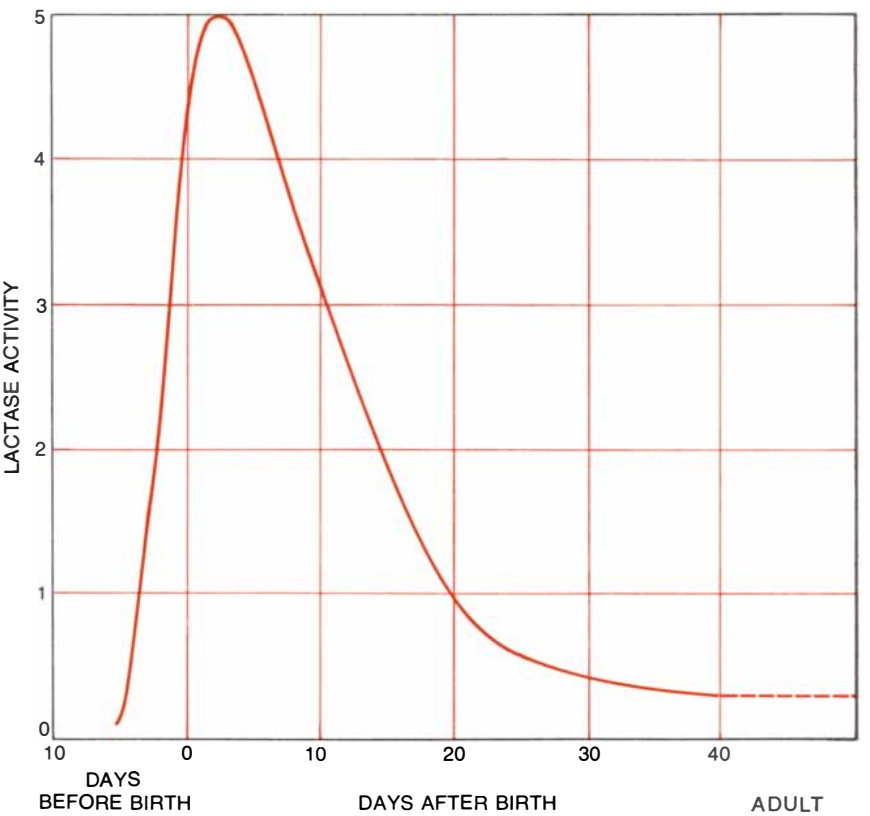
In 1965 Pedro Cuatrecasas and his colleagues and Theodore M. Bayless and Norton S. Rosensweig, all of whom were then at the Johns Hopkins School of Medicine, administered lactose to American blacks and whites, none of whom had had gastrointestinal complaints, and reported some startling findings. Whereas only from 6 to 15 percent of the whites showed clinical symptoms of intolerance, about 70 percent of the blacks were intolerant. This immediately suggested that many human adults might be unable to digest lactose and, more specifically, that there might be significant differences among ethnic groups. The possibility was soon confirmed: G. C. Cook and S. Kajubi of Makerere University College examined two different tribes in Uganda. They found that only 20 percent of the adults of the cattle-herding Tussi tribe were intolerant to lactose but that 80 percent of the nonpastoral Ganda were intolerant. Soon one paper after another reported a general intolerance to lactose among many ethnic groups, including Japanese, other Orientals, Jews in Israel, Eskimos and South American Indians.

In these studies various measures of intolerance were applied. One was the appearance of clinical symptoms—flatulence and diarrhea—after the ingestion of a dose of lactose, which was generally standardized at two grams of lactose per kilogram (2.2 pounds) of body weight, up to a maximum of either 50 or 100 grams. Another measure was a finding of low lactase activity (less than two units per gram of wet weight of tissue) determined through an intestinal biopsy after ingestion of the same dose of lactose. A third was an elevation of blood glucose of less than 20 milligrams per 100 milliliters of blood after ingestion of the lactose. Since clinical symptoms are variable and the biopsy method is inconvenient for the subject being tested, the blood glucose method is preferable. It is a direct measure of lactose breakdown, and false-negative results are rare if the glucose is measured 15 minutes after lactose is administered.

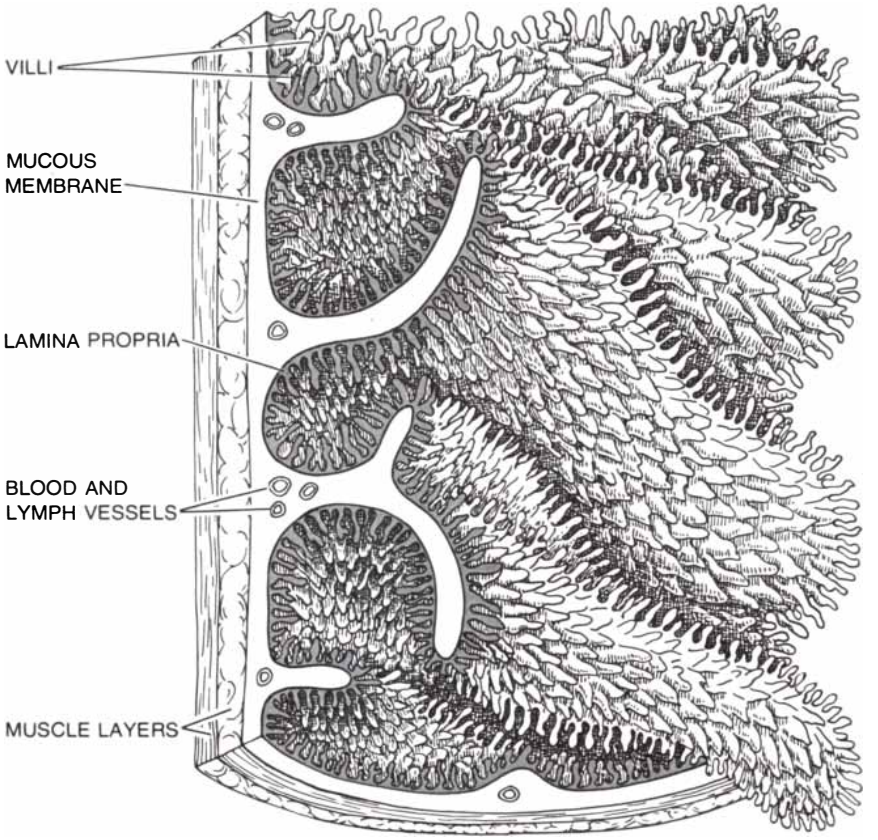
By 1970 enough data had been accumulated to indicate that many more groups all over the world are intolerant to lactose than are tolerant. As a matter of fact, real adult tolerance to lactose has so far been observed only in northern Europeans, approximately 90 percent of whom tolerate lactose, and in the

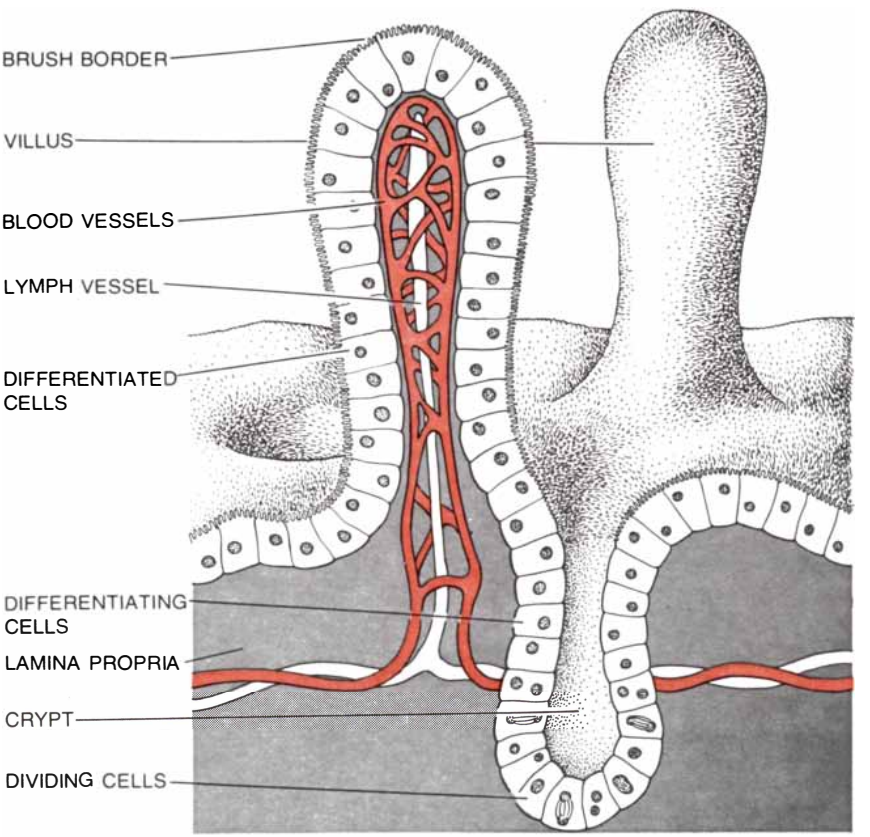


CONCENTRATION OF LACTOSE varies with the source of the milk. In general the less lactose, the more fat, which can also be utilized by the newborn animal as an energy source.



LACTASE is present in mammals other than man, and in most humans, in the fetus before birth and in infancy. The general shape of the curve of enzyme activity, shown here for the rat, is about the same in all species. Enzyme activity, given here in relative units, is determined by measuring glucose release from intestinal tissue in the presence of lactose.





WALL OF SMALL INTESTINE, seen in longitudinal section (*top*), has outer muscle layers, a submucosa layer and an inner mucous membrane. The mucous membrane (*bottom*) has a connective-tissue layer (lamina propria), which contains blood and lymph capillaries, and an inner surface of epithelial cells. The cells multiply and differentiate in the crypts and migrate to the villi. At what stage the lactase is manufactured is not known; it is found primarily in the microvilli, which constitute the brush border of the differentiated cells.

members of two nomadic pastoral tribes in Africa, of whom about 80 percent are tolerant. Although many other generally tolerant groups will be found, they will always belong to a minority of the human species. In this situation it is clearly more interesting and potentially more fruitful to focus the investigation on tolerant people in an effort to explain adult tolerance, a characteristic in which man differs from all other mammals.

There are two kinds of explanation of adult tolerance to lactose. The first, and perhaps the most immediately apparent, originates with the fact that most people who tolerate lactose have a history of drinking milk. Maybe the mere presence of milk in the diet suffices to stimulate lactase activity in the individual, perhaps by "turning on" genes that encode the synthesis of the enzyme. Individual enzymatic adaptation to an environmental stimulus is well known, but it is not transferable genetically. The other explanation of tolerance is based on the concept of evolution through natural selection. If in particular populations it became biologically advantageous to be able to digest milk, then the survival of individuals with a genetic mutation that led to higher intestinal lactase activity in adulthood would have been favored. An individual who derived his ability to digest lactose from this classical form of Darwinian adaptation would be expected to be able to transfer the trait genetically.

These two points of view have become the subject of considerable controversy. I suspect that each of the explanations is valid for some of the adult tolerance being observed, and I should like to examine both of them.

The possibility of individual adaptation to lactose has been considered since the beginning of the century, usually through attempts to relate lactase activity to the concentration of milk in the diet of animals. Almost without exception the studies showed that although there was a slight increase in lactase activity when a constant diet of milk or milk products was consumed, there was no significant change in the characteristic curve reflecting the developmental rise and fall of enzymatic activity. Recently there have been reports pointing toward adaptation, however. Some studies, with human subjects as well as rats, indicated that continued intensive feeding of milk or lactose not only made it possible for the individual to tolerate the sugar but also resulted in a measurable increase in lactase activity. The discrepancy among the findings could be partly

attributable to improvement in methods for assaying the enzyme activity.

On balance it would appear that individual adaptation may be able to explain at least some cases of adult tolerance. I shall cite two recent studies. John Godell, working in Lagos, selected six Nigerian medical students who were absolutely intolerant to lactose and who showed no physiological evidence of lactose hydrolysis. He fed them increasing amounts of the sugar for six months. Godell found that although the students did develop tolerance for the lactose, there was nevertheless no evidence of an increase of glucose in the blood—and thus of enzymatic adaptation—following test doses of the sugar. The conjecture is that the diet brought about a change in the bacterial flora in the intestine, and that the ingested lactose was being metabolized by the new bacteria.

In our laboratory at the Stanford School of Medicine Emanuel Lebenthal and Sunshine found that in rats given lactose the usual pattern of a developmental decrease in lactase activity is maintained but the activity level is somewhat higher at the end of the experiment. The rise in activity does not appear to be the result of an actual increase in lactase synthesis, however. We treated the rats with actinomycin, which prevents the synthesis of new protein from newly activated genes. The actinomycin had no effect on the slight increase in lactase activity, indicating that the mechanism leading to the increase was not gene activation. It appears, rather, that the presence of additional amounts of the enzyme's substrate, lactose, somehow "protects" the lactase from degradation. Such a process has been noted in many other enzyme-substrate systems. The additional lactase activity that results from this protection is sufficient to improve the rat's tolerance of lactose, but that additional activity is dependent on the continued presence of the lactose.

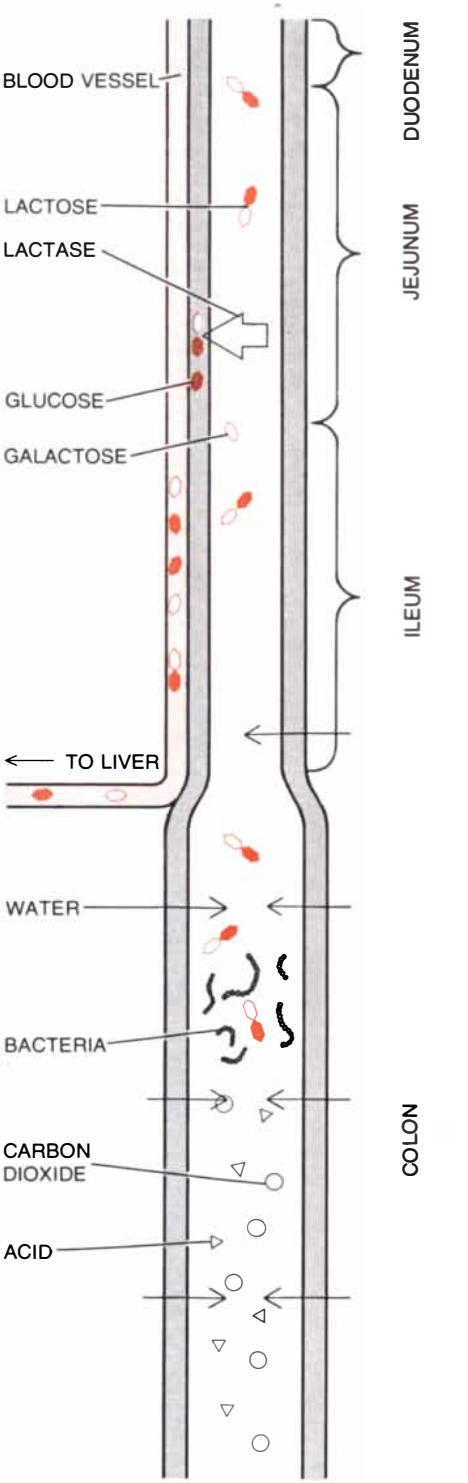
Testing the second hypothesis—that adult lactose tolerance is primarily the result of a long-term process of genetic selection—is more complicated. It involves data and reasoning from such disparate areas as history, anthropology, nutrition, genetics and sociology as well as biochemistry.

As I have noted, the work of Cuatrecasas, of Bayless and Rosensweig and of Cook and Kajubi in the mid-1960's pointed to the likelihood of significant differences in adult lactose tolerance among ethnic groups. It also suggested that one ought to study in particular black Americans and their ancestral populations in Africa. The west coast of Africa was the primary source of slaves for the New World. With the objective of studying lactose tolerance in Nigeria, we developed a joint project with a group from the University of Lagos Teaching Hospital headed by Olikoye Ransome-Kuti.

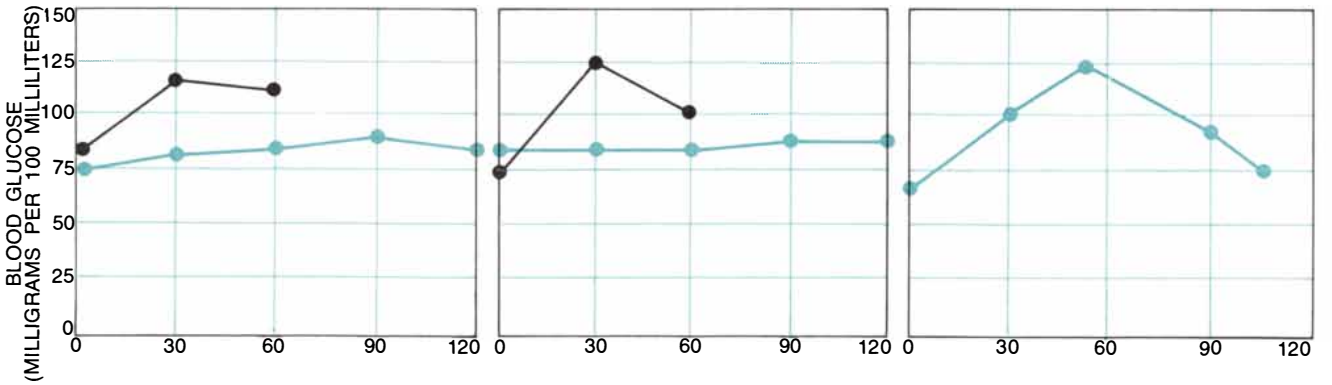
The four largest ethnic groups in Nigeria are the Yoruba in western Nigeria, the Ibo in the east and the Fulani and Hausa in the north. These groups have different origins and primary occupations. The Yoruba and the Ibo differ somewhat anthropometrically, but both are Negro ethnic groups that probably came originally from the Congo Basin; they were hunters and gatherers who became farmers. They eventually settled south of the Niger and Benue rivers in an area infested with the tsetse fly, so that they never acquired cattle (or any other beast of burden). Hence it was not until recent times that milk appeared in their diet beyond the age of weaning. After the colonization of their part of Nigeria by the British late in the 19th century, a number of Yoruba and Ibo, motivated by their intense desire for education, migrated to England and northern Europe; they acquired Western dietary habits and in some cases Western spouses, and many eventually returned to Nigeria.

The Fulani are Hamites who have been pastoral people for thousands of years, originally perhaps in western Asia and more recently in northwestern Africa. Wherever they went, they took their cattle with them, and many of the Fulani are still nomads who herd their cattle from one grazing ground to another. About 300 years ago the Fulani appeared in what is now Nigeria and waged war on the Hausa. (The Fulani also tried to invade Yorubaland but were defeated by the tsetse fly.) After the invasion of the Hausa region some of the Fulani moved into villages and towns.

As a result of intermarriage between the Fulani and the Hausa there appeared a new group known as the town-Fulani or the Hausa-Fulani, whose members no longer raise cattle and whose ingestion of lactose is quite different from that of the pastoral Fulani. The pastoral Fulani do their milking in the early morning and drink some fresh milk. The milk reaches the market in the villages and towns only in a fermented form, however, as a kind of yogurt called *nono*. As the *nono* stands in the morning sun it becomes a completely fermented, watery preparation, which is then thickened with millet or some other cereal. The final product is almost completely



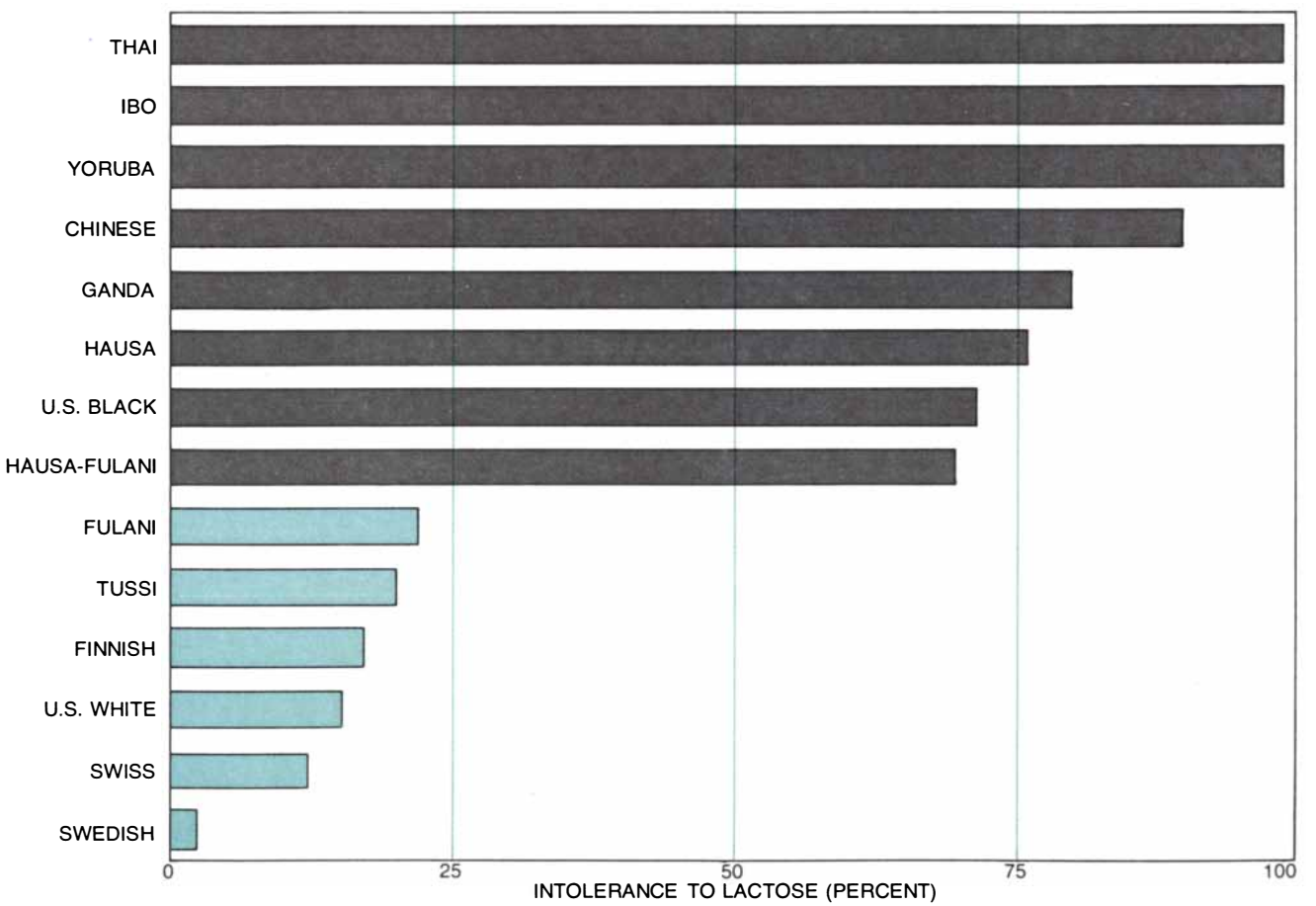
DIGESTION OF LACTOSE is accomplished primarily in the jejunum, where lactase splits it into glucose and galactose. Some glucose is utilized locally; the rest enters the bloodstream with the galactose and both are utilized in the liver. In the absence of enough lactase some undigested lactose enters the bloodstream; most goes on into the ileum and the colon, where it draws water from the tissues into the intestine by osmotic action. The undigested lactose is also fermented by bacteria in the colon, giving rise to various acids and carbon dioxide gas.



LACTOSE INTOLERANCE is determined by measuring blood glucose after ingestion of lactose. The absence of a significant rise in blood glucose after lactose ingestion (*color*) as contrasted with a rise in blood glucose after ingestion of sucrose, another sugar (*black*), indicates that a Yoruba male (*left*) and an American Jewish male (*middle*) are lactose-intolerant. On the other hand, the definite rise in blood glucose after ingestion of lactose in a Fulani male (*right*) shows that the Fulani is tolerant to lactose.

free of lactose and can be ingested without trouble even by a person who cannot digest lactose.

We tested members of each of these Nigerian populations. Of all the Yorubas above the age of four who were tested, we found only one person in whom the blood glucose rose to more than 20 milligrams per 100 milliliters following administration of the test dose of lactose. She was a nurse who had spent six years in the United Kingdom and had grown accustomed to a British diet that included milk. At first, she said, the milk disagreed with her, but later she could tolerate it with no adverse side effects. None of the Ibos who were studied showed an elevation of glucose in blood greater than 20 milligrams per 100 milliliters. (The major problem in all these studies is determining ethnic purity. All the Yorubas and Ibos who participated in this portion of the study indicated that there had been no intermarriages in their families.) Most of the Hausa and Hausa-Fulani



INTOLERANCE VARIES WIDELY among populations. The bars are based on tests conducted by a number of investigators by different methods; they may not be strictly comparable or accurately reflect the situation in entire populations. Among the groups studied to date lactose intolerance is prevalent except among northern Europeans (and their descendants) and herders in Africa.

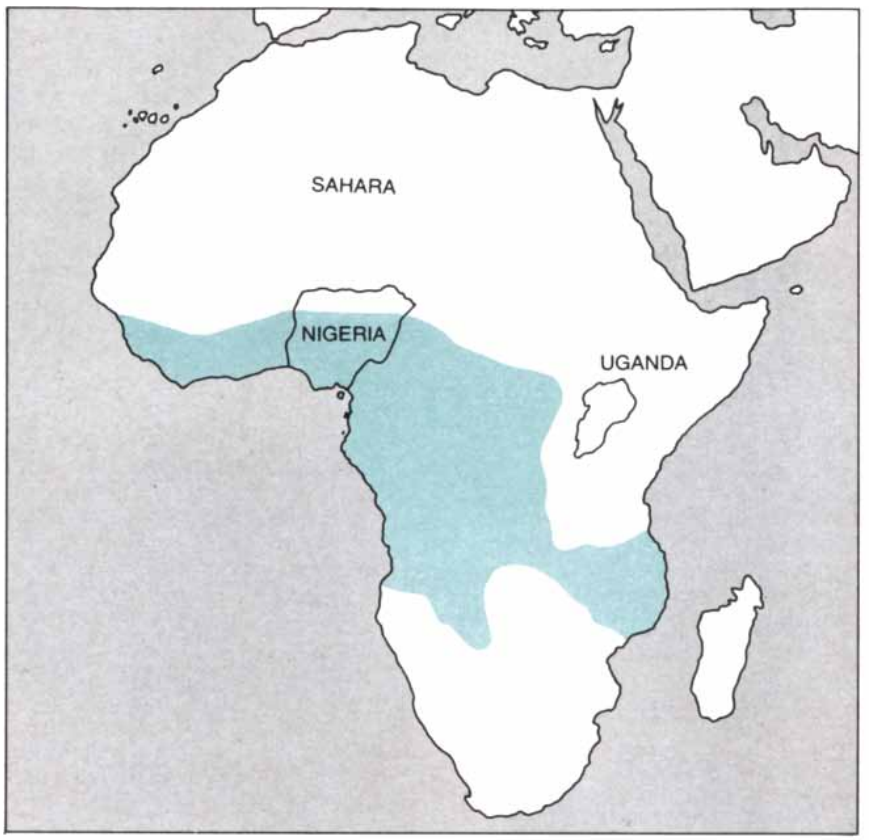
(70 to 80 percent) were intolerant to lactose. In contrast most of the nomadic Fulani (78 percent) were tolerant to it. In their ability to hydrolyze lactose they resembled the pastoral Tussi of Uganda and northern Europeans more than they resembled their nearest neighbors.

Once the distribution of lactose intolerance and tolerance was determined in the major Nigerian populations, we went on to study the genetics of the situation by determining the results of mixed marriages. One of the common marriages in western Nigeria is between a Yoruba male and a British or other northern European female; the reverse situation is less common. Our tests showed that when a tolerant northern European marries a lactose-intolerant Yoruba, the offspring are most likely to be lactose-tolerant. If a tolerant child resulting from such a marriage marries a pure Yoruba, then the children are also predominantly tolerant. There is no sex linkage of the genes involved: in the few cases in which a Yoruba female had married a northern European male, the children were predominantly tolerant.

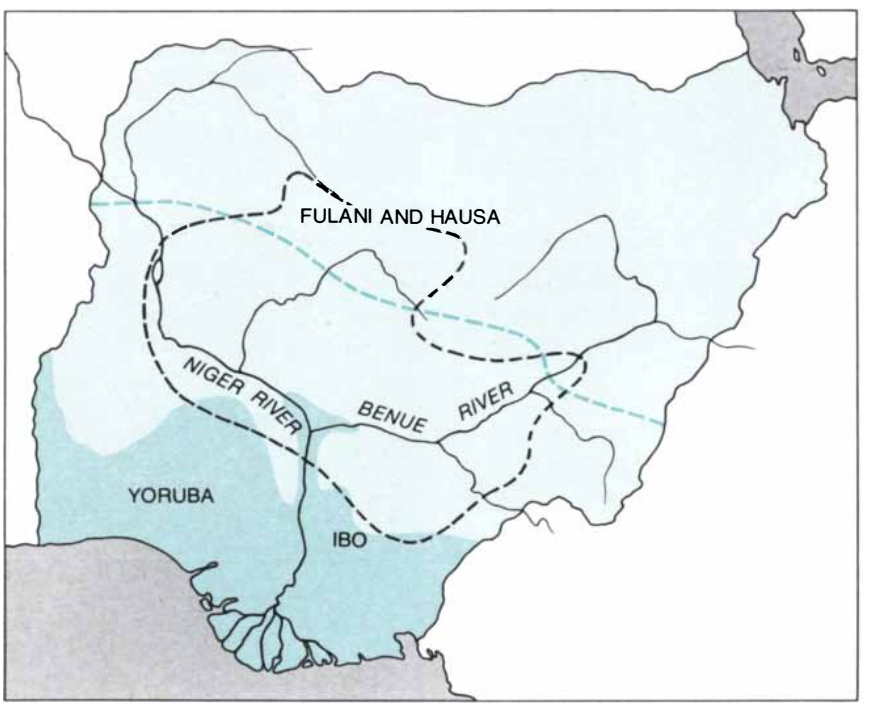
On the basis of these findings one can say that lactose tolerance is transmitted genetically and is dominant, that is, genes for tolerance from one of the parents are sufficient to make the child tolerant. On the other hand, the children of two pure Yorubas are always intolerant to lactose, as are the children of a lactose-intolerant European female and a Yoruba male. In other words, intolerance is also transmitted genetically and is probably a recessive trait, that is, both parents must be lactose-intolerant to produce an intolerant child. When the town-dwelling royal line of the Fulani was investigated, its members were all found to be unable to digest lactose—except for the children of one wife, a pastoral Fulani, who were tolerant.

Among the children of Yoruba-European marriages the genetic cross occurred one generation ago or at the most two generations. Among the Hausa-Fulani it may have been as much as 15 generations ago. This should explain the general intolerance of the Hausa-Fulani. Presumably the initial offspring of the lactose-tolerant Fulani and the lactose-intolerant Hausa were predominantly tolerant. As the generations passed, however, intolerance again became more prevalent. The genes for lactase can therefore be considered incompletely dominant.

The blacks brought to America were primarily Yoruba or Ibo or similar West African peoples who were originally



GEOGRAPHICAL EXTENT of dairying coincides roughly with areas of general lactose tolerance. According to Frederick J. Simoons of the University of California at Davis, there is a broad belt (*color*) across Africa in which dairying is not traditional. Migrations affect the tolerance pattern, however. For example, the Ganda, a lactose-intolerant group living in Uganda, came to that milk-drinking region from the nonmilking central Congo.



LARGEST ETHNIC GROUPS in Nigeria are the Ibo in the east, the Yoruba in the west and the Hausa and Fulani in the north. Map shows regions of mangrove swamp or forest (*dark color*) and grassland or desert (*light color*). Southern livestock limit (*broken colored line*) is set by climate, vegetation and tsetse fly infestation (*broken black line*).

intolerant to lactose. American blacks have been in this country for between 10 and 15 generations, in the course of which a certain complement of white northern European genes has entered the black population. Presumably as a result lactose intolerance among American blacks has been reduced to approximately 70 percent. One can speculate that if this gene flow eventually stopped, lactose intolerance would approach 100 percent among American blacks.

What events in human cultural history might have influenced the development of tolerance to lactose in the adults of some groups? Frederick J. Simoons of the University of California at Davis has proposed a hypothesis based on the development of dairying. It would appear that the milking of cattle, sheep, goats or reindeer did not begin until about 10,000 years ago, some 100 million years after the origin of mammals and therefore long after the mammalian developmental pattern of lactase activity had been well established. Man presumably shared that pattern, and so adults were intolerant to lactose. When some small groups of humans began to milk animals, a selective advantage was conferred on individuals who, because of a chance mutation, had high enough lactase activity to digest lactose. A person who could not digest lactose might have difficulty in a society that ingested nonfermented milk or milk products, but the lactose-tolerant individual was more adaptable: he could survive perfectly well in either a milk-drinking or a non-milk-drinking society.

The genetic mutation resulting in the capability to digest lactose probably occurred at least 10,000 years ago. People with the mutation for adult lactase activity could be members of a dairying culture, utilize their own product for food (as the Fulani do today) and then sell it in the form of a yogurt (as the Fulani do) or cheese to the general, lactose-intolerant population. These statements are presumptions, not facts, but they are based soundly on the idea that tolerance to lactose is a mutation that endowed the individual with a nutritional genetic advantage and on the basic assumption, which is supported by fact, that lactose intolerance is the normal genetic state of adult man and that lactose tolerance is in a sense abnormal.

What are the implications of all of this for nutrition policy? It should be pointed out that many people who are intolerant to lactose are nevertheless able to drink some milk or eat some milk products; the relation of clinical symptoms to lactose ingestion is quantitative. For most people, even after the age of four, drinking moderate amounts of milk has no adverse effects and is actually nutritionally beneficial. It may well be, however, that programs of indiscriminate, large-scale distribution of milk powder to intolerant populations should be modified, or that current moves toward supplying lactose-free milk powder should be encouraged.

FULANI WOMAN offers *nono*, a yogurt-like milk drink, for sale in the marketplace of a town in northern Nigeria. The pastoral Fulani drink fresh milk. The partially fermented *nono*, with reduced lactose content, is tolerated by villagers who could not digest milk.

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THE CARBON CHEMISTRY OF THE MOON

Exhaustive analysis of the Apollo samples reveals various simple organic compounds. These substances did not originate with life, but they add to the store of information on how life originated

by Geoffrey Eglinton, James R. Maxwell and Colin T. Pillinger

It seems increasingly likely that we are not alone in the universe. There may be millions of inhabited planets like our own. It is a prime goal of science to search for life or its remnants elsewhere in the solar system or the universe. We want to know how unique the earth's life-forms may be and how they originated. We want to test, if we can, the hypothesis of chemical evolution: the gradual development of increasingly complex organic compounds from simple precursors, leading to the spontaneous generation of life wherever conditions are favorable. We cannot, however, dismiss an alternate hypothesis: that the emergence of life is extremely rare but that living forms can seed themselves in some fashion across the vast reaches of space.

The samples returned from the moon have provided the first opportunity to test our life-detection methods on samples that have been carefully collected and protected from terrestrial contamination, thereby avoiding the bitter controversy surrounding the analysis of meteorites. This first search has now been completed. No life-forms, living or dead, have been found in the lunar samples after intensive studies with sophisticated techniques capable of revealing any biochemicals or their derived products in amounts exceeding a few parts in a thousand million (10^9).

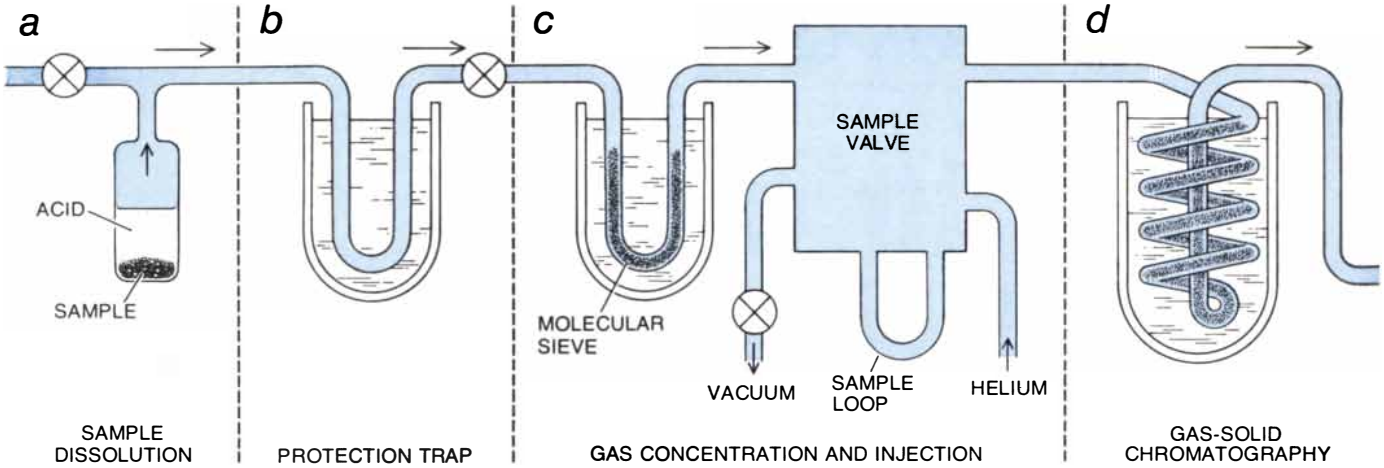
The samples have revealed much, however, about the carbon chemistry of the moon. It is entirely different from the carbon chemistry of the earth and is more closely related to cosmic physics than to conventional organic chemistry. We shall explain how we have come to this realization by presenting the story chronologically, at least up to the time of the First Annual Lunar Science Conference in January, 1970, which marked the end of the initial phase of study of the returned samples. For the purpose of continuity the account is largely from the viewpoint of our own group at the University of Bristol, although other investigators have obtained similar results independently.

Before the landing of *Apollo 11* in July, 1969, there were many divergent views on the possibility of finding traces of life on the moon. The smooth, dark regions on the moon, so clearly visible from the earth, had long been called maria, meaning seas, and it did not seem totally unreasonable to regard them as evaporated seas. The rilles, or winding valleys, seen through telescopes were frequently described as dried-up river or glacial valleys. Only a few months before the flight of *Apollo 11* one prominent worker predicted that the maria would be found to contain huge quantities of organic matter. Another even suggested that the dark maria were solidified seas of bitumen. A more modest proposal, made by Harold C. Urey of the University of California at San Diego, was that the lunar surface could well have been contaminated by organisms transported from the earth's biosphere early in the evolution of the earth-moon system.

In any event enough was known about the moon to realize that its environment is extremely hostile to life. The temperature of its surface varies between −140 and +150 degrees Celsius. Lacking an atmosphere and a significant magnetic field, it is exposed to ultraviolet radiation from the sun and an intense flux of atomic particles in the solar "wind" and cosmic rays. Indeed, the flux of radiation and particles would be expected to destroy most carbon compounds lying unprotected at the surface. Furthermore, in the late 1960's automatic remote analyses by Surveyor moon-landers had shown that the elemental composition of the material at three different sites qualitatively resembled terrestrial basaltic igneous rock. One could infer from these analyses that the high temperatures (over 1,100 degrees C.) needed for basalt formation would certainly obliterate by pyrolysis all record of previous life. The moon's carbon chemistry might then be mainly inorganic (as it is in terrestrial igneous rocks, where elemental carbon is accompanied by trapped gases such as carbon dioxide and carbon monoxide).

A moon with an outer skin of volcanic rocks was not an exciting prospect for biologists and organic chemists. Even if the rocks were volcanic, however, the multibillion-year bombardment of the moon's surface by meteorites (and possibly comets) might have given a peculiar twist to the moon's carbon chemistry. If one could find traces of these extraterrestrial wanderers, particularly the meteorites known as carbonaceous chondrites, in samples collected by the astronauts, one might be able to learn something about their carbon chemistry

ASTRONAUT CHARLES M. DUKE, JR., uses a sampling scoop to collect lunar soil during the first extravehicular activity of *Apollo 16* on April 21, 1972. He is standing at the rim of Plum Crater at the Descartes landing site. The parked Lunar Roving Vehicle is in the far left background. The two bright spots near the top are reflections of the sun from the inside of the camera lens. Duke's sun visor reflects the figure of Commander John W. Young as he takes the photograph. More than 30 soil samples collected by the astronauts of *Apollo 16* were returned to the earth; most of them are being analyzed for their carbon content. Samples from the four earlier landings of the Apollo program have been analyzed.



GAS CHROMATOGRAPHY is one method of analyzing the lunar fines (sieved soil) for their carbon content. The fines are dissolved in deuterated acid (acid in which the hydrogen is replaced by deuterium) under vacuum (*a*); the dissolution releases the gases such as methane trapped in the fines and deuterocarbons from reactions between the deuterated acid and carbide. Less volatile (less reactive) gases evolved in the dissolution (two-carbon and three-carbon hydrocarbons and deuterocarbons) and the vapors of the acid are retained in a protection trap (*b*) that is cooled by liquid nitrogen. The methanes evolved are retained and concentrated on a molecular sieve (*c*) at the same temperature. The valve between the sieve and the protection trap is closed, and the molecular sieve is warmed to room temperature. The methanes expand and travel into the evacuated loop of the sampling valve. A known fraction of the methanes is injected into the gas chromatographic column (*d*) by switching the sample loop into a stream of helium gas. The gas chromatographic column is packed with Graphon (graphitized carbon), which holds back methane (CH_4) more than the deuterocarbon CD_4 at −78 degrees Celsius. The CH_4 and CD_4 separate, and the emerging gases are detected by the change in electrical signal when

without the confusing terrestrial contamination that had plagued studies of meteorites picked up on the earth.

On the other hand, since meteorites strike the moon with undiminished cosmic velocity (around 22,000 kilometers per hour), they must be nearly totally vaporized on impact. As a result their known content of extractable carbon compounds, polymeric organic material, carbonates, metal carbides and graphite could hardly survive in its original form but would presumably be lost rapidly to space as gaseous products such as carbon monoxide and carbon dioxide. The question was: Would any trace of meteoritic carbon be left on the surface? One bold proposal, made by Samuel Tolansky of the University of London, was that the shock waves would generate diamond from any carbon in the surface rocks.

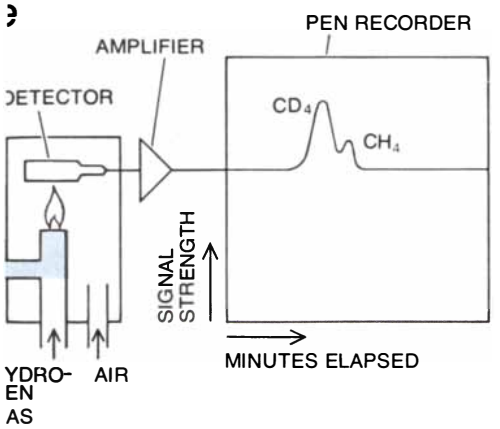
Another source of carbon that seemed certain to contribute to the moon was the solar wind: the flux of atomic nuclei expelled by the sun. Elements abundant in the solar wind should be found implanted in the moon's surface. By far the most abundant element is hydrogen, but for approximately every 7,500 hydrogen nuclei in the solar wind there is one carbon nucleus. The total flux of carbon nuclei is 40,000 per square centimeter per second. In the summer of 1969 we hypothesized that this carbon might make a sizable contribution to the carbon content of the lunar soil. We believed that a readily identifiable carbon compound formed at the lunar surface from hydrogen and carbon present in the solar wind would be methane (CH_4). We resolved to search for methane and other simple hydrocarbons.

First, however, we planned in company with a number of other organic chemists to undertake a search for "biological markers," or "chemical fossils": organic compounds whose distinctive structure can only have originated with compounds produced by living organisms [see "Chemical Fossils," by Geoffrey Eglinton and Melvin Calvin; SCIENTIFIC AMERICAN, January, 1967]. We were very pessimistic about the chances of finding such compounds, but it was a search that had to be made. In other laboratories parallel investigations would involve efforts to cultivate viable lunar organisms and to recognize nonviable organisms and microfossils.

Accordingly the months preceding September, 1969, were a time of frenzied preparation for the organic chemists. Experience laboriously acquired from the analysis of meteorites and ancient rocks was turned to improving laboratory facilities and the sensitivity of detection methods. A parallel effort went into the equally important control of contamination. As one investigator said later: "The noise of the sharpening of tools was deafening."

In the specially built Lunar Receiving Laboratory at the Manned Spacecraft Center in Houston groups of scientists and technicians faced the unprecedented task of sorting, examining, cataloguing and distributing the lunar harvest. Contamination of all kinds had to be restricted while a mandatory quarantine operation was maintained to protect the terrestrial biosphere from potentially harmful hypothetical lunar organisms. Such procedures were regarded by many as a dress rehearsal for the return of samples from elsewhere in the solar system where primitive life-forms might exist, for instance a Martian sample. The boxes containing the *Apollo 11* samples were to be opened inside a complex interconnected system of vacuum and nitrogen-filled glove boxes constituting the primary biological barrier inside a secondary barrier: the quarantine area. Some problems of contamination in the system were reduced to a low level by the efforts of Bernd R. Simoneit of the University of California at Berkeley and Donald A. Flory of the University of Houston, who compiled a "Domesday Book" of contemporary contaminants.

Four types of material were returned by the *Apollo 11* astronauts: two varieties of igneous rock (one fine-grained with bubbles and the other medium-grained with larger voids), brecciated rocks (tightly compacted grains of soil) and the soil itself (a heterogeneous mixture of microbreccias, fragments of crystalline rock and amorphous blobs and beads of glass). All the samples were clearly igneous in origin; the crystalline rocks had evidently been deposited as



DETECTOR SYSTEM

they burn in the hydrogen of a flame ionization detector (*e*). The strength of the signal versus time elapsed is recorded on a moving chart. The two-carbon and three-carbon hydrocarbons can be analyzed in a similar way. A second detector (*not shown*) that relies on thermal conductivity of the gases is fitted in series for the detection of gases such as carbon monoxide that are not detectable with the flame ionization detector.

basaltic lava flows between three and four billion years ago. It was also evident that the various minerals had been formed in an atmosphere extremely low in water vapor, oxygen and sulfur; the samples contained no evidence of water, either free or combined in the minerals.

The microscopic appearance of the minerals, the presence of brecciated materials and the variety of micrometeorite craters on exterior surfaces clearly indicated that the samples had been exposed to bombardment from meteorites of all sizes. The presence of detectable quantities of the isotope aluminum 26, known to be produced by nuclear reactions, suggested a prolonged exposure to cosmic rays. The soils and breccias had also been subjected to prolonged bombardment by the nuclei of the solar wind, as was indicated by the composition and the quantities of noble gases released by heating (chiefly helium, neon and argon).

Two methods had been set up at Houston for making a preliminary assessment of the content of organic matter. The simplest involved pyrolysis of a small sample at 800 degrees C.; volatile compounds and pyrolysis products would be carried by a stream of helium and hydrogen into a flame ionization detector. The second method involved heating a small sample to a lower temperature (500 degrees C.). The gases evolved would be monitored continuously and identified by a mass spectrometer coupled with a computer. There was a worldwide flurry of excitement when it was announced that preliminary results of the first experiment indicated that the lunar soil contained as much carbonaceous matter as a lean earth soil: about 100 parts per million (p.p.m.). Analyses by the second method, however, soon demonstrated that if carbon monoxide (CO), carbon dioxide (CO_2) and other small carbon-containing molecules were ignored, the lunar samples contained less than one p.p.m. of volatile and pyrolyzable organic matter. It was clear that identification of the organic compounds possibly present in the samples was not going to be easy.

Meanwhile biologists had fed or applied small amounts of all lunar samples to a wide variety of organisms, including germ-free mice, quail, fishes, insects, other invertebrates, tissue cultures and many kinds of plants. No pathogenic effects were observed. All attempts to cultivate viable lunar organisms on a variety of nutrient media also proved vain. The contamination of our biosphere by a harmful lunar organism was therefore deemed unlikely, and official approval was given in August, 1969, to lift the quarantine restrictions. The distribution of samples to the various groups of expectant investigators got under way in September and the race was on to get results by the time of the January conference. Until then no publication of results was allowed in an effort to prevent hasty studies and premature announcements.

Our own first lunar sample, 100 grams of soil, reached us at Bristol on October 23, 1969. Together with our colleagues Paul I. Abell of the University of Rhode Island, John Hayes of Indiana University and Harry Draffan of our own group, we opened the sample in our organic clean facility, a miniature lunar receiving laboratory supplied with cleaned, filtered air. Our first search was for biolipids such as hydrocarbons, alcohols and fatty acids. We rigorously applied the organic geochemical procedures and contamination controls that had been developed for the samples containing minute amounts of organic compounds. We placed 14 grams of the dark lunar dust inside a closed glass-and-Teflon system containing a controlled environment of inert gas. In this system we carried out a classical procedure familiar to all chemistry students: a mixture of benzene and methanol was added to the sample to extract any organic compounds that might be present. The solvent was then removed and evaporated. A chemical reaction was performed that would convert certain compounds into derivatives suitably volatile for gas chromatography; for example, organic acids would be converted into trimethysilyl esters. Our gas-chromatographic and mass-spectrometric detection systems could not, however, detect any compounds above the background levels. Therefore we could specify that the lunar dust contained no more than five parts per billion by weight of hydrocarbons, alcohols or fatty acids of medium molecular weight. Although the result was in some ways disappointing, it was also gratifying, considering the manifold possibilities for the contamination of the samples.

There seemed to be little point in repeating these experiments, and so we turned to our second objective: a search for methane (CH_4) and other hydrocarbons of low molecular weight (conceivably built up from the nuclei in the solar wind) and for trapped gases such as carbon monoxide and carbon dioxide. We were hopeful of finding something of interest, since Carleton B. Moore of Arizona State University had circulated preliminary results, obtained by burning the lunar soil in oxygen at high temperature, indicating that the soil contained some 140 to 260 p.p.m. of total carbon.

For the first step in this search we conducted a carefully controlled pyrolysis (maximum temperature 900 degrees C.) with mass-spectrometric analysis of all substances driven out of the sample. As the temperature was raised our spectrometer showed abundant hydrogen, then small amounts of methane, other hydrocarbons of low molecular weight and the noble gases. The next compounds evolved were traces of benzene, alkylbenzenes, thiophene and related substances. Throughout the pyrolysis, particularly at higher temperatures, the sample released substantial amounts of carbon dioxide and carbon monoxide, the carbon dioxide being the most abundant at first and the carbon monoxide becoming the principal component above 700 degrees C. Except for the noble gases any of these products might have been either trapped in the lunar soil or produced by the pyrolytic decomposition of other compounds.

We inferred from the large amounts of carbon monoxide and carbon dioxide evolved and the high temperature at which they appeared that their origin was predominantly pyrolytic. On the other hand, the methane appeared at such a low temperature (below 500 degrees C.) that we had reason to hope it was indeed a trapped gas of solar origin.

As the next step we attempted crushing the lunar soil to release trapped gases. The results were inconclusive. We

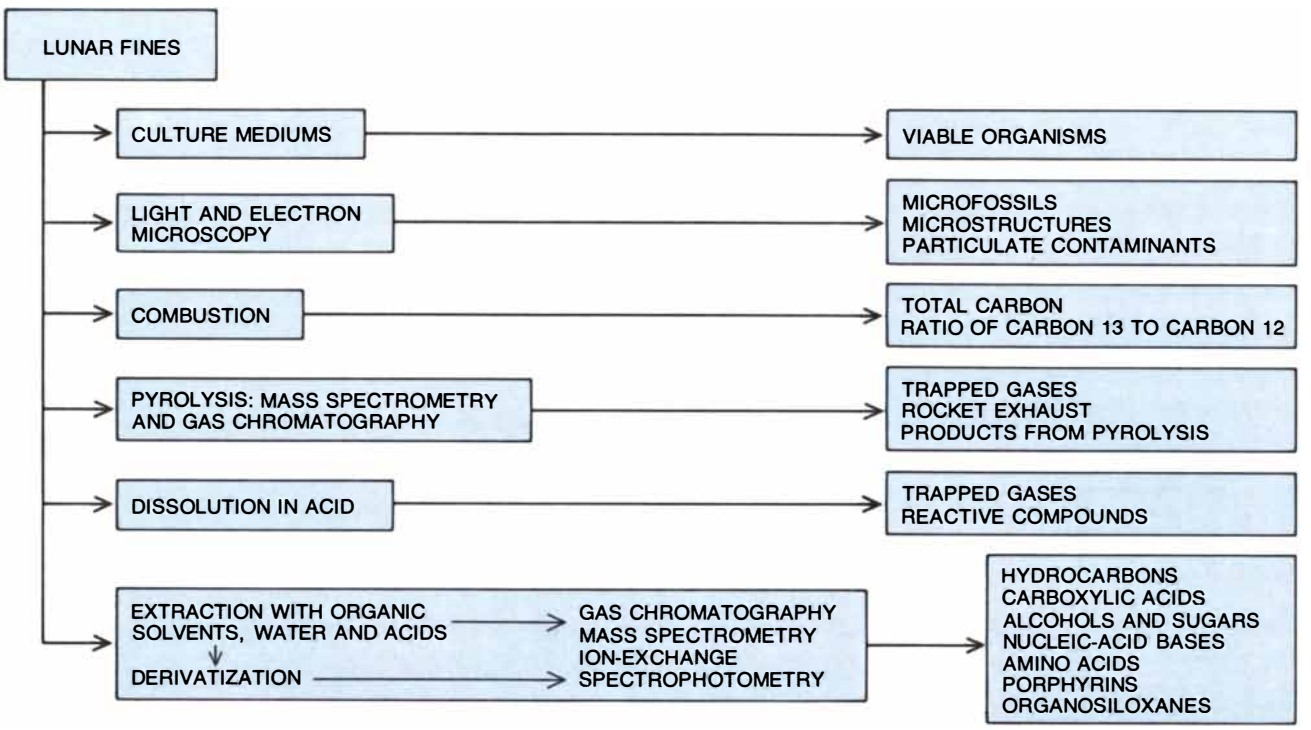
decided to decompose the soil in hydrofluoric acid. The fines dissolved so readily that the mixture frothed up in the tube. We captured the released gases in low-temperature traps and then fractioned them into a mass spectrometer. The noble gases helium, neon and argon were recognized in their solar proportions, as had already been observed by the preliminary-examination team at Houston, together with several parts per million of the hoped-for methane. We set off for Houston with our preliminary conclusions that the lunar soil contained no detectable biolipids but did contain methane, possibly of solar-wind origin.

On January 5, 1970, approximately 1,000 investigators, coinvestigators, officials of the National Aeronautics and Space Administration and newsmen gathered at Houston for the First Lunar Conference. Each investigator avidly read the abstracts of papers submitted by others, anxious to glean whatever information he could before delivering his own paper. One was reminded of the atmosphere after an important final examination, where one looks for assurance by seeking others who have obtained similar results.

Among biologists and micropaleontologists there were no problems. Attempts to discover viable organisms in the lunar samples by Vance I. Oyama of the Ames Research Center of NASA had continued to be unsuccessful. Efforts to detect fossil organisms proved similarly barren. Although no indication of any structure with a biological morphology was discovered, J. William Schopf of the University of California at Los Angeles reported finding fibers that could only have been introduced as a contaminant during preparation of the sample.

As for biolipids, there was general but not universal agreement that most organic compounds considered as "biological markers" were not present above the limits of detection. For example, one important class of biological markers, alkanes with more than 12 carbon atoms, was shown to be absent at a detection level of one part per billion by Warren G. Meinschein of Indiana University. There was some controversy, however, over the possible presence of amino acids and porphyrins, the former compounds being the building blocks of proteins and the latter being related to the biological pigments chlorophyll and hemoglobin.

Moore's preliminary finding that lunar fines contain between 140 and 260 p.p.m. of total carbon was confirmed by two other investigators. The igneous rocks were found to contain substantially less. Moore and Isaac R. Kaplan of the

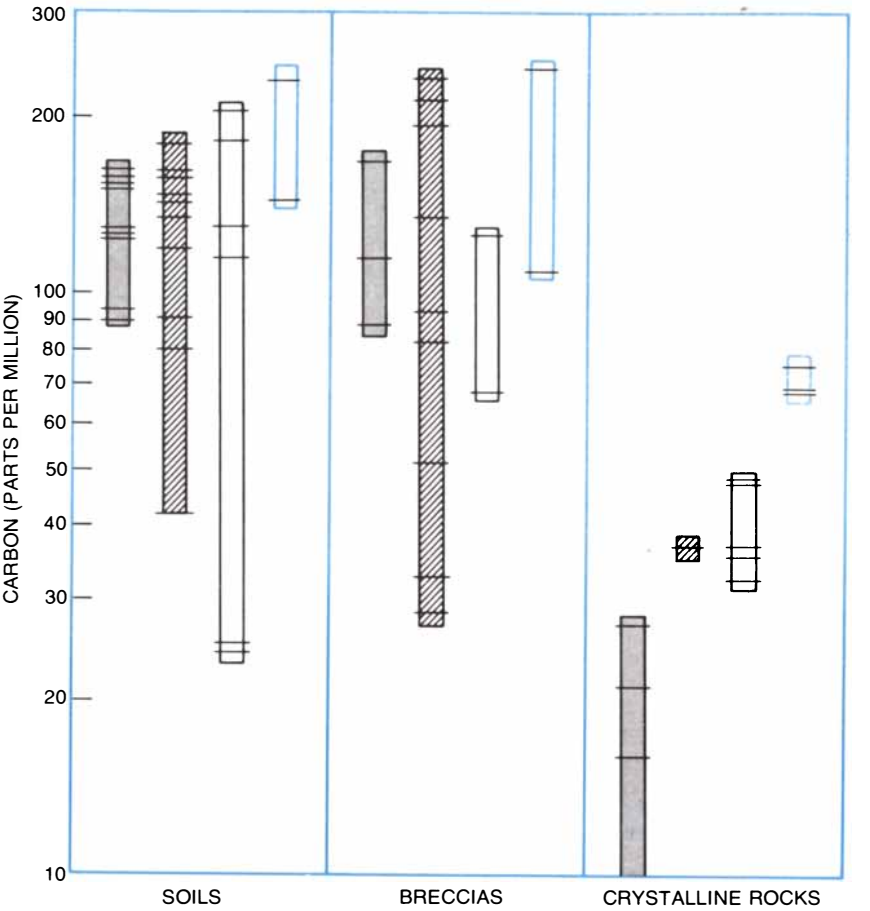


LUNAR FINES WERE ANALYZED with half a dozen different methods by the bioscience investigators. The fines were cultured in various mediums to see if they contained viable microorganisms; none was detected. Under light and electron microscopes no microfossils were revealed; vesicles (small cavities), one graphite particle and a few fragments of the mineral cohenite were observed, however. Handling the samples contaminated them with biological fibers, silicone rubber and fragments of Teflon. Combustion yielded a total carbon content of between 25 and 260 parts per million (p.p.m.), depending on the sample. Deviations in the ratio of carbon 13 to carbon 12 ranged from −4 to +20 parts per thousand compared with a terrestrial standard (calcium carbonate in a fossil called the Pee Dee belemnite). Portions of the lunar fines were pyrolized (heated to a very high temperature); several compounds containing nitrogen were identified as coming from rocket exhaust. The products of the pyrolysis consisted mainly of carbon monoxide, carbon dioxide and a few p.p.m. of methane, plus compounds of nitrogen and sulfur, and traces of aliphatic (straight-chain) and aromatic (ring) hydrocarbons. Methane and two-carbon and three-carbon hydrocarbons trapped in the samples were released when the fines were dissolved in acid. At least 20 p.p.m. of reactive carbides were found in the *Apollo 11* fines; carbides are ubiquitous constituents of all soils examined so far. Most organic compounds such as carboxylic acids, alcohols, sugars and nucleic acid bases were absent above the levels of detection of the gas chromatograph and mass spectrometer, which means that they could not be present in quantities greater than a few parts per billion. One exception was amino acids, which were detected in amounts up to 70 parts per billion total in the *Apollo 11* fines and were possibly formed during the period of analysis from nitrogen-containing precursors. Some 40 p.p.m. of organo-siloxanes were also detected, but later work showed that they were probably artifacts of the experiment.

University of California at Los Angeles had gone on to show that carbon was concentrated in the finest particles of the soil and that the breccias had a carbon content consistent with their being formed by compaction of the fines.

Since biological carbon compounds were evidently not the major constituents of the samples, the question was: In what forms was the carbon in the fines? Pyrolysis products were examined in several laboratories and found to contain aromatic hydrocarbons of low molecular weight. The groups led by Bartholomew S. Nagy of the University of Arizona and Klaus Biemann of the Massachusetts Institute of Technology were able to identify many of these trace components. There was general agreement, however, that pyrolysis of the fines released most of the carbon as carbon monoxide and carbon dioxide; the monoxide was most abundant at high temperatures and the dioxide at lower temperature. The group led by Cyril Ponnamperuma at the Ames Research Center proposed that the reaction of elemental carbon with oxides, particularly iron oxide, would be thermodynamically favorable for forming carbon monoxide.

Further information came from acid-dissolution experiments similar to our own. With hydrochloric acid as the solvent, the Ames group analyzed the released gases by gas chromatography and found that methane and a series of two-carbon, three-carbon and four-carbon hydrocarbons totaled 20 p.p.m. of carbon. A similar series of hydrocarbons was evolved when the same treatment was given to a sample of cohenite, an iron-nickel carbide obtained from the Canyon Diablo meteorite. The Ames group therefore ascribed the hydrocarbons released from the lunar fines by acid to the hydrolysis of metal carbides. On the other hand, Melvin Calvin's group at the University of California at Berkeley, working with high-resolution mass spectrometry, found that the gases evolved by hydrofluoric acid contained methane but that carbon monoxide was by far the largest component. This suggested to them that carbon monoxide might exist in the fines as such.



CARBON CONTENT OF LUNAR SAMPLES from *Apollo 11* (*open color bar*), *12* (*open black bar*), *14* (*hatched bar*) and *15* (*gray bar*) was determined by heating the samples in an oxygen atmosphere. The resulting carbon dioxide was assayed by gas chromatography. The vertical bars represent the range of carbon found in samples of various types (soils, breccias and crystalline rocks); the horizontal marks are measurements of individual samples. The vertical scale on the left is logarithmic. Total carbon content of most soils and samples of breccias is systematically higher than the carbon content of igneous (crystalline) rocks. This fact indicates that most of the carbon in the soil might originate from the solar wind and meteorites. Trend of lower carbon content of igneous rocks with each mission suggests that procedures for controlling contamination of samples have been improved.

Thus two very important questions seemed to be posed. First, were the hydrocarbons indigenous or did they result from the reaction of some carbide species with the mineral acids? The latter source seemed to be strongly supported by two mineralogists who independently said they had seen a microscopic fragment of the mineral cohenite in the fines. The second question was: Is carbon monoxide produced only by pyrolysis or does it also exist as such in the fines?

We found that we were not alone in suggesting that the solar wind played an important role in lunar carbon chemistry. Moore had calculated that the excess carbon in the lunar fines and breccias, compared with samples of crystalline lunar rock, could be accounted for by solar-wind carbon. Further evidence was provided by measuring the proportion of carbon that was present as the isotope carbon 13. A certain ratio of carbon 13 to carbon 12 (the most abundant carbon isotope) is established as the terrestrial standard. Deviations from this standard in parts per thousand provide a value designated $\delta^{13}C$. If the value is positive, the sample is richer in carbon 13 than the standard; if it is negative, the sample is leaner in carbon 13. When Kaplan and Samuel Epstein of the California Institute of Technology independently measured the carbon-13/carbon-12 ratio in a variety of lunar samples, they found that the crystalline lunar rocks, like terrestrial basalts, have carbon-13 values of -20 to -30, whereas the fines and breccias have values of $+10$ to $+20$. Kaplan proposed that the enrichment could be explained on the basis that the two isotopes of carbon on the moon were converted into volatile compounds (hydrocarbons) by solar-wind hydrogen and that the compounds incorporating carbon 12 escaped a little more readily than those incorporating carbon 13. That would leave the carbon in the fines enriched in carbon 13. Epstein had observed similar enrichments with the heavy isotopes of oxygen and

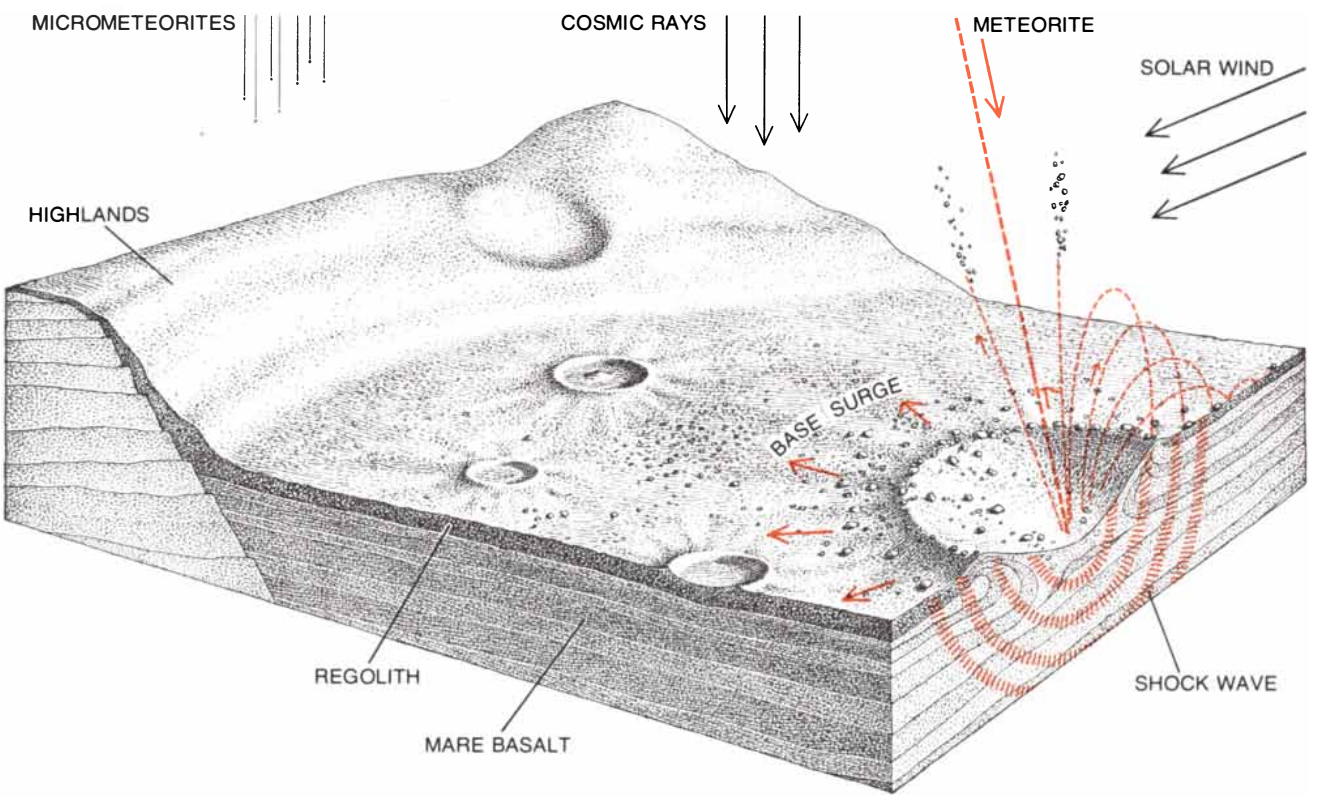
silicon and suggested two alternative explanations for carbon: The observed enrichment may reflect the actual carbon-13/carbon-12 ratio of the solar wind, which is unknown, or the carbon 12 may be volatilized more readily than carbon 13 by heating of the samples during impact processes.

After the *Apollo 11* conference some investigators continued to report that the lunar soil contained small quantities of amino acids and porphyrins. Other workers failed to confirm these reports and the controversy persisted through the Second Annual Lunar Science Conference. Since contamination was an ever present possibility, collaborative experiments were carried out by the dissenting groups. Neither Joon H. Rho of the Jet Propulsion Laboratory nor Gordon W. Hodgson of the University of Calgary could find porphyrins in the *Apollo 14* soil sample, but Hodgson did observe a porphyrin-like fluorescence corresponding to .05 nanogram per gram in extracts from *Apollo 11* and *Apollo 12* samples. Hodgson believes this result may represent the laboratory oxidation of porphyrin precursors contributed to the samples by the rocket exhaust of the landing module. In one case, however, he suspects that the porphyrin precursors may really be lunar in origin. Rho maintains that Hodgson is observing uncorrected light-scattering anomalies and that the upper limit for porphyrins in lunar samples is .005 nanogram per gram.

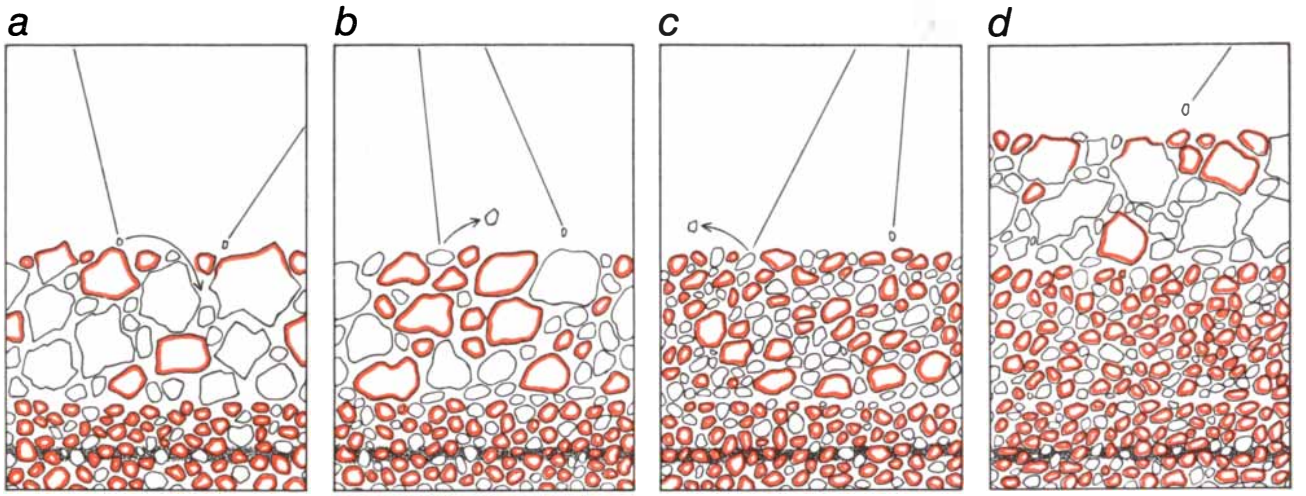
The situation with regard to amino acids has been more or less resolved by a collaborative set of measurements. It appears that the lunar soil contains amino acid precursors that yield up to 70 parts per billion of amino acid on hydrolysis. Sidney W. Fox of the University of Miami, who has consistently found evidence for amino acids, suggests that their precursors are abiogenic in origin, possibly involving the solar wind, meteorites, comets or even interstellar dust clouds. He maintains that the lack of water on the moon has blocked the chemical evolution of these precursors of amino acids. In favor of an abiogenic origin is the fact that the amino acids found on the hydrolysis of lunar samples are chemically the simplest possible: glycine is the most abundant, alanine and glutamic acid are present in lesser amounts and more complex molecules are only found in trace amounts.

After the First Lunar Conference we decided that rather than engage in controversy over the presence or absence of extremely small quantities of biologically significant compounds, we would try to locate, identify and determine origins for the carbon known to be in the samples. In particular we wanted to determine the role, if any, of the solar wind in lunar carbon chemistry.

The first step we took was designed to resolve whether or not indigenous gases or carbides gave rise to the hydrocarbons observed on acid hydrolysis. We therefore devised an isotopic labeling method to be used in conjunction with the acid-dissolution experiments. For this purpose we used hydrochloric acid and water in which all the ordinary hydrogen was replaced by the heavy isotope deuterium (D). By this means we could establish the source of any hydrogen (deuterium) that combined with carbon in the sample to produce a hydrocarbon (actually a deuterocarbon). When we performed the labeling experiment, we found that only 15 percent of the



PROCESSES OF EROSION on the surface of the moon are extremely slow compared with the processes on the earth. Bombardment by micrometeorites is believed to be the main cause, removing approximately a one-millimeter skin of rock in a million years. A large meteorite strikes the surface very rarely, excavating bedrock and ejecting it over thousands of square kilometers, sometimes as long rays of material radiating from the resulting crater. Much of the meteorite itself is vaporized on impact, and larger fragments of the debris create secondary craters. Such an event at a mare site pulverizes and churns the rubble and dust that form the regolith. Accompanying base surges of hot clouds of dust, gas and shock waves might compact the dust into breccias. Cosmic rays continually bombard the surface. During lunar day ions from the solar wind and unshielded solar radiation impinge on the surface.



LUNAR REGOLITH BUILDS UP in a series of discrete events, according to the analysis of core samples by Roald Fryxell of Washington State University and Grant Heiken of the Manned Spacecraft Center of NASA. A cratering event, such as the impact of a meteorite, ejects material and deposits it on top of a layer of dark, fine-grained, well-gardened soil (*a*), which is interleaved with a thin layer of fine dust from a distant event. Median size of grains in the fresh sediment is large. Except for a few isolated particles previously exposed, only the uppermost grains are exposed to the solar wind, which impregnates their surfaces with ions (*color*). Over a period of time micrometeorite impacts, electrostatic effects, movement of the material down slopes and other processes rework the fresh sediment (*b*). Particles exposed to the solar wind are stirred into the surface. The continual shifting and erosion decrease the size of the grains; the amount of spattered iron and glassy agglutinates increases until the matter ejected during the cratering event is "mature" (*c*). The deposition process repeats itself (*d*), although it could have done so at any of the previous stages. Regoliths at the mare sites visited so far are a few meters thick; evidently each meter of debris takes about a billion years to accumulate.

methane and 30 percent of the ethane came out unlabeled; the balance was heavily labeled with deuterium. We concluded that the deuterocarbons were created by reactions involving the deuterated hydrochloric acid (DCl) and the deuterium oxide (D_2O). Such a reaction would indicate the hydrolysis of metal carbides, as had been suggested by the Ames group.

The unlabeled methane and ethane, on the other hand, could not have been produced by hydrolysis and therefore were presumably indigenous to the samples. These small amounts of hydrocarbon could well represent molecules synthesized by a process involving the hydrogen (and possibly the carbon) of the solar wind. Evidently both the Ames group and our own had been partly correct in their initial deductions. More recent work has shown that ethylene (C_2H_4) also has a dual origin; part is indigenous and part is derived from carbides. Both propane (C_3H_8) and propylene (C_3H_6) may have a dual origin too, but so far the relative contribution of each source has not been estimated. A small amount of acetylene (C_2H_2) is also present, but nothing can be said about its origin.

Although carbon monoxide and carbon dioxide are both given off copiously when lunar fines are intensely heated, there now seems to be little doubt that the two gases are not indigenous, except perhaps in trace amounts. The carbon monoxide observed in early acid-dissolution experiments conducted by the Berkeley group was later discovered by them to be an artifact produced during the analysis of the samples. Everett K. Gibson, Jr., of the Manned Spacecraft Center of NASA has shown that meteoritic cohenite yields carbon monoxide when it is mixed with the major minerals found in the lunar fines and heated above 600 degrees C. Both Gibson and Juan Oró of the University of Houston have recognized a component of carbon dioxide that results from contamination of the samples by gas from the terrestrial atmosphere. The origin of the major portion of the carbon monoxide and carbon dioxide evolved by the pyrolysis of the lunar fines, however, calls for further investigation.

Having established by our labeling technique the presence of both indigenous methane and carbide in the lunar fines, we next undertook to measure both components in a variety of samples from different locations to see if there was any correlation with the degree of exposure of a sample to the solar wind. One would expect the slow mixing and churning ("gardening") of the lunar soil by micrometeorites to stir the surface grains, exposing them to the solar wind. At any time the impact of a large meteorite would cause a sudden blanket deposition of freshly pulverized and formerly unexposed material, effectively decreasing the average solar-wind exposure at a particular site.

The *Apollo 12* mission was the first to return samples from a variety of sites. At the Second Lunar Conference we presented data showing a promising correlation between indigenous methane and the probable length of exposure of the samples to the solar wind.

For example, an estimate of exposure can be made by measuring a sample's content of noble gases, notably argon 36, an isotope prominent in the solar wind. It turns out that there is a close relation between the argon-36 content and the amount of methane in lunar soils. Additional support for a solar-wind origin of the methane has been obtained by estimating the number of soil grains that have either an amorphous outer coating or high densities of cosmic ray tracks.

Under an electron microscope one can see that tiny grains (one or two micrometers in diameter) are often crystalline on the inside but highly disordered, or amorphous, on the outside. The disordering resembles what is observed when crystalline solids suffer massive radiation damage. In the lunar soil such damage could be caused by lengthy exposure to the solar wind. Grains that exhibit high densities of cosmic ray tracks presumably have been exposed to the high-energy particles ejected from the sun periodically by intense solar flares and hence have a greater likelihood of having spent some time on the lunar surface. As we

had anticipated, the highest concentration of indigenous methane is found in soil samples that have the highest proportion of grains with an amorphous coating and the highest proportion of grains with a high density of cosmic ray tracks.

The concentration of carbide and the quantity of carbon present as methane quite closely parallels the abundance of total carbon in the lunar fines. Thus the *Apollo 11* soil, which has apparently had the most exposure of those samples collected so far, has the largest total carbon content, releases the greatest quantity of carbon as the deuterocarbon CD_4 (20 p.p.m.) and has the highest methane concentration (5 p.p.m.). Our conclusion is that the methane, the carbide and a substantial proportion of the total carbon in the fines have an extralunar origin.

The major contributors of carbon throughout the history of the moon would be the solar wind, meteorites (including comets) and volcanism. The small amounts of carbon in the igneous rocks are presumably of volcanic origin. During the impact processes leading to the formation of the fines, however, a substantial part of the carbon from this source would be lost to the atmosphere in gaseous compounds. Obvious extralunar sources of carbon are carbonaceous chondrites, which can contain up to 3.5 percent carbon in various forms, and iron meteorites, which contain much smaller amounts of carbon in the form of iron-nickel carbides along with grains of graphite. On the basis of the abundance of certain trace elements the amount of carbonaceous-chondrite material present in the lunar soil has been estimated to be about 2 percent by Edward Anders of the University of Chicago. If all the carbon available from this source ended up in the soil, the soil would be far richer in carbon than it actually is. Evidently much of the carbon present in meteorites is immediately vaporized on impact and simply escapes into space. The few distinct grains of cohenite of meteoritic composition observed suggest, however, that some material survives. Although there is no carbide in carbonaceous chondrites, they may be indirectly involved in the formation of carbide in the lunar soil. One possibility is that iron carbide or something similar to it could condense onto exposed surfaces from a vapor cloud produced by impact. Another is that impact could produce the abundant iron blebs and inclusions found in the soil by the reduction of minerals and glass. Carbon already present in the soil or in the cloud of vapor associated with the impact could dissolve in the iron to generate carbide. Carbide could also come from the solar wind through the implantation of carbon atoms in the metallic iron on the surface of the lunar fines.

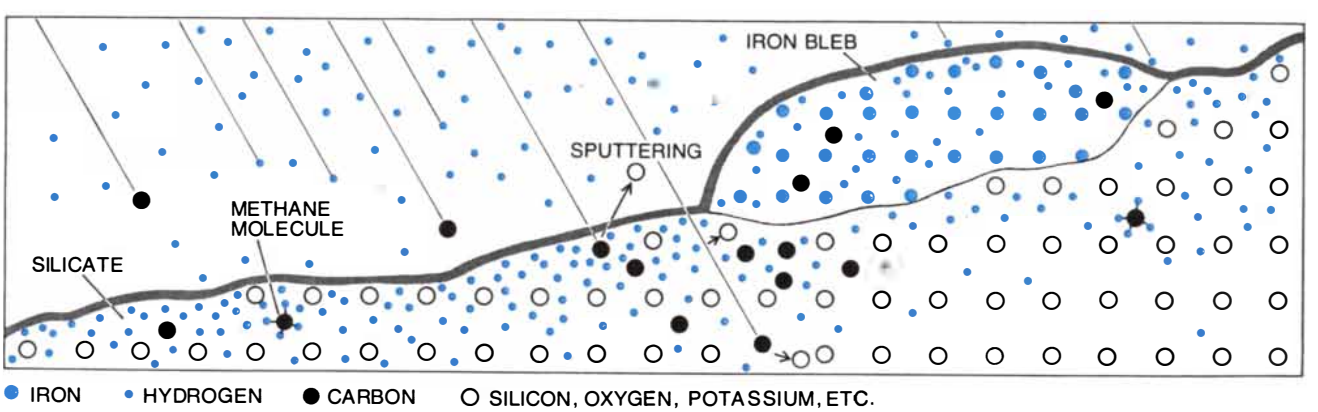
Although neither meteoritic nor volcanic sources are likely to have contributed directly to the methane in the lunar soil, there are several ways in which the solar wind could account for the appearance of the methane. The most obvious route is the direct reaction of solar-wind hydrogen with solar-wind carbon or with carbon from other sources. Hydrogen and oxygen implanted by the solar wind might also combine to yield water or at least hydroxyl groups (OH). One can then visualize methane being generated *in situ* by the hydrolysis of carbides in the exposed grains at the lunar surface.

A basic difficulty in defining the sources of the carbon compounds in the lunar soil is that erosion, sputtering and volatilization presumably result in a recycling of material through the lunar atmosphere, tenuous though that atmosphere is. The best one can do is to distinguish the most recent origin of a particular compound; the complete history of the constituent carbon atoms will probably never be known.

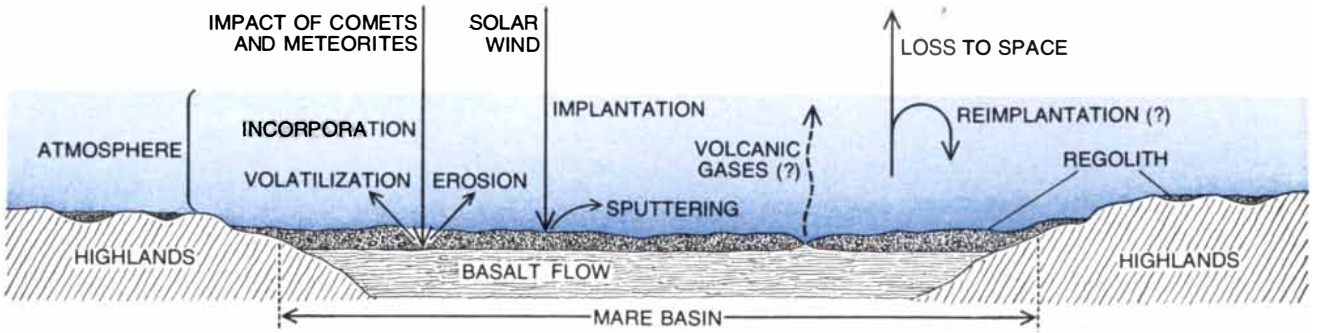
If one could establish the precise location of carbide and methane in the particles of lunar soil, one might obtain important clues to their origin. In general atomic nuclei implanted by the solar wind are not energetic enough to penetrate more than 100 millimicrons below the surface of a target particle. Therefore one would expect the concentration of elements implanted by the solar wind to increase as particle size decreases, since the smallest particles will have the greatest surface area per unit mass. This relationship was demonstrated by many investigators for argon 36 and other solar-wind gases in *Apollo 11* samples. Subsequently we sieved a batch of lunar soil into grains of various sizes and found that the concentrations of indigenous methane and carbide indeed increase with decreasing grain size.

Undoubtedly the clearest method of demonstrating a surface location would be to selectively remove microlayers of material from the surface of the particles and analyze the substances released or, alternatively, left behind. We have made one preliminary shallow-etching experiment and have found that some 60 percent of the methane resided in the surface layers that had been etched away.

The surface location of the methane is consistent with an origin involving the solar wind. For the carbide, however,



SOLAR WIND plays an important role in the carbon chemistry of the lunar surface. An area of lunar soil is enlarged some 10^8 times to show a silicate grain with an iron bleb adhering to it. Carbon atoms implanted by the solar wind could be converted to methane by the vast excess of hydrogen in the solar wind. Damage to the crystalline structure of the silicate creates defects and voids that accommodate the gas and allow some compounds to escape by diffusion. More complex hydrocarbons are probably generated as well with decreased efficiency. Carbon atoms implanted into the iron bleb might react chemically to form iron carbide. Other elements in the solar wind, such as nitrogen, oxygen and rare gases, are simultaneously implanted to a depth of a few hundred angstroms.



CARBON AT THE LUNAR SURFACE is contained primarily in the regolith of the maria and of the flatter areas of the lunar highlands where layers of dust have slowly accreted. It is not expected that layers of coarse ejecta will contain much carbon, and the crystalline igneous rocks so far examined contain only a few p.p.m. of carbon. The present distribution of carbon and other volatile elements in the regolith is a consequence of a dynamic equilibrium. Carbon is contributed from sources outside the moon such as the solar wind, meteorites and comets, and from lunar sources such as volcanism and the attrition (wearing down) of the igneous rocks. Possibly the tenuous lunar atmosphere reimplants some of the carbon released to it. Carbon is lost to the atmosphere by diffusion, erosion and volatilization. Carbon is constantly lost from the moon to space, sometimes very rapidly, as during the impact of a meteorite. The carbon content of the lunar fines measured now represents the end result of more than three billion years of these processes. The dust of the maria may be regarded as both the reservoir and the reaction site for the carbon at the surface of the moon.

the processes involving meteorites would also be expected to give rise to surface material. It may eventually be possible to determine whether the carbon was supplied predominantly by the solar wind or by meteorites, but a decisive test will not be easy.

To verify some of our hypotheses we have carried out a number of laboratory experiments designed to simulate some of the processes believed to occur on the lunar surface. For example, in collaboration with W. A. Grant and M. J. Nobes of the University of Salford we have implanted ions of carbon 13 and deuterium at estimated solar-wind energies in several targets, including lunar fines. When the isotopically labeled products were released from the fines, we found that deuteromethane containing both carbon 12 and carbon 13 had been synthesized. Carbides containing carbon 13 were produced in ostensibly pure targets of aluminum and iron, but since a certain amount of carbon 12 was present as an impurity, some carbon 12 also appeared in the deuteromethane.

We draw the following inferences for lunar carbon chemistry. First, hydrogen from the solar wind and carbon from the solar wind (or carbon already present from some other source, such as meteorites) can react to form methane. Second, solar-wind carbon can react with a component in the fines (probably iron) to produce carbide. Third, a cloud of vapor containing iron and carbon compounds generated by a meteorite impact could deposit carbide on exposed surfaces.

An important study yet to be made is how carbon 13 and carbon 12 fractionate under various simulated conditions. Other important studies will involve the multiple irradiation of suitable targets with the nuclei of elements such as carbon, nitrogen, oxygen, sulfur and hydrogen, all of which are abundant in the solar wind.

At present we are unable to provide a firm quantitative listing of the various components of the lunar carbon. Indeed, some significant fractions may still be unrecognized. Although carbide probably represents a substantial portion, a major uncertainty arises because the acid-labeling technique does not convert carbide totally into deuterocarbons. Moreover, we urgently need a good model of a carbon budget for the surface of the moon. Coming into the model system would be carbon contributed by the solar wind, meteorites and comets and volcanic processes such as the escape of gases. Going out of it would be the immediate losses from the moon when impacts generate velocities sufficient for gases and particles to escape from the lunar atmosphere into space. Through such processes as diffusion, erosion, volatilization, transportation and reimplantation carbon would tend to be concentrated in the lunar dust residing primarily in the flatter areas of the moon. A terrestrial analogy would be the concentration of dissolved substances in lakes and oceans by the runoff of precipitation. Using as a guide the much simpler equilibrium conditions for a noble gas such as argon 36, it should be possible to work out an approximate budget for present inflow and outflow of carbon. In order to project this budget backward in time one will need to make allowances for the high frequency of cratering events in the early history of the moon and possible fluctuations in the strength of the solar wind.

The soil and rocks returned from the moon by the Apollo missions have given biologists and organic chemists their first opportunity to study carbon compounds that had not been modified in any way by biological processes of the terrestrial kind. Although the processes that have operated on the moon are undoubtedly different from those that operated on the atmosphere-shrouded primitive earth, the lunar processes must in many ways resemble those operating elsewhere in the solar system and the universe. The carbon chemistry of the moon can be regarded as a particular example of syntheses involving solar atomic species.

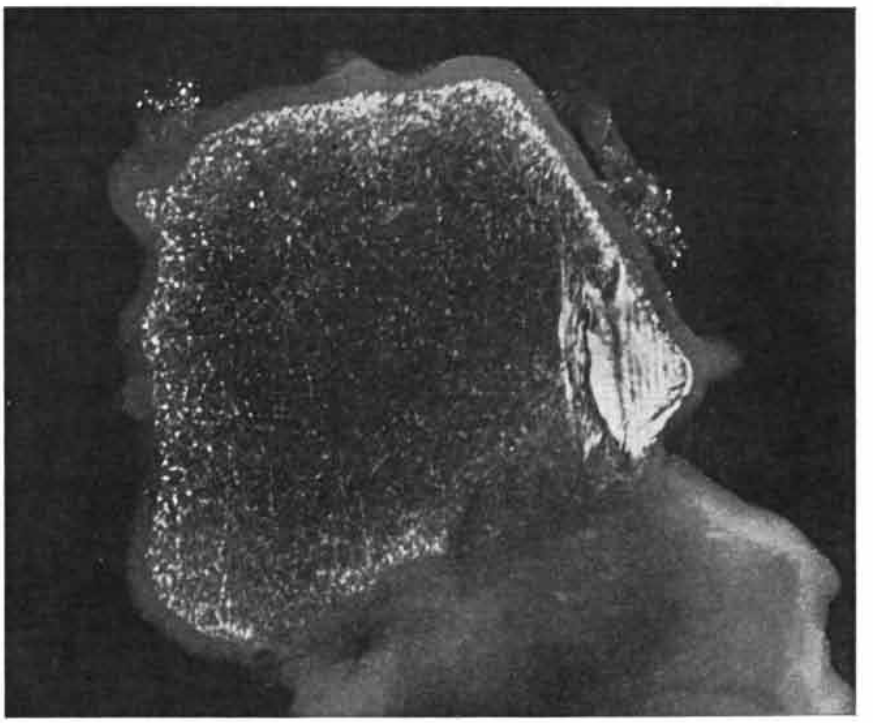
Such syntheses may be important for generating the tiny amounts of amino acid precursors believed to be present in the lunar fines. In fact, there is evidence from Alma L. Burlingame's group at the University of California at Berkeley that the lunar soil may contain cyanides, molecules incorporating an atom of carbon and an atom of nitrogen. Cyanides are known intermediates in important reactions that lead to the formation of amino acids.

Hydrogen, carbon and nitrogen are concentrated at the surfaces of the grains of the lunar fines. A fourth element, oxygen, is actually more abundant in the solar wind than either carbon or nitrogen. It has not yet been shown, however, that oxygen has been implanted in the surface of lunar grains, presumably be-

cause such oxygen is drowned by the superabundance of oxygen from silicates and other lunar sources. The mechanisms involving the interaction of these atomic species will need to be investigated before the chemical processes occurring at the lunar surface can be properly understood. The chemistry that has evidently taken place on the lunar surface also has important general implications for the synthesis of molecules in interplanetary and interstellar dust clouds. Within the past few years astronomers have identified in the gases of dust clouds some 20 small molecules, including those of methyl alcohol (CH_3OH), formaldehyde (CH_2O) and hydrogen cyanide (HCN).

Considering the great cost of the Apollo program, not to mention the lives risked, one may well ask: Could the same information have been obtained by unmanned missions to the moon? If the missions had been limited to automatic chemical analyses conducted directly on the lunar surface, the answer is clearly no. Even our brief account of the work that is beginning to unravel the moon's carbon chemistry should indicate how little could have been learned by means of the relatively simple experiments one might hope to have conducted on the moon itself with automatic landers.

If, on the other hand, one considers unmanned missions in which samples of the lunar surface would be scooped up and returned to the earth, there is obviously no limit to what might be achieved. The U.S.S.R. has already demonstrated the feasibility of that approach. Since the manned program will end with the flight of *Apollo 17* in December, the automatic return of samples provides the only hope for obtaining soil and rocks from unvisited—and perhaps unvisitable—regions such as the far side of the moon. Similar considerations of cost and feasibility apply even more forcefully to the study of the chemistry of Mars and other bodies in the solar system. Although a certain amount of knowledge can be gained by automatic analysis *in situ*, far more will be learned if the samples can be returned to the earth. There may or may not be life on Mars, but its carbon chemistry should provide a fascinating contrast with the carbon chemistry of the earth and with what we now know about the carbon chemistry of the moon.



PARTICLE OF LUNAR DUST sieved from the fines returned by *Apollo 11* shows a rounded shape and an outer coating approximately 500 angstroms thick (one angstrom is 10^{-8} centimeter). The particle is crisscrossed by a myriad of short tracks, as shown in the microphotograph taken by L. Durrieu and C. Jouret with a one-million-electron-volt electron microscope at the Laboratoire d'Optique Electronique at Toulouse in France. Electron diffraction patterns show that the interior is a crystalline silicate whereas the coating is amorphous (having no crystalline structure). The coating has been ascribed to radiation damage produced by the solar wind. The tracks may have been caused by more energetic particles, possibly suprathermal ions from the sun. The rounding of the edges and the amorphous coating can be simulated by bombarding the particles with ions of the noble gases.

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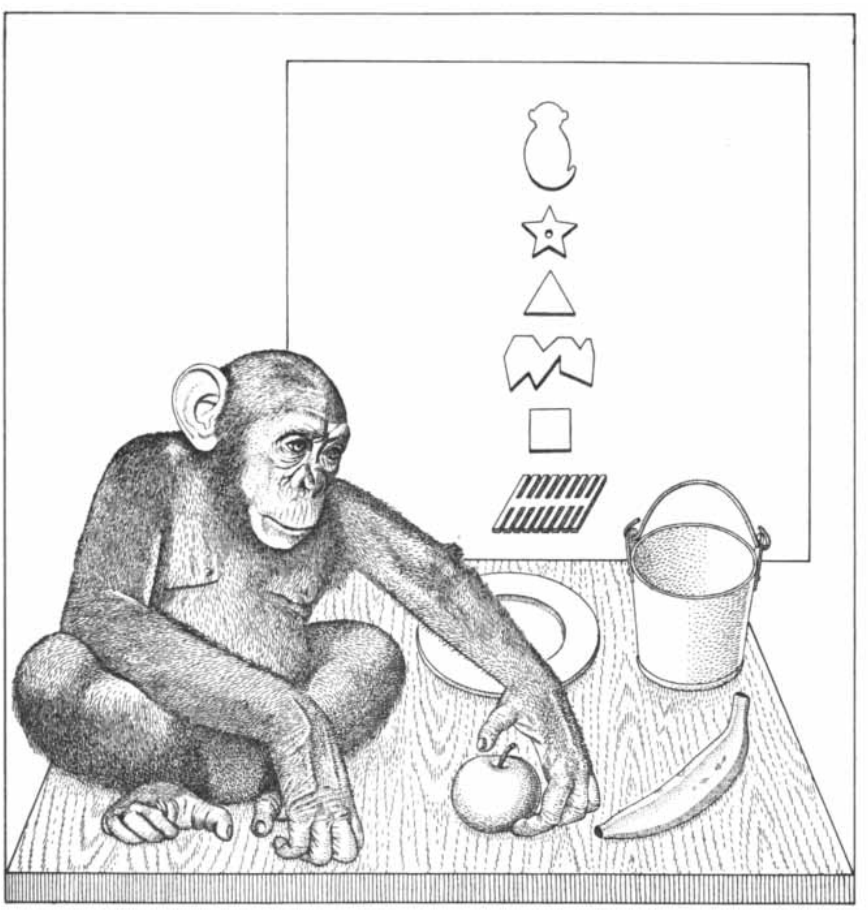
Teaching Language to an Ape

Sarah, a young chimpanzee, has a reading and writing vocabulary of about 130 "words." Her understanding goes beyond the meaning of words and includes the concepts of class and sentence structure

by Ann James Premack and David Premack

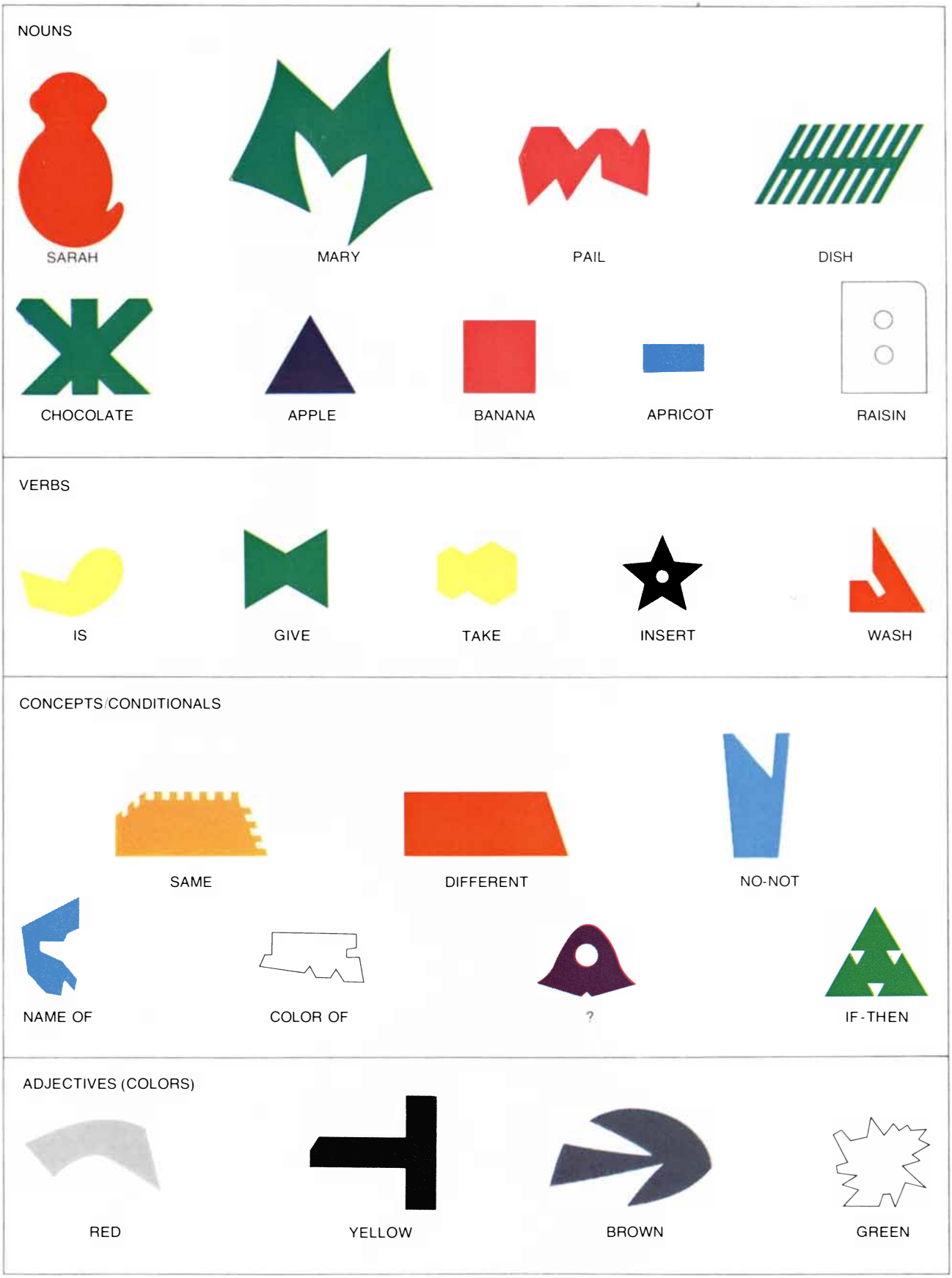
Over the past 40 years several efforts have been made to teach a chimpanzee human language. In the early 1930's Winthrop and Luella Kellogg raised a female chimpanzee named Gua along with their infant son; at the age of 16 months Gua could understand about 100 words, but she never did try to speak them. In the 1940's Keith and Cathy Hayes raised a chimpanzee named Vicki in their home; she learned a large number of words and with some difficulty could mouth the words "mama," "papa" and "cup." More recently Allen and Beatrice Gardner have taught their chimpanzee Washoe to communicate in the American Sign Language with her fingers and hands. Since 1966 in our laboratory at the University of California at Santa Barbara we have been teaching Sarah to read and write with variously shaped and colored pieces of plastic, each representing a word; Sarah has a vocabulary of about 130 terms that she uses with a reliability of between 75 and 80 percent.



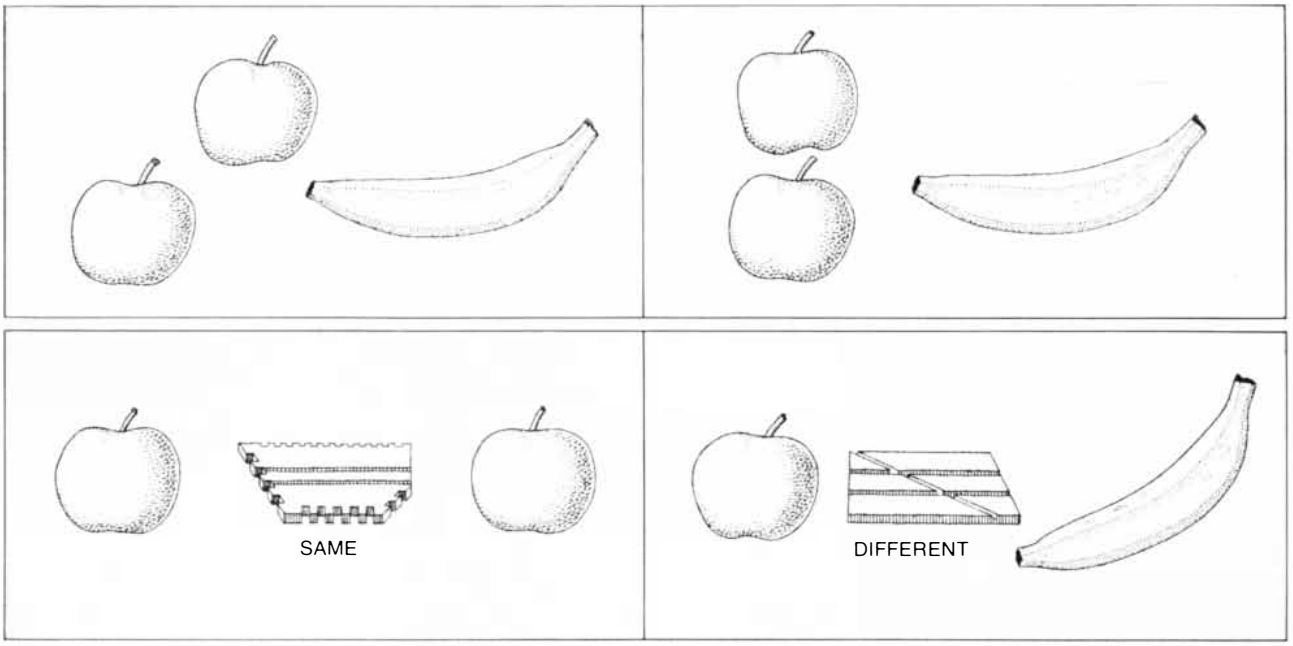
SARAH, after reading the message "Sarah insert apple pail banana dish" on the magnetic board, performed the appropriate actions. To be able to make the correct interpretation that she should put the apple in the pail and the banana in the dish (not the apple, pail and banana in the dish) the chimpanzee had to understand sentence structure rather than just word order. In actual tests most symbols were colored (*see illustration on opposite page*).

Why try to teach human language to an ape? In our own case the motive was to better define the fundamental nature of language. It is often said that language is unique to the human species. Yet it is now well known that many other animals have elaborate communication systems of their own. It seems clear that language is a general system of which human language is a particular, albeit remarkably refined, form. Indeed, it is possible that certain features of human language that are considered to be uniquely human belong to the more general system, and that these features can be distinguished from those that are unique to the human information-processing regime. If, for example, an ape can be taught the rudiments of human language, it should clarify the dividing line between the general system and the human one.

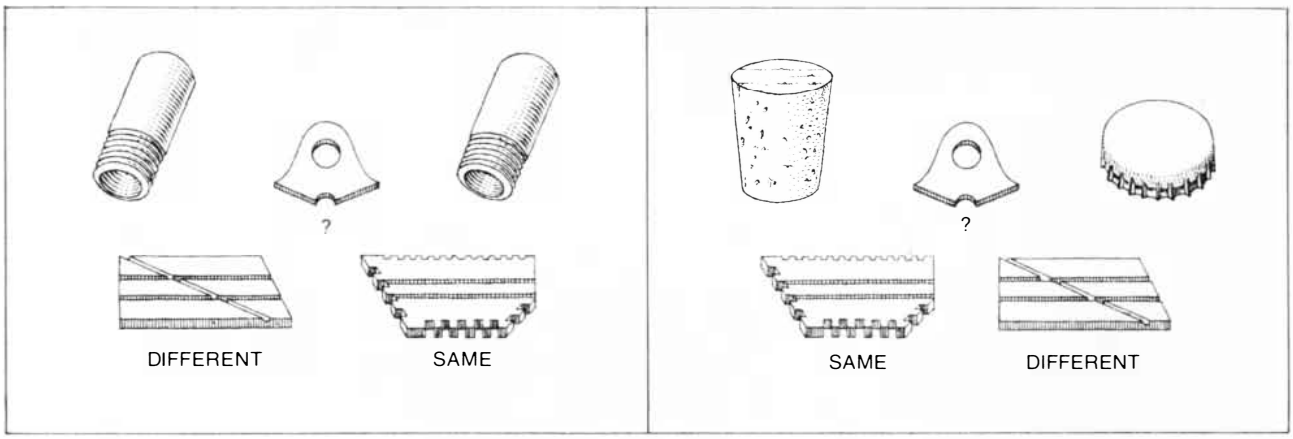
There was much evidence that the chimpanzee was a good candidate for the acquisition of language before we began our project. In their natural environment chimpanzees have an extensive vocal "call system." In captivity the chimpanzee has been taught to sort pictures into classes: animate and inanimate, old and young, male and female. Moreover, the animal can classify the same item in different ways depending



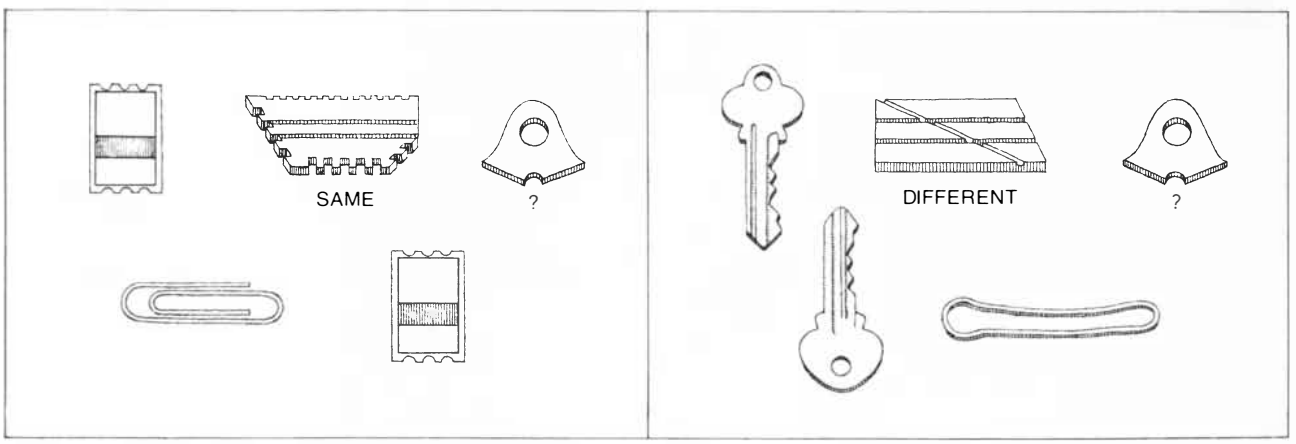
PLASTIC SYMBOLS that varied in color, shape and size were chosen as the language units to be taught to Sarah. The plastic pieces were backed with metal so that they would adhere to a magnetic board. Each plastic symbol stood for a specific word or concept. A "Chinese" convention of writing sentences vertically from top to bottom was adopted because at the beginning of her training Sarah seemed to prefer it. Sarah had to put the words in proper sequence but the orientation of the word symbols was not important.



CONCEPTS "SAME" AND "DIFFERENT" were introduced into Sarah's vocabulary by teaching her to pair objects that were alike (*top illustration*). Then two identical objects, for example apples, were placed before her and she was given plastic word for "same" and induced to place word between the two objects. She was also taught to place the word for "different" between unlike objects.



THE INTERROGATIVE was introduced with the help of the concepts "same" and "different." A plastic piece that meant "question mark" was placed between two objects and Sarah had to replace it with either the word for "same" or the word for "different."



NEW VERSION OF THE INTERROGATIVE was taught by arranging an object and plastic symbols to form questions: "What is [Object A] the same as?" or "What is [Object A] different from?" Sarah had to replace question marker with the appropriate object.

on the alternatives offered. Watermelon is classified as fruit in one set of alternatives, as food in another set and as big in a third set. On the basis of these demonstrated conceptual abilities we made the assumption that the chimpanzee could be taught not only the names of specific members of a class but also the names for the classes themselves.

It is not necessary for the names to be vocal. They can just as well be based on gestures, written letters or colored stones. The important thing is to shape the language to fit the information-processing capacities of the chimpanzee. To a large extent teaching language to an animal is simply mapping out the conceptual structures the animal already possesses. By using a system of naming that suits the chimpanzee we hope to find out more about its conceptual world. Ultimately the benefit of language experiments with animals will be realized in an understanding of intelligence in terms not of scores on tests but of the underlying brain mechanisms. Only then can cognitive mechanisms for classifying stimuli, for storing and retrieving information and for problem-solving be studied in a comparative way.

The first step in teaching language is to exploit knowledge that is already present. In teaching Sarah we first mapped the simple social transaction of giving, which is something the chimpanzee does both in nature and in the laboratory. Considered in terms of cognitive and perceptual elements, the verb "give" involves a relation between two individuals and one object, that is, between the donor, the recipient and the object being transferred. In order to carry out the act of giving an animal must recognize the difference between individuals (between "Mary" and "Randy") and must perceive the difference between donors and recipients (between "Mary gives Randy" and "Randy gives Mary"). In order to be able to map out the entire transaction of giving the animal has to distinguish agents from objects, agents from one another, objects from one another and itself from others.

The trainer began the process of mapping the social transaction by placing a slice of banana between himself and Sarah. The chimpanzee, which was then about five years old, was allowed to eat the tasty morsel while the trainer looked on affectionately. After the transaction had become routine, a language element consisting of a pink plastic square was placed close to Sarah while the slice of banana was moved beyond her reach. To obtain the fruit Sarah now had to put the plastic piece on a "language board" on the side of her cage. (The board was magnetic and the plastic square was backed with a thin piece of steel so that it would stick.) After Sarah had learned this routine the fruit was changed to an apple and she had to place a blue plastic word for apple on the board. Later several other fruits, the verb "give" and the plastic words that named each of them were introduced.

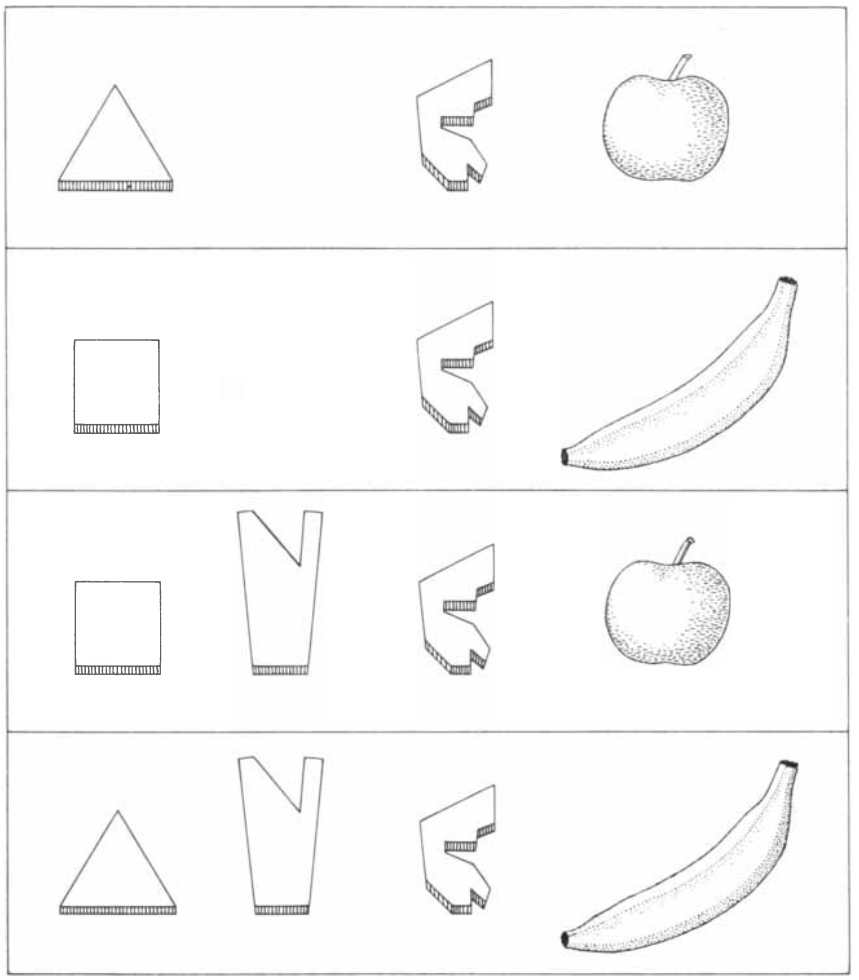
To be certain that Sarah knew the meaning of "give" it was necessary to contrast "give" with other verbs, such as "wash," "cut" and "insert." When Sarah indicated "Give apple," she was given a piece of apple. When she put "Wash apple" on the board, the apple was placed in a bowl of water and washed. In that way Sarah learned what action went with what verb.

In the first stage Sarah was required to put only one word on the board; the name of the fruit was a sufficient indicator of the social transaction. When names for different actions—verbs—were introduced, Sarah had to place two words on the board in vertical sequence. In order to be given an apple she had to write "Give apple." When recipients were named, two-word sentences were not accepted by the trainer; Sarah had to use three words. There were several trainers, and Sarah had to learn the name of each one. To facilitate the teaching of personal names, both the chimpanzees and the trainers wore their plastic-word names on a string necklace. Sarah learned the names of some of the recipients the hard way. Once she wrote "Give apple Gussie," and the trainer promptly gave the apple to another chimpanzee named Gussie. Sarah never repeated the sentence. At every stage she was required to observe the proper word sequence. "Give apple" was accepted but "Apple give" was not. When donors were to be named, Sarah had to identify all the members of the social transaction: "Mary give apple Sarah."

The interrogative was introduced with the help of the concepts "same" and "different." Sarah was given a cup and a spoon. When another cup was added, she was taught to put the two cups together. Other sets of three objects were given to her, and she had to pair the two objects that were alike. Then she was taught to place the plastic word for "same" between any two similar objects and the plastic word for "different" between unlike objects. Next what amounted to a question mark was placed between pairs of objects. This plastic shape (which bore no resemblance to the usual kind of question mark) made the question explicit rather than implicit, as it had been in the simple matching tests. When the interrogative element was placed between a pair of cups, it meant: "What is the relation between cup *A* and cup *B*?" The choices provided Sarah were the plastic words "same" and "different." She learned to remove the interrogative particle and substitute the correct word [*see top illustration on opposite page*]. Sarah was able to transfer what she had learned and apply the word "same" or "different" to numerous pairs of objects that had not been used in her training.

Any construction is potentially a question. From the viewpoint of structural linguistics any construction where one or more elements are deleted becomes a question. The constructions we used with Sarah were "*A* same *A*" and "*A* different *B*." Elements in these constructions were removed and the deletion was marked with the interrogative symbol; Sarah was then supplied with a choice of missing elements with which she could restore the construction to its familiar form. In principle interrogation can be taught either by removing an element from a familiar situation in the animal's world or by removing the element from a language that maps the animal's world. It is probable that one can induce questions by purposively removing key elements from a familiar situation. Suppose a chimpanzee received its daily ration of food at a specific time and place, and then one day the food was not there. A chimpanzee trained in the interrogative might inquire "Where is my food?" or, in Sarah's case, "My food is?" Sarah was never put in a situation that might induce such interrogation because for our purposes it was easier to teach Sarah to answer questions.

At first Sarah learned all her words in the context of social exchange. Later, when she had learned the concepts "name of" and "not name of," it was possible to introduce new words in a more direct way. To teach her that objects had names, the plastic word for "apple" and a real apple were placed on the table and Sarah was required to put the plastic word for "name of" between them. The same procedure was repeated for banana. After she had responded correctly several times, the symbol for "apple" and a real banana were placed on the table and Sarah had to put "not



TEACHING LANGUAGE WITH LANGUAGE was the next step. Sarah was taught to put the symbol for "name of" between the word for "apple" and an apple and also between the word for "banana" and a banana. She learned the concept "not name of" in the same way. Thereafter Sarah could be taught new nouns by introducing them with "name of."

name of" between them. After she was able to perform both operations correctly new nouns could be taught quickly and explicitly. The plastic words for "raisin" and "name of" could be placed next to a real raisin and Sarah would learn the noun. Evidence of such learning came when Sarah subsequently requested "Mary give raisin Sarah" or set down "Raisin different apple."

An equally interesting linguistic leap occurred when Sarah learned the predicate adjective and could write such sentences as "Red color of apple," "Round shape of apple" and "Large size of apple." When asked for the relation between "Apple is red ? Red color of apple" and given "same" and "different" as choices, she judged the sentences to be the same. When given "Apple is red ? Apple is round," she judged the sentences to be different. The distinctions between similar and different, first learned with actual objects, was later applied by Sarah in linguistic constructions.

In English the conditional consists of the discontinuous elements "if-then," which are inconvenient and conceptually unnecessary. In symbolic logic the conditional consists of the single sign $\supset$, and we taught Sarah the conditional relation with the use of a single plastic word. Before being given language training in the conditional, she was given contingency training in which she was rewarded for doing one thing but not another. For example, she was given a choice between an apple and a banana, and only when she chose the apple was she given chocolate (which she dearly loved). "If apple, then chocolate, if banana, then no chocolate" were the relations she learned; the same relations were subsequently used in sentences to teach her the name for the conditional relation.

The subject was introduced with the written construction: "Sarah take apple ? Mary give chocolate Sarah." Sarah was provided with only one plastic word: the conditional particle. She had to remove the question mark and substitute the conditional in its place to earn the apple and the chocolate. Now she was presented with: "Sarah take banana ? Mary no give chocolate Sarah." Again only the conditional symbol was provided. When Sarah replaced the question mark with the conditional symbol, she received a banana but no chocolate. After several such tests she was given a series of trials on each of the following pairs of sentences: "Sarah take apple if-then Mary give chocolate Sarah" coupled with "Sarah take banana if-then Mary no give chocolate Sarah," or "Sarah take apple if-then Mary no give chocolate Sarah" coupled with "Sarah take banana if-then Mary give chocolate Sarah."

At first Sarah made many errors, taking the wrong fruit and failing to get her beloved chocolate. After several of her strategies had failed she paid closer attention to the sentences and began choosing the fruit that gave her the chocolate. Once the conditional relation had been learned she was able to apply it to other types of sentence, for example "Mary take red if-then Sarah take apple" and "Mary take green if-then Sarah take banana." Here Sarah had to watch Mary's choice closely in order to take the correct action. With the paired sentences "Red is on green if-then Sarah take apple" and "Green is on red if-then Sarah take banana," which involved a change in the position of two colored cards, Sarah was not confused and performed well.

As a preliminary to learning the class concepts of color, shape and size Sarah was taught to identify members of the classes red and yellow, round and square and large and small. Objects that varied in most dimensions but had a particular property in common were used. Thus for teaching the word "red" a set of dissimilar, unnamed objects (a ball, a toy car, a Life Saver and so on) that had no property in common except redness were put before the chimpanzee. The only plastic word available to her was "red." After several trials on identifying red with a set of red objects and yellow with a set of yellow objects, Sarah was shifted to trials where she had to choose between "red" and "yellow" when she was shown a colored object. Finally completely new red and yellow objects were presented to her, including small cards that were identical except for their color.

Again she performed at her usual level of accuracy.

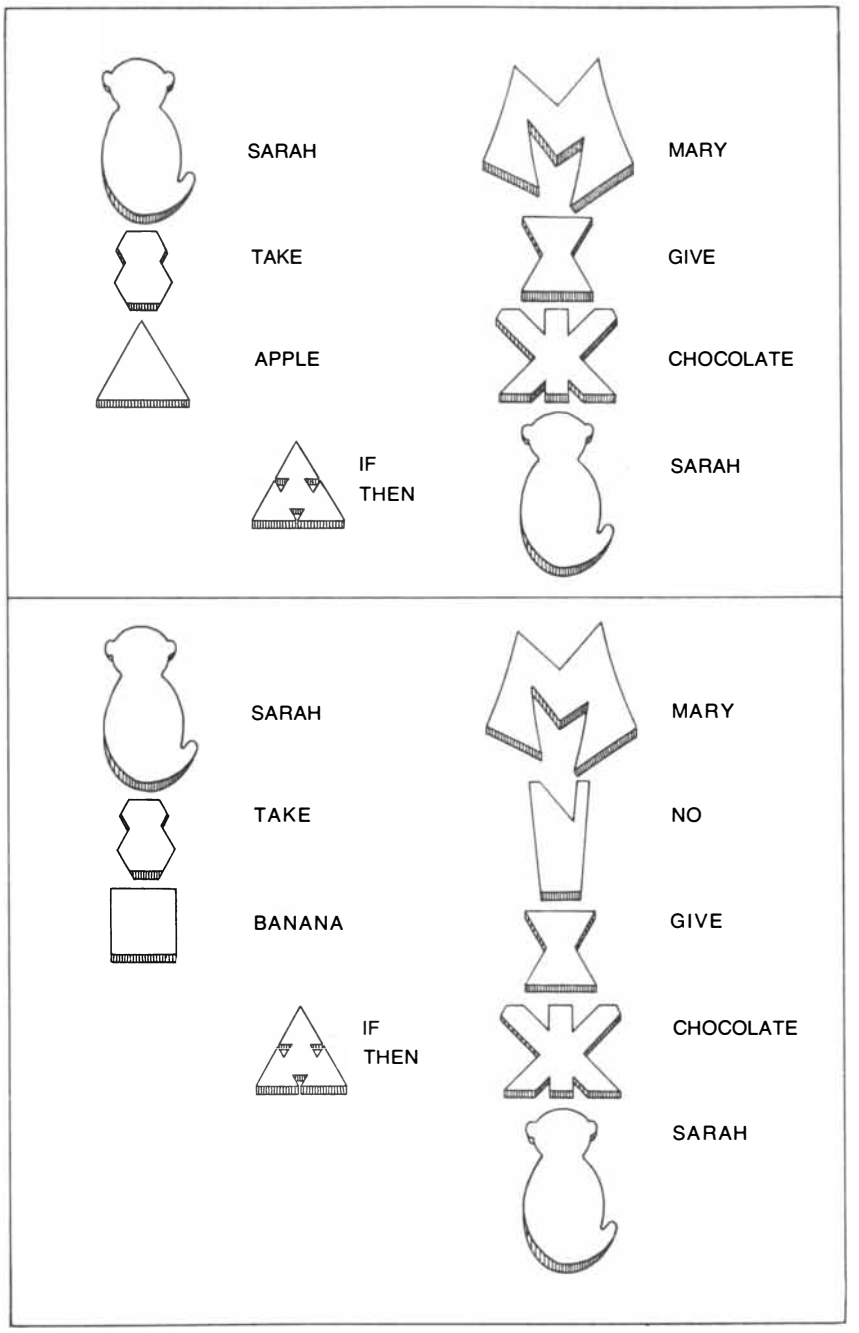
Sarah was subsequently taught the names of shapes, "round" and "square," as well as the size names "large" and "small." These words formed the basis for teaching her the names of the class concepts "color of," "shape of" and "size of." Given the interrogative "Red ? apple" or "Yellow ? banana," Sarah was required to substitute the plastic word for "color of" for the question mark. In teaching class names a good many sentences were not written on the board but were presented as hybrids. The hybrid sentences consisted of a combination of plastic words and real objects arranged in the proper sentence sequence on Sarah's worktable. Typical sentences were "Yellow ?" beside a real yellow balloon or "Red ?" beside a red wood block.

The hybrid sentences did not deter Sarah in the least. Her good performance showed that she was able to move with facility from symbols for objects to actual objects. Her behavior with hybrid constructions recalls the activity of young children, who sometimes combine spoken words with real objects they are unable to name by pointing at the objects.

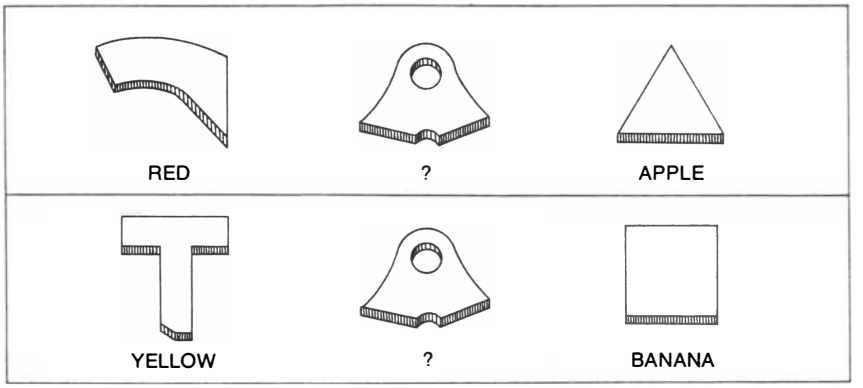
Was Sarah able to think in the plastic-word language? Could she store information using the plastic words or use them to solve certain kinds of problem that she could not solve otherwise? Additional research is needed before we shall have definitive answers, but Sarah's performance suggests that the answers to both questions may be a qualified yes. To think with language requires being able to generate the meaning of words in the absence of their external representation. For Sarah to be able to match "apple" to an actual apple or "Mary" to a picture of Mary indicates that she knows the meaning of these words. It does not prove, however, that when she is given the word "apple" and no apple is present, she can think "apple," that is, mentally represent the meaning of the word to herself. The ability to achieve such mental representation is of major importance because it frees language from simple dependence on the outside world. It involves displacement: the ability to talk about things that are not actually there. That is a critical feature of language.

The hint that Sarah was able to understand words in the absence of their external referents came early in her language training. When she was given a piece of fruit and two plastic words, she was required to put the correct word for the fruit on the board before she was allowed to eat it. Surprisingly often, however, she chose the wrong word. It then dawned on us that her poor performance might be due not to errors but to her trying to express her preferences in fruit. We conducted a series of tests to determine her fruit preferences, using actual fruits in one test and only fruit names in the other. Sarah's choices between the words were much the same as her choices between the actual fruits. This result strongly suggests that she could generate the meaning of the fruit names from the plastic symbols alone.

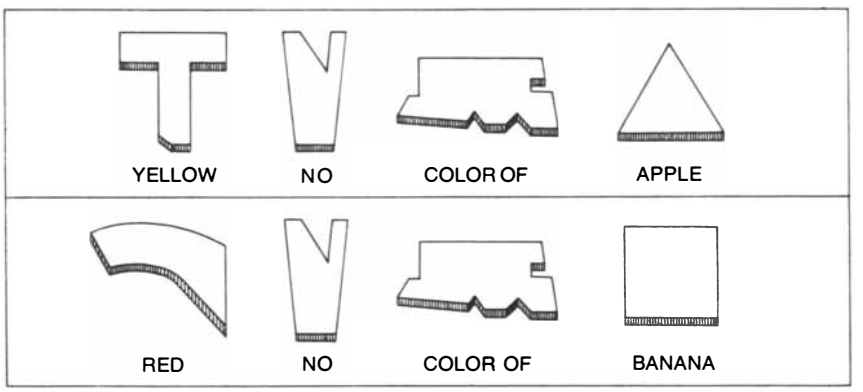
We obtained clearer evidence at a later stage of Sarah's language training. In the same way that she could use



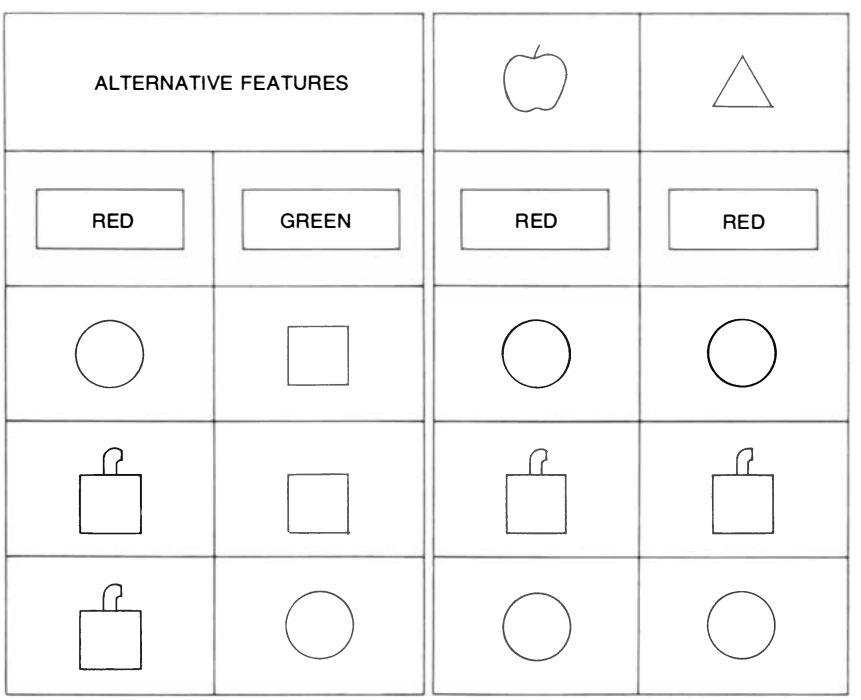
CONDITIONAL RELATION, which in English is expressed "if ... then," was taught to Sarah as a single word. The plastic symbol for the conditional relation was placed between two sentences. Sarah had to pay attention to the meaning of both sentences very closely in order to make the choice that would give her a reward. Once the conditional relation was learned by means of this procedure, the chimpanzee was able to apply it to other situations.



CLASS CONCEPT OF COLOR was taught with the aid of sentences such as "Red ? apple" and "Yellow ? banana." Sarah had to replace the interrogative symbol with "color of."



NEGATIVE CONCEPT was introduced with "no-not." When asked "Yellow ? apple" or "Red ? banana," Sarah had to replace interrogative symbol with "color of" or "not color of."



FEATURE ANALYSIS of an actual apple and the plastic word for "apple" was conducted. Sarah was shown an apple or the word and made to choose from alternative features: red or green, round or square, square with stem or plain square and square with stem or round. Sarah gave plastic word for "apple" same attributes she had earlier assigned to apple.

"name of" to learn new nouns, she was able to use "color of" to learn the names of new colors. For instance, the names "brown" and "green" were introduced in the sentences "Brown color of chocolate" and "Green color of grape." The only new words at this point were "brown" and "green." Later Sarah was confronted with four disks, only one of which was brown, and when she was instructed with the plastic symbols "Take brown," she took the brown disk. Since chocolate was not present at any time during the introduction of the color name "brown," the word "chocolate" in the definition must have been sufficient to have Sarah generate or picture the property brown.

What form does Sarah's supposed internal representation take? Some indication is provided by the results of a test of ability to analyze the features of an object. First Sarah was shown an actual apple and was given a series of paired comparisons that described the features of the apple, such as red v. green, round v. square and so on. She had to pick the descriptive feature that belonged to the apple. Her feature analysis of a real apple agreed nicely with our own, which is evidence of the interesting fact that a chimpanzee is capable of decomposing a complex object into features. Next the apple was removed and the blue plastic triangle that was the word for "apple" was placed before her and again she was given a paired-comparison test. She assigned the same features to the word that she had earlier assigned to the object. Her feature analysis revealed that it was not the physical properties of the word (blue and triangle) that she was describing but rather the object that was represented by the word [*see bottom illustration at left*].

To test Sarah's sentence comprehension she was taught to correctly follow these written instructions: "Sarah insert apple pail," "Sarah insert banana pail," "Sarah insert apple dish" and "Sarah insert banana dish." Next instructions were combined in a one-line vertical sequence ("Sarah insert apple pail Sarah insert banana dish"). The chimpanzee responded appropriately. Then the second "Sarah" and the second verb "insert" were deleted to yield the compound sentence: "Sarah insert apple pail banana dish." Sarah followed the complicated instructions at her usual level of accuracy.

The test with the compound sentence is of considerable importance, because it provides the answer to whether or not

Sarah could understand the notion of constituent structure: the hierarchical organization of a sentence. The correct interpretation of the compound sentence was "Sarah put the apple in the pail and the banana in the dish." To take the correct actions Sarah must understand that "apple" and "pail" go together but not "pail" and "banana," even though the terms appear side by side. Moreover, she must understand that the verb "insert" is at a higher level of organization and refers to both "apple" and "banana." Finally, Sarah must understand that she, as the head noun, must carry out all the actions. If Sarah were capable only of linking words in a simple chain, she would never be able to interpret the compound sentence with its deletions. The fact is that she interprets them correctly. If a child were to carry out the instructions in the same way, we would not hesitate to say that he recognizes the various levels of sentence organization: that the subject dominates the predicate and the verb in the predicate dominates the objects.

Sarah had managed to learn a code, a simple language that nevertheless included some of the characteristic features of natural language. Each step of the training program was made as simple as possible. The objective was to reduce complex notions to a series of simple and highly learnable steps. The same program that was used to teach Sarah to communicate has been successfully applied with people who have language difficulties caused by brain damage. It may also be of benefit to the autistic child.

In assessing the results of the experiment with Sarah one must be careful not to require of Sarah what one would require of a human adult. Compared with a two-year-old child, however, Sarah holds her own in language ability. In fact, language demands were made of Sarah that would never be made of a child. Man is understandably prejudiced in favor of his own species, and members of other species must perform Herculean feats before they are recognized as having similar abilities, particularly language abilities. Linguists and others who study the development of language tend to exaggerate the child's understanding of language and to be extremely skeptical of the experimentally demonstrated language abilities of the chimpanzee. It is our hope that our findings will dispel such prejudices and lead to new attempts to teach suitable languages to animals other than man.

The Texture of the Nuclear Surface

The nuclei of atoms do not have a smooth surface; instead of being evenly distributed the protons and neutrons tend to cluster into alpha particles, making the surface lumpy

by Chris D. Zafiratos

The nucleus of an atom is a fantastically dense bit of matter that occupies less than a trillionth of the volume of the atom and yet accounts for more than 99.9 percent of the atom's mass. The fundamental building block of the nucleus is the nucleon. When this particle is in its electrically neutral state, it is a neutron; when it is in its electrically charged state, it is a proton. There are a number of plausible ways in which nucleons might be grouped to make up a nucleus. Perhaps they form a sphere of uniform density, or perhaps the spacing between them increases smoothly toward the surface. A third possibility is that in the more rarefied surface region of the nucleus there is a tendency for the protons and neutrons to clump into small, dense clusters. If the number of protons and neutrons falls off smoothly with distance, it can be said that the nuclear surface is smooth; if clustering is important, the region is lumpy.

The concept of an atomic nucleus was first proposed by Ernest Rutherford in 1911 and was verified by the experiments involving the scattering of alpha particles (helium nuclei) by Hans Geiger and Ernest Marsden in 1913. That same year Niels Bohr put forward his model of the atom in which the orbits of the electrons were quantized, that is, the electrons in the atom could occupy only certain allowed energy states. Bohr's theory explicitly included a massive central nucleus, and it successfully predicted the position of lines in the spectrum of the hydrogen atom. The alpha particles Geiger and Marsden had used as a probe to find the nucleus came from the decay of naturally occurring radioactive isotopes. Such alpha particles were used to initiate a few nuclear reactions, but real progress in knowledge of the nucleus itself awaited the development of nuclear-particle accelerators in the 1930's. The intervening years have brought a much deeper understanding of the general structure of nuclei.

The known atomic nuclei comprise from one nucleon to approximately 250 nucleons. The lighter nuclei have roughly equal numbers of protons and neutrons; more massive nuclei have more neutrons than protons. In the usual notation the total number of nucleons is given as a superscript and the atomic number is indicated by the symbol for the chemical species of the atom. Thus ^{34}S is the sulfur nucleus consisting of 34 nucleons. Since the atomic number of sulfur is 16, there are 16 protons and 18 neutrons in the nucleus.

The nucleus is held together by the most intense force known in nature. Although the nuclear force acts between all nucleons, whether they are protons or neutrons, it must overcome the disruptive influence of the electrical repulsion between the positive charges of the protons in the nucleus. Since the electric force is the second-strongest force in nature and can act over a greater distance than the nuclear force, the balance between the nuclear and electric forces in nuclei can become delicate. This opposition is the chief reason for the instability of large, highly charged nuclei that leads to nuclear fission and to the radioactive emission of alpha particles (which can be characterized as nuclear fission on a small scale). It would seem that the nucleus would be more stable if it were made up exclusively of neutrons. Interestingly enough, however, the Pauli exclusion principle (which states that no more than one identical particle in an atom can occupy the same quantum state) ensures that stable nuclei must be composed of a mixture of protons and neutrons. Thus all nuclear matter, except for the neutron itself and perhaps neutron stars, must be positively charged and can therefore attract a cloud of negative electrons to make an atom.

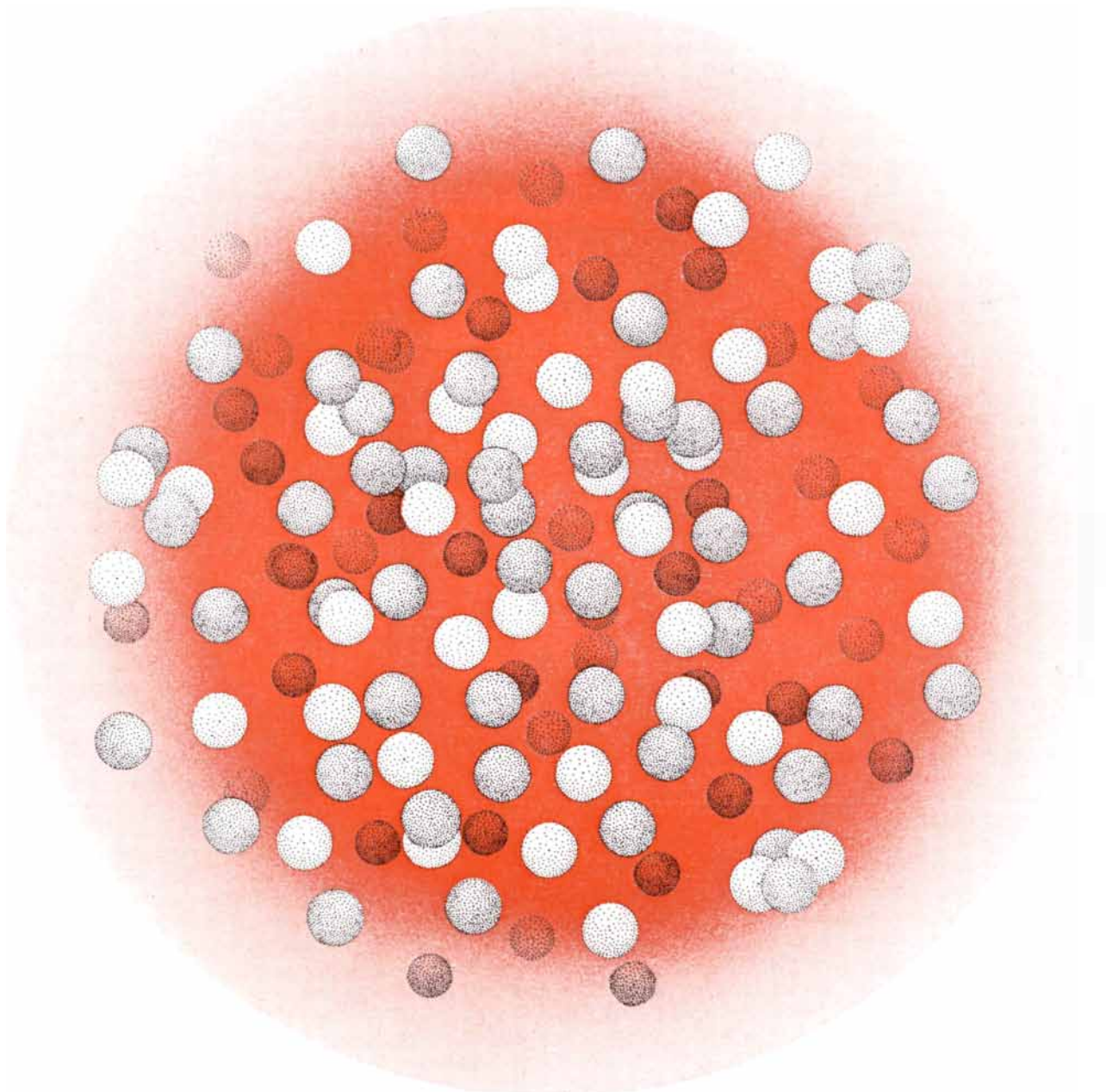
This state of affairs becomes profoundly significant when we reflect on the fact that the charge of the nucleus determines the number of electrons in the atom, and that this number in turn determines the chemical properties of the atom. Hence the presence of carbon in quantities sufficient for life to evolve is ultimately related to the stability of carbon 12 (^{12}C), whose nucleus consists of six protons and six neutrons; carbon 12 makes up 98.9 percent of the carbon in nature. It is now believed most of the elements heavier than hydrogen were (and still are) synthesized in the interior of stars by the same nuclear reactions that generate the energy of the stars. Some of the heavier elements may be born only during the cataclysmic explosions of supernovas, which occur roughly once per 100 years per galaxy. So it is that the "big picture" of the universe—its energy sources and its overall chemical composition—is deeply related to the properties of atomic nuclei.

The realm of nuclear dimensions is so far removed from our experience in the macroscopic world that some of its phenomena seem contradictory. The short range of the intense nuclear force causes the nucleus to behave in many ways like a dense drop of liquid with a large surface tension. Most of the behavior of a nucleus undergoing nuclear fission can be understood as the splitting of a shimmying electrically charged drop, and so can many other collective aspects of nuclear dynamics. Yet at the same time the protons and neutrons move around within this dense nuclear matter so freely that they behave in many ways as if they were independent of one another. The individual nucleons move in discrete

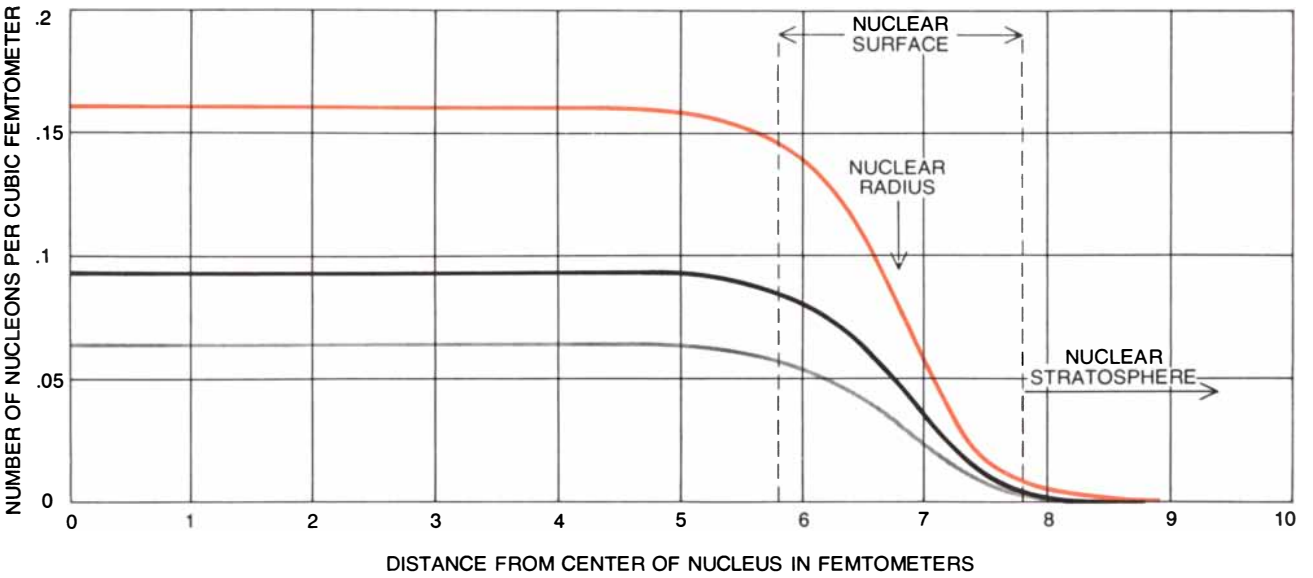
quantum states just as the electrons in the atom exist in discrete quantum states. The electrons form shells around the nucleus, and the atoms are classified in the periodic table of the chemical elements according to these shells. In nuclei there also is a periodic recurrence of certain properties as nucleons are added to fill successive shells of quantum states.

There is an apparent conflict between the behavior of the nucleus as a dense liquid drop and the fact that nuclei exhibit shell structure. The particles of a real liquid drop are continuously in motion; the liquid-drop model of a nucleus would seem to suggest that the individual nucleons are constantly colliding with one another and that they do not remain in well-defined shells. The conflict is resolved by the Pauli exclusion principle. Since every available quantum state in the nucleus is filled, there is essentially nowhere for a nucleon to go. It remains locked in its orbit. This independence of each nucleon from the others paradoxically implies that the nucleons must somehow cooperate in order to move past one another smoothly. So it is that nuclei simultaneously exhibit the properties of both independent and collective particles.

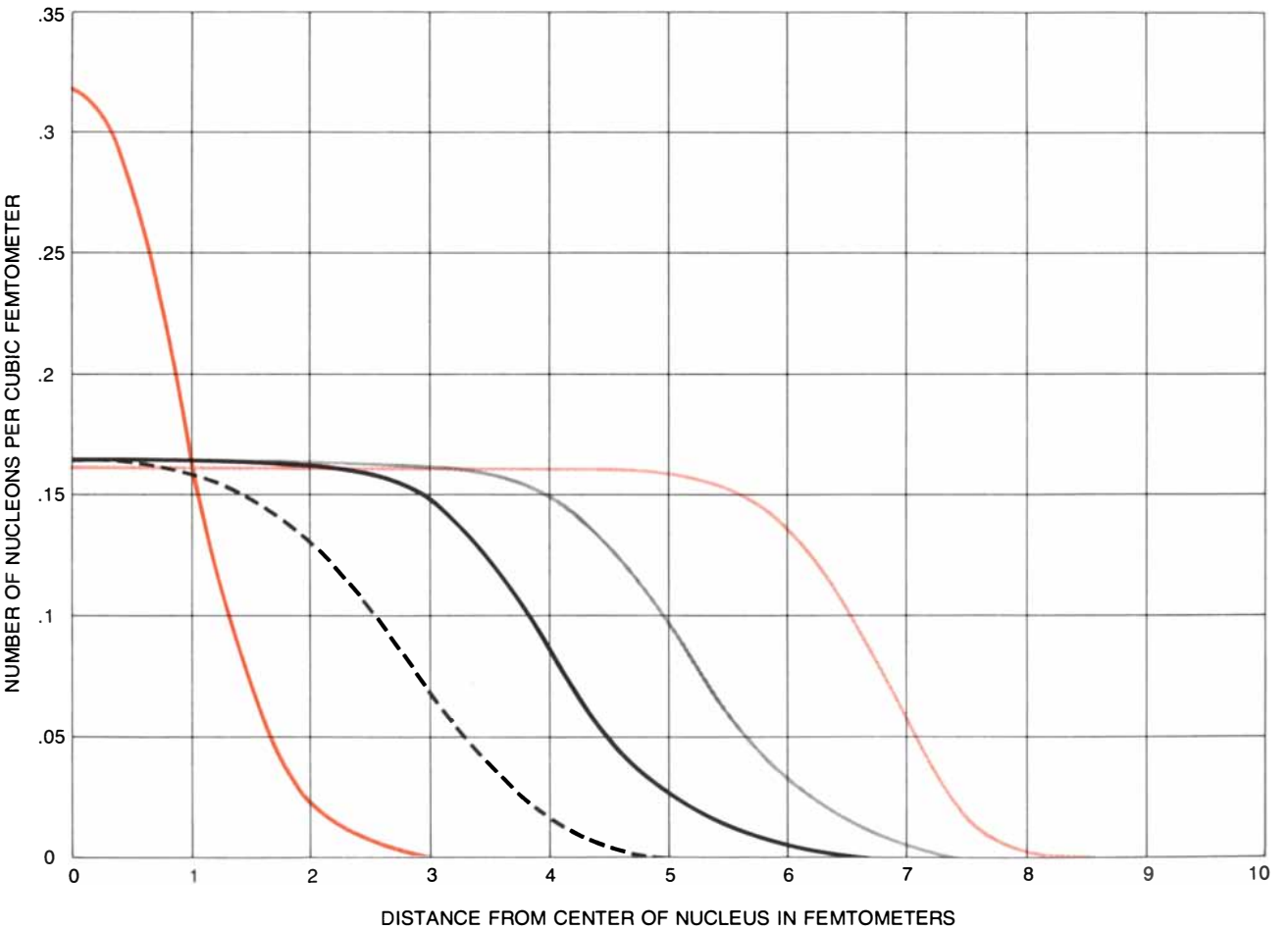
Most nuclei are spherical, although



NUCLEUS OF GOLD ATOM is spherical and consists of 197 nucleons: protons (*lighter stippling*) and neutrons (*heavier stippling*). Although the nucleus is 10^{15} times denser than the remainder of the atom, even in it there is a great deal of "empty space." Each nucleon has a diameter of approximately one femtometer (10^{-15} meter); the center-to-center distance between neighboring nucleons is some two femtometers. The density of nucleons and the strength of the intense nuclear force (*dark color*) are uniform in the interior of the nucleus and fade off gradually toward the surface (*light color*). The nuclear force does not drop off abruptly with the last nucleon but diminishes slowly. Here and there in the surface of the nucleus two protons and two neutrons coalesce into an alpha particle. These alpha particles are not immutable structures; the clusters continually appear and dissolve in the nuclear surface as the individual neutrons and protons from the interior shuttle in and out of the surface as they follow their separate orbits.



NUMBER OF NUCLEONS per cubic femtometer is shown in relation to increasing distance from the center of the gold nucleus (*color*). There are 118 neutrons to 79 protons, so that the density of neutrons (*black*) is somewhat higher than the density of protons (*gray*). The density of nucleons is not zero at the edge of the nucleus; the region labeled "nuclear stratosphere" has a density approximately 1/20th the density of the interior regions and falls to zero at larger distances. The radius of the nucleus is generally taken to be the point where the density is half of its maximum (interior) value; the gold nucleus has a radius of seven femtometers.



DENSITIES OF NUCLEI are compared. The heavier nuclei such as gold 197 (*light color*), tin 120 (*gray*) and cobalt 59 (*black*) have an interior region of constant density and a surface region that is generally about two femtometers thick. Lighter nuclei such as magnesium 24 (*broken line*) tend to be "all surface," or composed almost entirely of alpha-particle clusters. The high density of the helium-4 nucleus (*dark color*) is due to its unusually strong binding; it is termed an alpha particle when it is a projectile.

some are slightly deformed into ellipsoidal shapes. Information gleaned from the scattering of high-energy electrons by nuclei shows that the density of large nuclei is roughly constant in the interior and falls off at the surface [*see illustrations on opposite page*]. This decrease in density typically occurs over a distance of about two femtometers. (One femtometer is 10^{-15} meter.) If the radius of the nucleus is taken as the point where the density is half of its maximum value, it is found that the mass of a nucleus is closely proportional to the cube of its radius. Since the volume of a sphere is proportional to the cube of its radius, the result indicates that all nuclei have similar densities. Fairly large nuclei have an interior region of constant density and a surface region of decreasing density about two femtometers thick. Nuclei lighter than the nucleus of aluminum 27 are essentially all surface in that they are not large enough to have an interior region of constant density.

It has long been argued that there may be a tendency for the nucleons in the outer fringes of the nucleus to clump into alpha particles, which consist of two protons and two neutrons. Before the 1960's the arguments for this belief were both theoretical and experimental, but no one of the arguments was direct. On the theoretical side it was argued that the Pauli exclusion principle was less effective in maintaining the separation of nucleons in the low-density regions of the nucleus than it was in maintaining the separation in the high-density regions. Because the alpha particle is by far the most tightly bound small cluster of nucleons, it was assumed that such clusters would appear at the nuclear surface. On the experimental side one would expect that the probability of the radioactive emission of alpha particles by a lumpy nucleus would be higher than the probability of such emission by a smooth nucleus. Indeed, alpha particles were emitted from radioactive nuclei at a greater rate than was expected for smooth nuclei. Furthermore, alpha particles were known to be copiously produced when nuclei were bombarded with energetic protons, which lent support to the lumpy model. Additional evidence came from the way in which another kind of particle, the K^- meson, was absorbed from its orbit after it had been captured by an atom. One of the reactions undergone by the captured K^- meson could only proceed with pairs of nucleons that were closely correlated. It appeared that the rate of this reaction was higher than it would be if the nucleons were evenly spaced at the surface.

The alpha-clustering proposed to explain these facts is not to be regarded as a rigid collection of alpha particles on the nuclear surface. The clusters must continually appear and dissolve in the surface as the individual nucleons from the interior shuttle in and out of the surface region while following their separate orbits. The average number of alpha particles at the surface will depend on how favorable the energy considerations are for nucleons to cluster while they are in that region. The cooperative behavior required of the nucleons by the Pauli exclusion principle is such that even a model where the nucleons are extremely independent, namely the nuclear-shell model, predicts some clustering of alpha particles at the surface. The degree of alpha-clustering expected in the nuclear-shell model falls precipitously from nearly 100 percent for the nucleus of lithium 6 to only 1 percent for the nucleus of calcium 40 and even less for heavier nuclei.

In 1961 and 1962 the hypothesis that the alpha-clustering was greater than was predicted by the shell model was directly tested at the Lawrence Berkeley Laboratory of the University of California by George Igo, L. F. Hansen and Terence J. Gooding. Nuclei were bombarded with alpha particles accelerated to an energy of 910 million electron volts by the 184-inch synchrocyclotron at the laboratory. It was argued that if structures resembling alpha particles existed at the surface of the target nuclei, they would be knocked off by the bombarding alpha particles. The crux of the experiment was to catch both alpha particles at the same instant in two separated particle detectors. Since alpha particles are the nuclei of helium atoms, the apparatus could be calibrated with a target of helium gas. In this way the probability that pairs of alpha particles—each pair consisting of a bombarding particle and a target particle—would be caught by the detectors was directly determined. Since the laws of conservation of energy and momentum operate in such a collision, the angle between the two alpha particles of a pair emerging from the target is unique for pairs of that energy. When no energy is lost in the collision, the scattering of the bombarding particle and the target particle is called elastic. Alpha particles that emerged from the helium target in pairs with the appropriate energy and angular spacing provided a unique "signature" for the elastic scattering from free alpha particles.

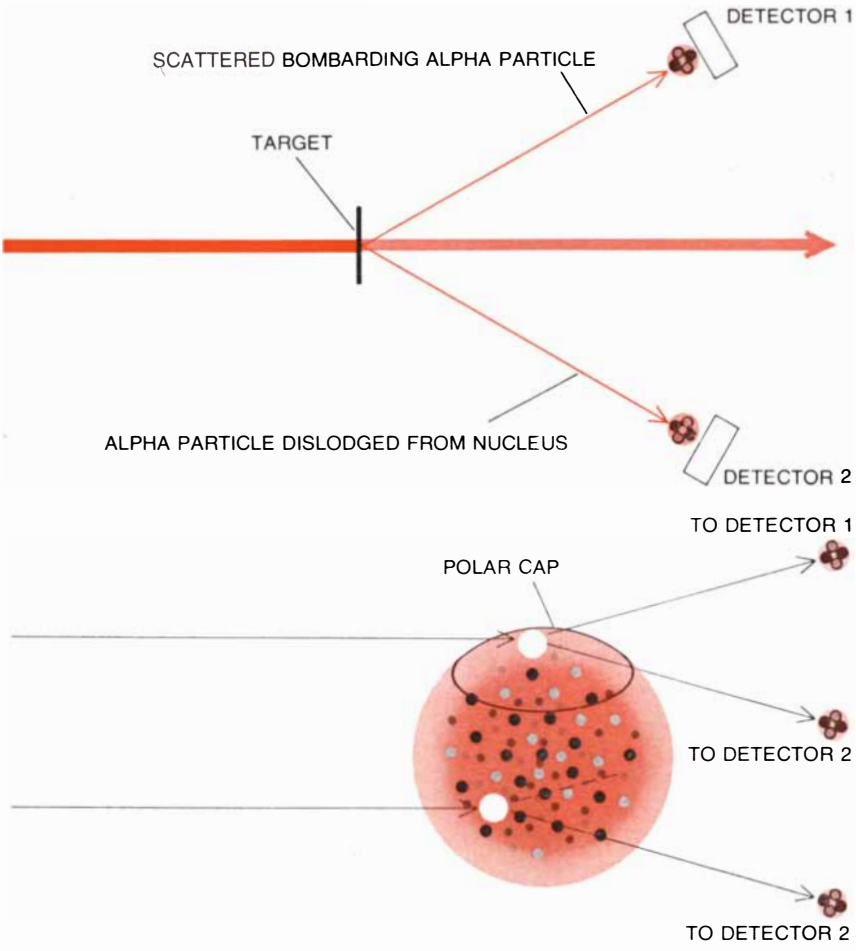
The observation of pairs of alpha particles with this unique signature emerging from heavy nuclei was taken to indicate the presence of essentially free alpha particles at the nuclear surface. Such scattering is called quasielastic because the particles are not totally free but are somewhat bound to the target nucleus. Their motion in the target causes the quasielastic scattering to be somewhat smeared out in energy and angle, but smeared out in a predictable way. The interior of the nucleus could not be a source of such alpha particles because either the bombarding particle or the outgoing particle would be absorbed as it passed through the nucleus. In fact, only those alpha particles at the "polar caps" of the target nuclei could contribute to the events that gave rise to simultaneous signals in both particle detectors.

Correcting for the fraction of the nuclear surface to which their experiment was sensitive, Igo, Hansen and Gooding concluded that essentially all the nucleons in the outer skin of the nucleus were marshaled in alpha particles. Although this outer skin, or "nuclear stratosphere," constitutes only a small fraction of a heavy nucleus, their result indicated that the clustering of alpha particles was far in excess of the predictions by the nuclear-shell model. Indeed, for the nucleus of carbon 12, which is essentially all surface, Igo, Hansen and Gooding observed three times as many alpha-particle pairs per nucleus as for a helium target, indicating that essentially all the nucleons in this nucleus are clustered in alpha particles.

Although the Lawrence Laboratory experiment was sensitive to the presence of alpha-particle clusters in a satisfyingly direct way, it suffered from some drawbacks. The beam of alpha particles produced by the synchrocyclotron was extremely attenuated (6×10^7 bombarding alpha particles per second), and very few events were recorded. This fact gave rise to large statistical uncertainties. Furthermore, the energy resolution that could be achieved at the high energy of 910 million electron volts was poor, which made it rather difficult to identify the true quasielastic alpha particles. Finally, the experiment sampled only the extreme outer fringes of the nucleus. Many similar experiments, with bombarding beams both of alpha particles and of protons, have since been conducted at lower energies with great-

er precision. Unfortunately the ease with which the nuclear-force field deflects particles of lower energy adds greatly to the difficulty of working backward from the experimental data to the probabilities of alpha-clustering. Several cyclotron laboratories are currently conducting or planning improved versions of this type of experiment. The results will be watched closely.

A somewhat different technique for the study of clustering employs more conventional accelerators (tandem Van de Graaff generators and cyclotrons in the energy range between 20 and 70 million electron volts). This technique is the study of nuclear reactions involving the transfer of a number of nucleons. In such reactions a projectile strikes the target and a single outgoing body is produced by the transfer of several nucleons from the target to the projectile or vice versa. When nucleons transfer from the target to the projectile, the process is called a multinucleon pickup reaction; the inverse process is a multinucleon stripping reaction. The experiments we have performed at the University of Colorado Nuclear Physics Laboratory over the past two years are typical of current experiments. My co-workers were Claude Détraz (on leave from the Institute of Nuclear Physics at Orsay), Clyde Zaidins, Calvin Moss and Harvey Rudolph.



NUCLEI WERE BOMBARDED with a beam of alpha particles in an experiment by George Igo, L. F. Hansen and Terence J. Gooding (*top*) to test the hypothesis that alpha particles cluster on the surface of the nuclei. The particles (*dark color*) were accelerated to an energy of 910 million electron volts by the synchrocyclotron at the Lawrence Berkeley Laboratory of the University of California. Most of the beam passed through the target undeflected (*light color*). If particles existed on the surface of the target nuclei, they would be knocked off by some of the bombarding alpha particles. The angle between the path of the bombarding particle and that of the target particle as they emerge from the target is unique for this process. The crux of the experiment was to catch both alpha particles at the same instant in two separate particle detectors. Only an alpha particle at one of the "polar caps" of a large target nucleus (*bottom*) could lead to the detection of two alpha particles in coincidence. Alpha particles elsewhere on the nucleus led to a scattering in which one of the pair of alpha particles was absorbed within the nucleus.

The probe we used in our studies was a 41-million-electron-volt beam of helium-3 nuclei, which lack one of the neutrons of an alpha particle. This energy corresponds to a velocity of a seventh the speed of light. The intensity of the beam was 3×10^{12} particles per second, compared with the 6×10^{7} of the Lawrence Laboratory experiment. The isotope helium 3 accounts for only one part per million of ordinary helium gas. Its cost had been prohibitively high for use in particle accelerators until recent years, when the price fell to $150 per atmosphere-liter. The present large supply of helium 3 comes chiefly from the radioactive decay of the large amounts of tritium (hydrogen 3) that are stockpiled for nuclear weapons and for research in fusion power.

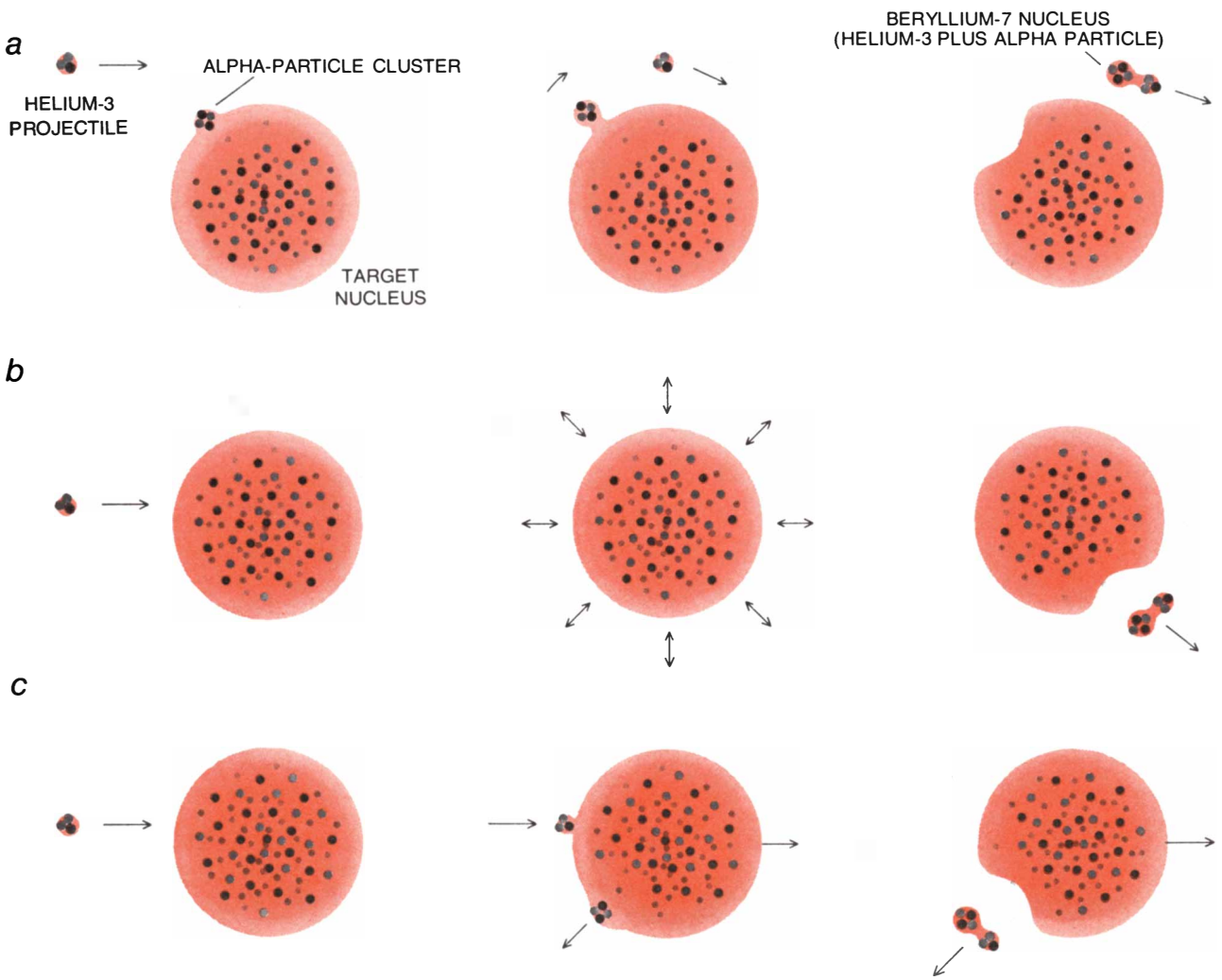
The helium-3 gas must be ionized so that electric fields can be used to accelerate the helium-3 nuclei. In our cyclotron at the University of Colorado the gas is passed at very low pressure through an electric-arc discharge in the center of the machine. This ion source consumes about a third of an atmosphere-liter of helium-3 gas per hour; most of the gas simply escapes from the source and is eventually lost in the vacuum pumps. Even at the present low price this consumption still amounts to $50 per hour, a cost that cannot be tolerated in experiments that typically last for several weeks. Fortunately our cyclotron is equipped with a highly efficient recovery system that continuously scavenges the exhaust gases of the various vacuum pumps that maintain the internal vacuum of the cyclotron. The fraction of helium 3 in these gases is extracted and fed back to the ion source for further use.

When the helium-3 nuclei have been accelerated in the cyclotron, they are extracted from the machine and delivered to a magnetic "switchyard." There the switching magnets bend the beam of particles into any one of several experimental areas. For our studies the beam was directed into an evacuated scattering chamber containing targets and detectors that could be positioned by remote control. The targets used in the study of nuclear reactions must be quite thin; in our studies they were about 1,000 atoms thick. Since atomic nuclei are so small, most of the particles in the beam pass through the target without interacting with a nucleus. (Thicker targets cannot be used because they cause the projectiles to lose an excessive amount of energy.) For this reason such large numbers of projectiles are required in nuclear-reaction studies. The projec-

tiles that do not strike a nucleus simply joggle their way through the electron clouds of the atoms in the target and continue on in a well-defined beam. They are caught in a Faraday cup, where their accumulated charge is used as a measure of the beam's intensity.

In our search for alpha-clustering we studied two different four-nucleon pickup reactions. One gave rise to an outgoing lithium-7 nucleus, indicating that one proton and three neutrons had been picked up; the other gave rise to an outgoing beryllium-7 nucleus, indicating that two protons and two neutrons had been picked up. If the second reaction was dominated by the transfer of an alpha particle, it would serve as a convenient means of studying alpha-clustering in the target nuclei. The first reaction could then serve as an experimental control. The two reactions are labeled (^{3}He,^{7}Li) and (^{3}He,^{7}Be).

Unfortunately many processes other than the alpha-particle pickup can lead to a (^{3}He,^{7}Be) reaction [*see illustration below*]. There is also a process that picks up four nucleons that are not in the alpha-particle configuration. A study of the control reaction (^{3}He,^{7}Li) helped us to estimate the strength of such processes, since the Pauli exclusion principle assures us that the four nucleons picked up in this reaction cannot be in the configuration of an alpha particle. It turns out that the rate at which clusters other than alpha particles are picked up is approximately a fifth of the rate at which alpha particles are picked up. In another competing process the incident helium-3 projectile is completely absorbed by the target. The resulting highly excited nucleus, called a compound nucleus, subsequently fragments in many different ways. One of them includes the emission of a beryllium-7 nucleus. The compound-nucleus process can be detected by varying the energy of the bombarding projectiles and searching for fluctuations in the

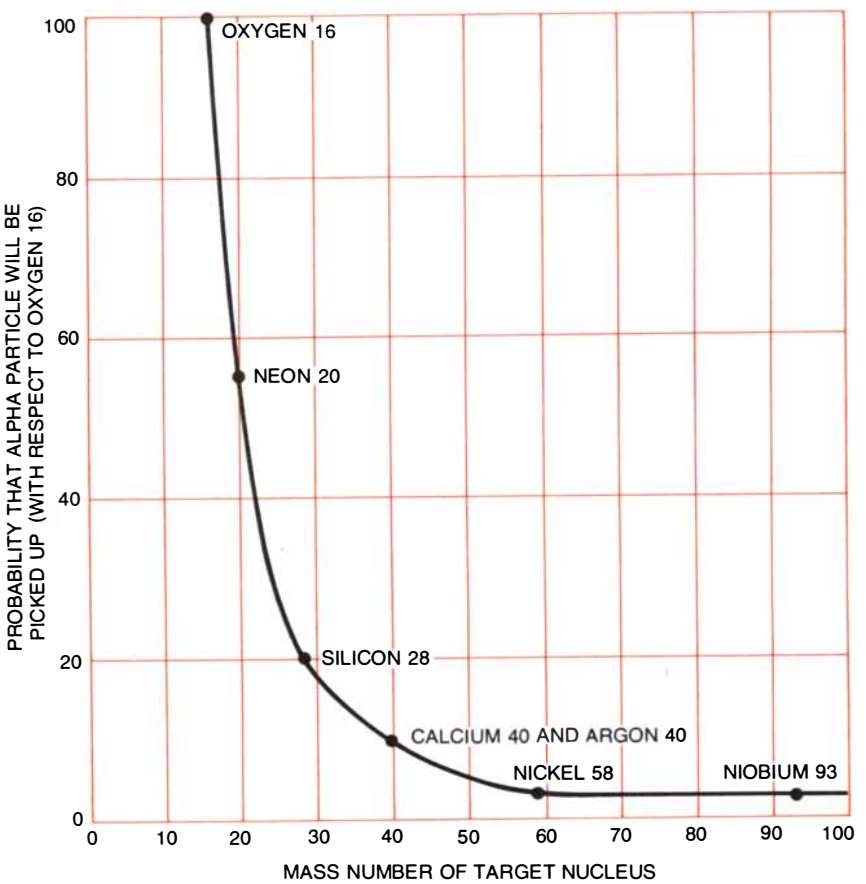


TRANSFER REACTIONS involving a number of nucleons were studied by the author and his co-workers at the University of Colorado Nuclear Physics Laboratory. In a transfer reaction a projectile strikes the target and a single outgoing body is produced by the transfer of several nucleons to the projectile. A beam of helium-3 nuclei (which lack one of the neutrons of an alpha particle) at an energy of 41 million electron volts bombarded target nuclei and picked up several nucleons. The reaction of interest was one in which a helium-3 nucleus picked up two protons and two neutrons to form a beryllium-7 nucleus. If the reaction involved the transfer of an alpha particle (*a*), it would serve as a convenient means of studying the clustering of alpha particles in the surface of target nuclei. Unfortunately processes other than the picking up of alpha particles can yield the beryllium-7 nucleus. In one reaction the incident helium-3 projectile is completely absorbed by the target (*b*). The resulting highly excited nucleus, called a compound nucleus, emits a beryllium-7 nucleus after a time delay of 10^{-19} second. In another competing process the projectile strikes the target nucleus, which recoils from the impact, leaving behind a clump of nucleons that form beryllium 7 (*c*).

yield caused by resonances in the compound nucleus. In a study of the (^{3}He,^{7}Li) and (^{3}He,^{7}Be) reactions in targets of fluorine 19 we were able to detect this process and make a small correction for its yield. In targets of heavier atoms the process was completely negligible.

One source of difficulty in these experiments is the wide variety of nuclear reactions that can be induced by helium-3 projectiles with an energy of 41 million electron volts. Our detectors were thus bombarded by a copious flux of gamma rays, neutrons, protons, deuterons, helium-3 nuclei, alpha particles and heavier nuclei produced by these reactions. We used a method common in modern nuclear-reaction studies to select the events that produced beryllium-7 ions. Our reaction-product detectors are essentially large semiconductor diodes. When a voltage with the appropriate polarity is applied, no current flows in a diode. A moving charged particle entering such a device, however, creates ions. The ions are collected rapidly (in less than a millionth of a second) by the voltage and produce an electrical signal proportional to the energy deposited by the moving charged particle.

We use a thin detector to measure the rate at which the moving particle deposits its energy. This detector absorbs only a fraction of the particle energy. The particle then enters a thick detector, which measures all the remaining energy. Different particles deposit their energy at different rates in the thin detector. An analogue computer, by multiplying the pulses from the thin and thick detectors, can generate a signal unique to each type of particle entering the detector system. When this signal corresponded to a beryllium-7 particle, our electronics were actuated so that the total energy of that particular particle was recorded. Typically we detected 5,000 events of all types per second with the system. In some cases fewer than 10 events per hour produced a beryllium-7 particle.

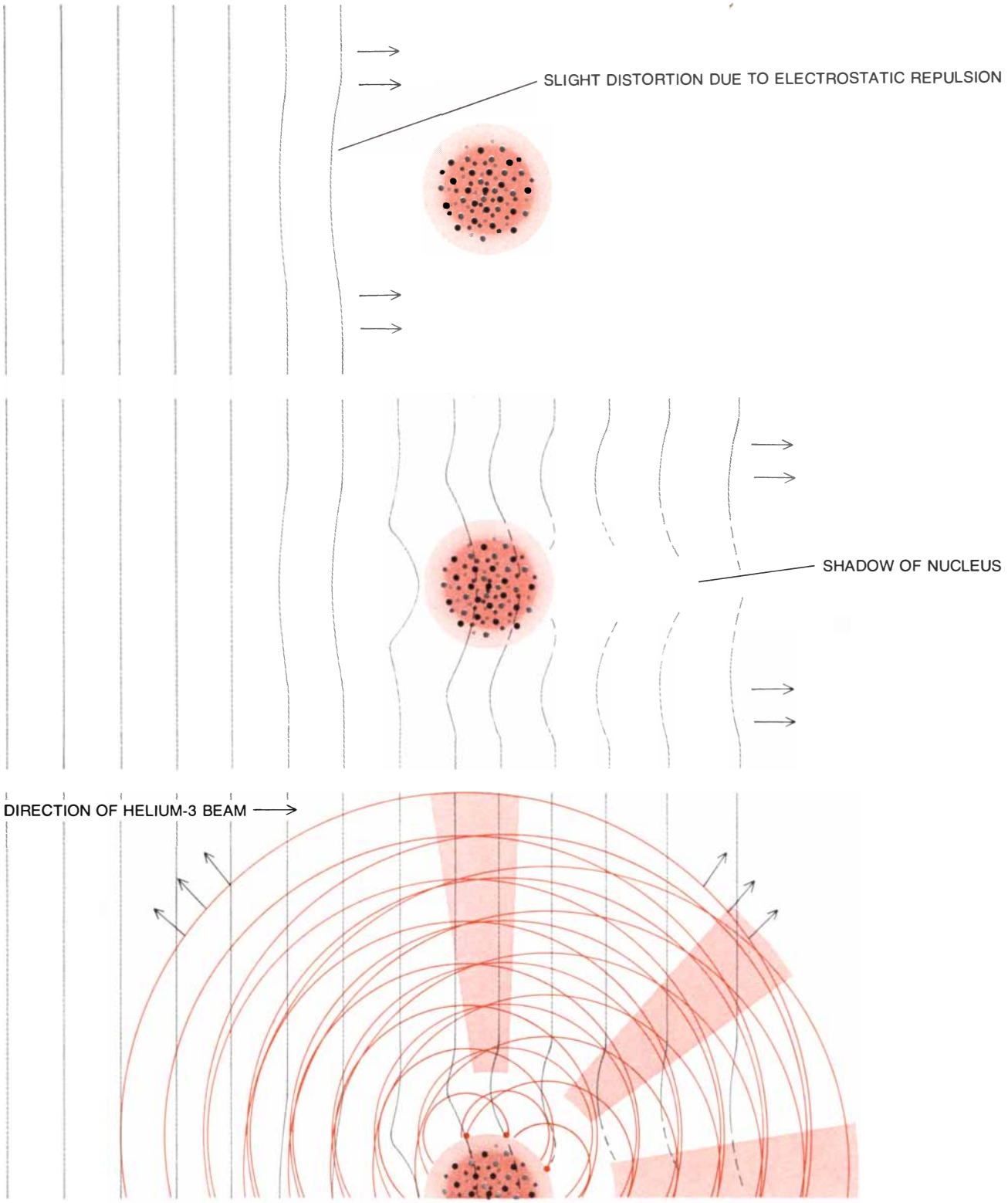


PROBABILITY that an alpha particle will be picked up from the surface of a target nucleus by helium 3 to make beryllium 7 varies with the mass of the target nucleus. The probability falls steeply from the lightest to the moderately heavy nuclei, and it levels out until it is nearly constant for the heaviest nuclei studied to date. The sharp decrease in probability was first ascribed to a decrease in alpha-clustering for heavier nuclei. The effect now appears to be due to the distorting influence of the nuclear force on the projectiles.

After a study of the (^{3}He,^{7}Li) and (^{3}He,^{7}Be) reactions in targets of nitrogen 14 and fluorine 19, we concluded that approximately 80 percent of the time the (^{3}He,^{7}Be) reaction is dominated by the alpha-pickup process. We then examined the variation in the probability of this reaction for various target nuclei: carbon 12, nitrogen 14, oxygen 16, fluorine 19, neon 20, aluminum 27, silicon 28, argon 40, calcium 40, zirconium 92 and niobium 93. Combining our results with the findings of other workers, notably a group at the Max Planck Institute for Nuclear Physics in Heidelberg, a general picture emerges. The probability of alpha particles' being picked up drops sharply (by a factor of 50) between carbon 12 and calcium 40, drops more slowly through the iron-nickel region and rises slightly for zirconium 92 and niobium 93 [*see illustration on this page*].

At first this behavior would seem to indicate a sharp decrease in alpha-clustering for heavier nuclei. It could be, however, that the bombarding particles and ejected particles are much more strongly absorbed by the larger nuclei, whereas the alpha-clustering probability remains nearly constant. In order to test this hypothesis we carried out quantum-mechanical calculations of the probability of the reaction for various targets. Such calculations explicity utilize the fact that the bombarding particles have the properties not only of particles but also of waves. Such "matter waves" are called de Broglie waves (after Louis de Broglie, who first suggested that the wave-particle duality observed for electromagnetic radiation might also exist for matter). The length of a de Broglie wave associated with a moving particle is given by Planck's constant divided by the momentum of the particle. Planck's constant is so small that we do not ordinarily detect the effect of these waves; their wavelength is too short to be observed. That is not the case, however, for objects with the dimensions of the atom or the nucleus. In fact, the wavelength of our bombarding particles and ejected particles was only slightly smaller than nuclear dimensions.

De Broglie waves, like other waves, can interfere with one another constructively and destructively. The interference of outgoing de Broglie waves in experiments such as ours gives rise to a particle intensity that varies with the angle of observation. The total probability of the reaction is affected by both the refraction of these waves by the strong nuclear attraction and their absorption in nuclear matter. A calculation tech-



WAVELIKE BEHAVIOR OF MATTER becomes evident when particles are of the dimensions of an atom or a nucleus. The beam of helium-3 nuclei bombarding the target possesses the properties of waves as well as the properties of particles. These "matter waves," or de Broglie waves (*gray lines*), refract around a nucleus in the target and are absorbed by it. As the waves first approach a target nucleus (*top*) they are repelled slightly because both the target nucleus and the beam of helium-3 nuclei are positively charged. As the de Broglie waves draw closer to the target nucleus (*middle*) the strong nuclear force overcomes the electrostatic repulsion and the waves are distorted toward the nucleus. They are partially absorbed by the nucleus, leaving a "shadow" behind it. Sometimes beryllium 7 results from the interaction of the target nucleus with the de Broglie waves of the helium-3 beam (*bottom*). The beryllium-7 nucleus also possesses its own de Broglie waves (*colored lines*), which emerge from the regions where the helium-3 waves can pick up an alpha particle to form beryllium 7. The rate at which beryllium 7 is produced depends both on distortion effects and on the number of alpha particles clustered in the surface of the target nucleus. The de Broglie waves from beryllium 7 interfere with one another, forming zones of constructive interference (*colored areas*) and destructive interference (*intervening spaces*).

nique for dealing with all these effects is called the distorted-wave Born approximation; it is widely used for the interpretation of many types of nuclear reaction. Such calculations call for a good-sized computer. In our case a CDC 6400 computer at the University of Colorado, operating on a program written by Dale Kunz, was pressed into service. The program is widely employed by nuclear physicists and is called DWUCK (distorted waves, University of Colorado, Kunz).

The distorted-wave calculations predict that because of distortion and absorption alone the probability of the (^{3}He,^{7}Be) reaction falls off with the increasing mass of the target nuclei at about the same rate as the experimental measurements. It is apparent, then, that the decrease in the picking up of alpha particles for heavier nuclei is due to the dynamics of the reaction and not to a decrease in the probability of alpha-clustering. We must conclude that the alpha-clustering probabilities are roughly constant for all nuclei studied.

Our results complement the early quasielastic studies of Igo, Hansen and Gooding, suggesting that the number of alpha particles per nucleus is roughly constant regardless of the mass of the nucleus. The precise number of alpha particles in each nucleus is still not known, largely because of insufficient refinements in the distorted-wave calculations. Nevertheless, the constancy of alpha-clustering, together with the quasielastic-scattering experiment indicating that the nucleus of carbon 12 consists of three alpha-particles, strongly suggests that all nuclei have a few alpha particles at the surface.

One possible breakdown of this appealingly simple picture deserves comment. Many nuclear physicists have argued that the heavier nuclei have a neutron "skin," that is, that the outer fringes of the nuclear surface have a large excess of neutrons. If this is the case, it may be that alpha-clustering is somewhat quenched in heavy nuclei. The alpha particle is composed of equal numbers of protons and neutrons, and if alpha-clustering is important in the nuclear surface, it would tend to keep proton and neutron numbers equal (although the surface would remain lumpy). More definitive studies of the surface region of the heaviest nuclei will be conducted with new accelerators. Coupled with more sophisticated wave-mechanical calculations, these new measurements may answer questions about the texture and composition of the nuclear surface quite soon.

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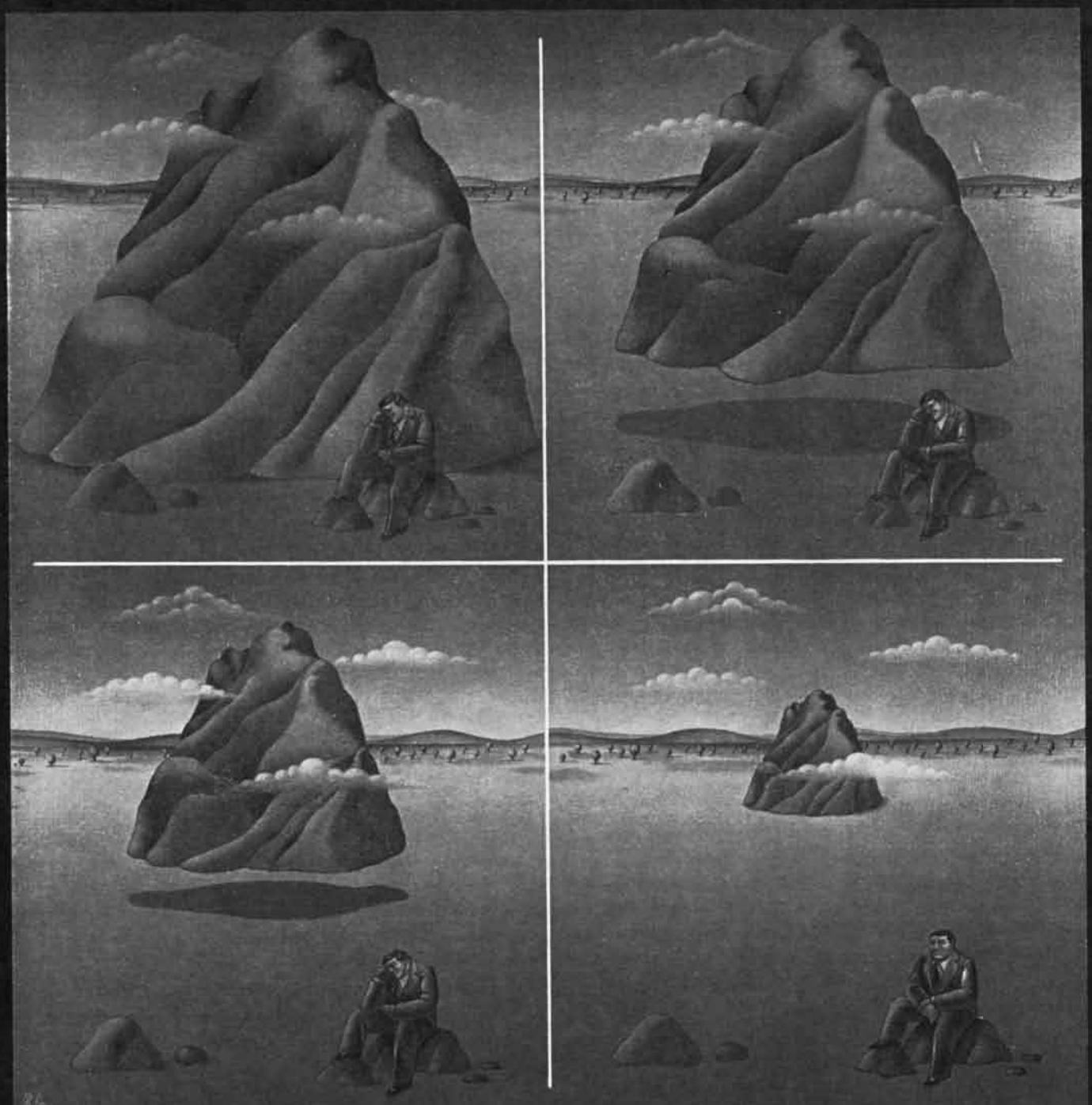

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MATHEMATICAL GAMES

Why the long arm of coincidence is usually not as long as it seems

by Martin Gardner

Don't worry.
Lightning
never strikes twice
in the same
—BILLY BEE

Since the beginning of history unusual coincidences have strengthened belief in the influence on life of occult forces. Events that seemed to miraculously violate the laws of probability were attributed to the will of gods or devils, God or Satan, or at the very least to mysterious laws unknown to science and mathematics.

On the other hand, skeptics have argued that in the unthinkably intricate snarls of human history, with billions on billions of events unfolding every second around the globe, the situation is really the other way around. It is surprising that *more* strange coincidences are not publicized. "Life," wrote G. K. Chesterton, "is full of a ceaseless shower of small coincidences.... It is this that lends a frightful plausibility to all false doctrines and evil fads. There are always such props of accidental arguments upon anything. If I said suddenly that historical truth is generally told by red-haired men, I have no doubt that ten minutes' reflection (in which I decline to indulge) would provide me with a handsome list of instances in support of it."

"We trip over these trivial repetitions and exactitudes at every turn," Chesterton continued, "only they are too trivial even for conversation. A man named Williams did walk into a strange house and murder a man named Williamson. ... A journalist of my acquaintance did move quite unconsciously from a place called Overstrand to a place called Overroads."

The improbable, said Aristotle, is extremely probable. All the same most coincidences surely go unrecognized. For instance, would you notice it if the license plate of a car just ahead of you bore digits that, read backward, gave your telephone number? Who except a numerologist or logophile would see the letters *U, S, A* symmetrically placed in LOUISIANA or at the end of JOHN PHILIP SOUSA, the name of the composer of our greatest patriotic marches? It takes an odd sort of mind to discover that Newton was born the same year that Galileo died, or that Bobby Fischer was born under the sign of Pisces (the Fish).

There are two other reasons why strange coincidences are seldom recorded. When trivial ones are noticed, it is easy to forget them, and when they are remarkable enough to be remembered, one may hesitate to speak about them for fear of being thought superstitious. Skeptics maintain that with all of this in mind the number of astonishing coincidences that continually occur as the result of ordinary statistical laws is far greater than even occultists realize.

The ancient view that many coincidences are too improbable to be explained by known laws has recently been revived by Arthur Koestler. In his latest book, *The Roots of Coincidence,* he devotes many pages to a theory developed by Paul Kammerer, an eccentric Austrian biologist, whose Lamarckian convictions were much admired by T. D. Lysenko and who was the hero of Koestler's previous book, *The Case of the Midwife Toad.* Kammerer wrote a book, *Das Gesetz der Serie* (Stuttgart, 1919), about his theory of coincidences. It describes exactly 100 coincidences—concerning words, numbers, people, dreams and so on—that he had collected over a period of 20 years.

Kammerer's seventh coincidence is typical. On September 18, 1916, his wife was in a doctor's waiting room admiring magazine reproductions of paintings by a man named Schwalbach. A door opened and the receptionist asked if Frau Schwalbach was in the room. Kammerer's 10th coincidence is even more impressive. Two soldiers were separately admitted to the same hospital. They were 19, had pneumonia, were born in Silesia, were volunteers in the Transport Corps and were named Franz Richter.

Kammerer was persuaded that such oddities could be accounted for only by assuming a universal law, independent of physical causality, that brought "like and like together." Koestler is sympathetic to this view. He suggests that some of the results of parapsychology, such as the tendency of falling dice to show a certain number more often than expected, can be explained not as the influence of mind on matter but as coincidences produced by a transcendent "integrative tendency."

Estimating the probability that a hidden law is at work behind a series of apparent coincidences is a difficult task, and statisticians have developed sophisticated techniques for doing so. How easy it is for our intuitions to go astray is illustrated by many familiar paradoxes. If 23 students are in a classroom and you pick two at random, the probability that their birthdays (month and day) match is about 1/365. The probability that at least two of the 23 have the same birth date, however, is a trifle better than 1/2. The reason is that now there are $1 + 2 + 3 + \ldots + 22 = 253$ possible matching pairs, and figuring the exact probability of coincidence is a bit tricky.

In a class of 35 students the probability of a birthday coincidence rises to about 85 percent. If students call out their birth dates one at a time until someone raises a hand to indicate that his birthday matches the one just called, you can expect a hand to go up after about nine calls (see "Note on the 'Birthday Problem,'" by Edmund A. Gehan in *The American Statistician,* April, 1968, page 28). William Moser has pointed out that chances are better than even that two people in a group of 14 will have birth dates that either are identical or fall on consecutive days of the year. Among seven people, he calculates, the probability is about 60 percent that two will have birthdays within a week of each other, and among four people the probability is about 70 percent that two will have birthdays within 30 days of each other.

Variants of the basic idea are endless. The next time you are in a gathering of a dozen or more people try checking on such things as the exact amount of change each person has, the first names of his parents, the street numbers of his home, the playing card each writes secretly on a slip of paper and so on. The number of coincidences may be scary.

Another simple demonstration of an event that seems improbable but actually is not can be given with a deck of playing cards. Shuffle the cards, then deal them while you recite their names in a predetermined order, say ace to

king of spades followed by the same sequence for hearts, clubs and diamonds. The probability that a card named in advance, such as the queen of hearts, will be dealt when it is named is 1/52, but the probability that at least one card will be dealt when named is almost 2/3. If you name only the values, the probability of a "hit" rises to 98 percent, or very close to certain.

In the foregoing instances the probabilities can be calculated precisely. For most events in daily life, however, probability estimates of coincidences are necessarily vague. For example, a great deal of research has been done on the "small-world problem." What is the probability that if you meet a stranger on an airplane, the two of you will have at least one acquaintance in common? Not only are accurate statistics hard to come by but also the very terms of the problem are impossible to define precisely. Who, for instance, is an "acquaintance"?

In spite of such formidable difficulties there is strong evidence that it is indeed a smaller world than most people imagine. Suppose a person is given a document and asked to transmit it to someone he does not know who lives in another city in another part of the U.S. The procedure is to send the document to a friend whom he knows on a first-name basis and who seems the most likely to know the "target" person. The friend in turn then sends the document to one of *his* friends with the same instructions, and the chain continues until the document reaches the target. How many intermediate links will the chain have? Most people guess about 100. When psychologist Stanley Milgram made actual tests, he found that the links varied from two to 10 and that the median was five.

Pick two women at random. The probability that both are wearing green shoes is low, but if you consider 20 ways the women can match—color of eyes, first names, type of hairdo and so on—the probability of a coincidence is close to certainty. It is hard to believe, but gross miscarriages of justice have resulted from a failure to understand just such trivial truths. In 1964 a black man and his white wife were convicted of a mugging in San Pedro, Calif., mainly because they were the only couple in the area who matched the reports of witnesses on five counts: the girl was a blonde, she had a ponytail, her companion was black, he had a beard, they drove a yellow car. The prosecutor estimated each probability separately—1/10 for a yellow car, 1/1,000 that a couple are black and white, and so on—then he multiplied the five fractions and convinced the jury that the probability was 1/12,000,000 that a matching couple lived in the vicinity. Not until four years later (see *Time,* April 26, 1968, page 41) did the California Supreme Court reverse the decision after a judge less ignorant of mathematics persuaded the court that the estimate should have been about 41/100.

Anyone who watches carefully for coincidences involving himself can easily find them. "Did you ever notice that remarkable coincidence?" F. Scott Fitzgerald wrote in 1928 to the British writer Shane Leslie. "Bernard Shaw is 61 years old, H. G. Wells is 51, G. K. Chesterton is 41, you're 31, and I'm 21—all the great authors of the world in arithmetical progression." Carl Sandburg was quoted in *The New York Times,* January 6, 1967, as saying that having completed his 89th birthday he confidently expected to live to 99. He had two great-grandfathers and a grandfather who had died in years that were multiples of 11. Having got safely past 88, Sandburg expected to go on to 99. Unfortunately he died six months later. Lewis Carroll recorded in his diary that most good things that happened to him, of which the best were meeting new and comely little girls, occurred on Tuesdays.

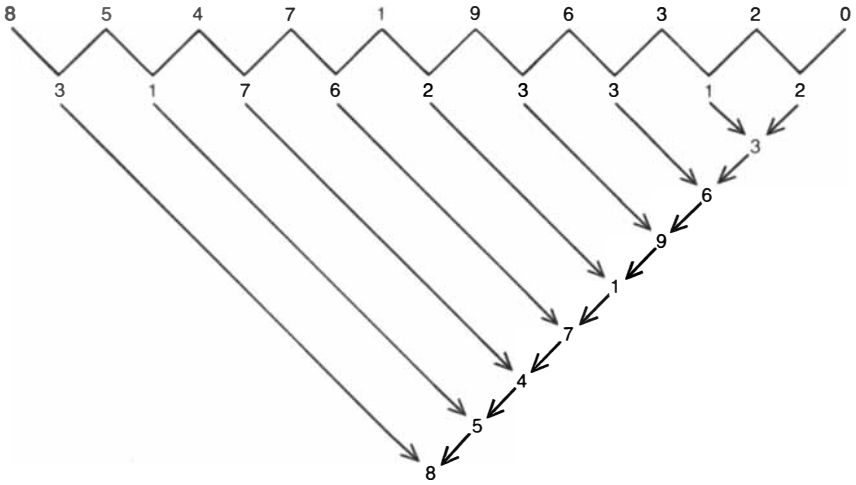
Surely the strangest coincidence involving a major U.S. magazine was the case of the "deadly double" ads in *The New Yorker,* November 22, 1941, which generated rumors about Japanese undercover agents for many years after. The long-submerged rumors surfaced in 1967 when a former U.S. naval intelligence agent, Ladislas Farago, told the story in a press release for his book *The Broken Seal,* an account of American and Japanese intelligence operations before World War II. Sixteen days before Pearl Harbor *The New Yorker* ran two advertisements (pages 32 and 86) for a new

We hope you'll never have to spend a long winter's night in an air-raid shelter, but we were just thinking . . . it's only common sense to be prepared. If you're not too busy between now and Christmas, why not sit down and plan a list of the things you'll want to have on hand. . . . Canned goods, of course, and candles, Sterno, bottled water, sugar, coffee or tea, brandy, and plenty of cigarettes, sweaters and blankets, books or magazines, vitamin capsules . . . and though it's no time, really, to be thinking of what's fashionable, we bet that most of your friends will remember to include those intriguing dice and chips which make Chicago's favorite game

THE DEADLY DOUBLE

$2.50 at leading Sporting Goods and Department Stores Everywhere

Two advertisements that appeared in **The New Yorker** ***for November 22, 1941***



Benson P. Ho's answer

dice game called The Deadly Double [*see illustrations on preceding page*]. Were these advertisements placed by the Japanese to inform their undercover agents of the planned attack on Pearl Harbor?

Farago's press release pointed out the following correlations. The attack was on December 7. In the smaller first advertisement note the 12 (for December) on one die and the 7 on the other. Above the dice are the words "Achtung. Warning. Alerte!" The numbers 5 and 0, Farago said, could have indicated the planned time for the attack, which did not start until 7:00 A.M. The XX, or 20, is the approximate latitude of Pearl Harbor. Farago admitted that he did not know what the 24 stood for.

The second advertisement shows two people playing the dice game during an air raid, with the XX repeated on the German symbol of the double-headed eagle. A *Times* story of March 12, 1967, based on Farago's press release, stated that the mysterious dice game had never existed. Farago told the *Times* that he had first learned of the ads from his friend Al Hirschfeld, the newspaper's theatrical caricaturist. When Farago questioned officials at *The New Yorker*, he said, "they were very closemouthed about it."

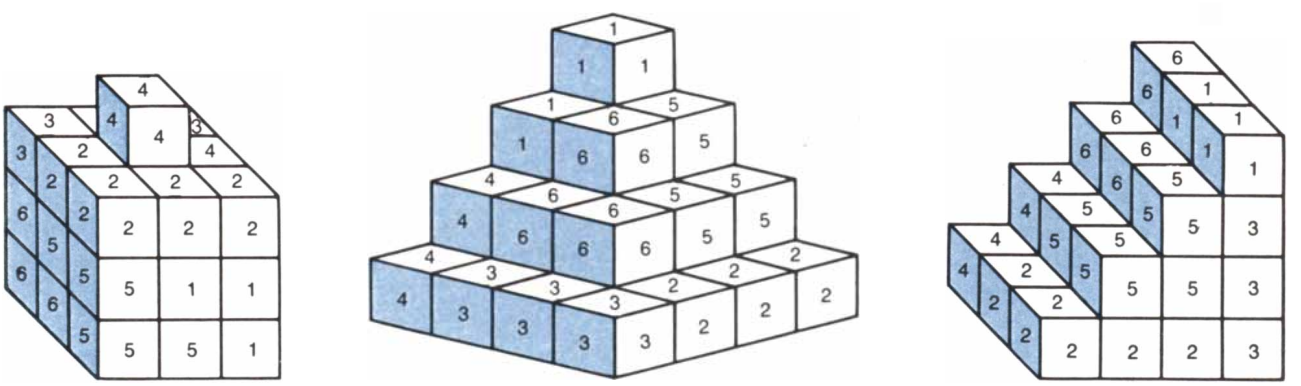
These fantastic allegations were quickly dissipated by the *Times*'s follow-up story on March 14. The dice game *did* exist. Mrs. E. Shaw Cole, widow of the man who invented it, had been found in Montclair, N.J. She had helped her late husband, Roger Paul Craig, write the ads. Several New York department stores were selling the game in 1941. Agents of the Federal Bureau of Investigation, Mrs. Cole said, actually had visited them after the Pearl Harbor attack, but any relation between the attack and the ads was just "one big coincidence."

"What can I say?" said Farago.

Several years ago I asked Dr. Matrix, the famous numerologist, for his opinion on the advertisements. The XX, he told me, indicates that two *X*'s are to be appended to the alphabet. The first number on the die, 12, instructs us to count to the 12th letter, *L*. The second number, 24, tells us to count 24 letters forward from *L*, including of course the extra *X*'s, and carrying the count back to the beginning. This second count ends on *H*. The 7 on the die at the right tells us to count seven letters forward from *H* to *O*. The three letters found in this straightforward manner are *L*, *H* and *O*, the initials of Lee Harvey Oswald. The advertisements in *The New Yorker* appeared in the November 22, 1941, issue. November 22 was the date of President John F. Kennedy's assassination, and 22 added to 1941 is 1963, the year of the assassination.

It is easy to understand how anyone personally involved in a remarkable coincidence will believe that occult forces are at work. You can hardly blame the winner of the Irish Sweepstakes for thinking that Providence has smiled on him even though he knows it is absolutely certain that someone will win. Gamblers are particularly susceptible to this belief, and they tend to be more superstitious than most. In every big city in the U.S. there are thousands of policy "hunch players" who like to bet on numbers prominent in the news. It is hardly surprising that now and then such hunches pay off. In 1958, for example, 48 people died when a Jersey Central commuter train plunged into Newark Bay. The last car taken from the water was shown in newspapers and on television with its number 932 clearly visible. Thousands of Manhattan policy players bet on 932 and won. A similar coincidence was reported in *The New York Times* for January 24, 1967. The President's daughter, Luci Johnson Nugent, had just given birth to a boy weighing eight pounds 10 ounces. All over Brooklyn bets were made on various permutations of these three digits. When 081 won, Brooklyn policy banks were closed for days because of the losses.

In science as in daily life it is not always easy to know if an observed correlation of "like and like" is pure coinci-



Solutions to the Soma problems

A LITTLE BOTTLE OF WINE SHOULDN'T MAKE YOU FEEL LIKE A FOOL.

Wine with a meal should be one of life's biggest pleasures.

But the act of ordering and tasting it can be one of life's biggest pains

That's because how much you know about wine has somehow become an index to how much you've been around And when the waiter hands you the wine list, it's as if he's handing you your final exam And the worst part is, it's an oral exam

We at Inglenook Vineyards would like to help We think if you knew exactly what all the ritual was about, you'd feel a lot more comfortable about ordering fine wine with your meals Which is certainly in our best interests

BE PREPARED.

First, you ought to be able to pronounce wine names correctly. Nothing can shake your confidence more thoroughly than to blurt out your order and pronounce it completely and totally wrong.

Or worse yet, just pointing to a wine on the list and saying, "Er, ah, we'll have a bottle of that one "

INGLENOOK'S GUIDE TO PRONUNCIATION

WHITE DINNER WINES	
Chablis	sha-blee'
Pinot Chardonnay	pea-no shar-doh-nay'
Pinot Blanc	pea-no blanh
Chenin Blanc	she-nahn blanh
Sauterne	so-tairn'
Sauvignon Blanc	so-vee-nyonh blanh
Semillon	say'-mee-yonh
Riesling	reez'-ling
Sylvaner	sil'-vah-ner
Traminer	trah-mee'-ner
RED DINNER WINES	
Charbono	shar-bo-no
Gamay	gah-may
Pinot Noir	pea-no no-ahr
Red Pinot	red pea-no
Cabernet Sauvignon	kab-er-nay' so-vee-nyonh
Zinfandel	zin-fan-dell
Gamay Beaujolais	gah-may boh-sho-lay

Most people have trouble with wine names because they're mostly French words Actually, they're really not that hard if you work at them a bit This pronunciation guide should help.

KNOW WHAT'S HAPPENING.

Now let's go through the whole thing step by step First you order the wine, pronouncing it correctly. So far, so good The waiter brings it out and shows it to you At this point, you're supposed to inspect the label to see if it's the wine you ordered. Check the brand, the type of wine, and the vintage

That done, the waiter should now open the wine This is a ritual in itself. A good wine steward should remove the cork and smell it This is to see if everything is alright. If the bottle has been stored in an upright position, the cork could dry up and air could get through and spoil the wine.

The cork should be placed beside your plate and the wine left open on the table, but not poured. This allows the wine to come into contact with air, which expands its bouquet and gives it a fuller taste. Just before the main course, the waiter should return to pour the wine.

"IT'S A GOOD POISON, BUT IT'S NOT A GREAT POISON."

What follows here is a ritual dating back to the Middle Ages At that time, a good way to kill off your enemies was to invite them to dinner and slip a little poison in their wine

Needless to say, everyone soon got a little paranoid about going over to someone's castle for dinner. So in order to set the guests at ease, the host would take the first sip of wine.

We do the same thing today, but there's a more practical reason for this. The host, or man at the table, takes the first sip of wine simply to see if the wine has turned If a wine has "turned" it has begun to dry out or oxidize. All wines will become corky and sour, if they are exposed to the air for a long period of time. So if the wine tastes unsatisfactory to you, send it back.

AN EASY WAY OUT.

If you still feel a little threatened by the whole situation, here's an easy way to get on top of it.

Ask the waiter which wines on the list are estate bottled.

An estate bottled wine is made only from grapes grown in vineyards under the constant supervision of the vintner.

Then ask him, of those wines, which ones come from Napa Valley.

And of those, which wines are vintage wines.

That should narrow it down to Inglenook.

Which will probably be the most expensive wine on the list, and the best.

The waiter is sure to give you some points for your selection of wine.

Because no fool ever ordered Inglenook with his dinner.

INGLENOOK

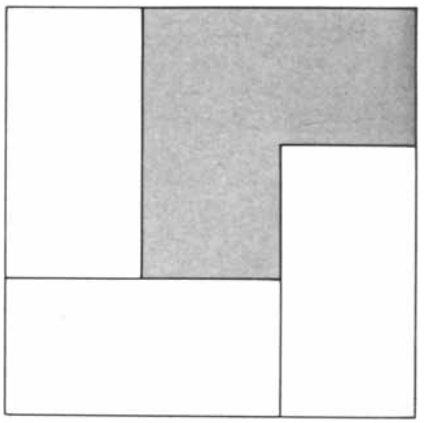
We make the most expensive wine in America

This ad is one of a series. If you'd like copies of the other ads, send your name and address to The Cellarmaster, Box J, Inglenook Vineyards, Rutherford, CA 94573.

dence or evidence of underlying structure. It was coincidence (plus some fudging) that the planetary orbits fitted Kepler's pattern of nested Platonic solids but not coincidence that data on their orbits fitted his patterns of ellipses. It is undoubtedly coincidental that the disks of the sun and moon, seen from the earth, are almost exactly the same size. The sun's diameter is 400 times that of the moon, but incredibly it is just 400 times as far away, as though nature planned it that way to give us a spectacular display of the sun's corona during a total eclipse. On the other hand, for half a century most geologists were convinced that the fit of the edges of the land masses on each side of the Atlantic was sheer coincidence. Alfred L. Wegener's theory that the two land masses had once been a supercontinent that had split and drifted apart (a notion that had been advanced by Francis Bacon) was considered crankish until about 10 years ago. Now it is the preferred hypothesis.

There are similar difficulties in mathematics. The curious repetition of 1828 in the first nine decimals of e (2.718281828...) is almost certainly coincidental. Consider now the square roots of .999 and .9999999. They are respectively .9994... and .99999994.... Is it accidental that in each case the irrational square root of a decimal fraction consisting of n 9's begins with n 9's followed by a 4? No, as Richard G. Gould has pointed out in a letter; it can be shown to be true of all such "rep-9" decimal fractions. You have only to express their square roots as $(1 - 10^{-a})^{1/2}$, expand the expression by the binomial theorem and interpret the results properly to establish the theorem.

The number 4 is a square number, and if you append to it the next consecutive square number, 9, the result is 49, another square. Is it a coincidence or a special case of a general law? One more curious question (both will be answered next month): An old brainteaser asks for the ordering principle behind the sequence 8547196320, which contains all 10 digits. The answer is that they are in the alphabetical order of their names. When the Massachusetts Institute of Technology's *Technology Review* printed this answer in its issue of July, 1967, page 10, it added a second answer that had been supplied by a reader named Benson P. Ho. His solution is best explained by his diagram [*see top illustration on page 112*]. The digit above the right arm of each V is subtracted from the digit above the left arm. If the result is negative, add 10. The result goes under each V. Arrow pairs point to digits that are the sum of the two digits at the back of each arrow. If the sum is greater than 10, subtract 10. Note that the diagonal series of digits, when they are read upward, repeats the original series. It is a remarkable coincidence. Or is it?



Solution to the tricube problem

Solutions to last month's Soma tasks of building the penthouse (with one interior hole) and the tower and stairsteps (each with three inside holes) are shown in the bottom illustration on page 112. Numerals indicate the pieces as they are numbered in Piet Hein's instruction booklet for the Soma cube currently being marketed.

Thomas H. O'Beirne's simple procedure for building the 3-by-3-by-3 cube with nine bent tricubes is to use six of them to make three 1-by-2-by-3 slabs. The remaining three tricubes are piled into a stack of height 3, then the slabs are placed vertically [*see illustration above*]. The picture is a view of the cube from above.

Last month I said that the number of heptacubes had not been calculated. I have since learned from David Klarner and C. J. Bouwkamp that an ALGOL-60 program written in 1969 by A. J. Dekkers at the Philips Research Laboratories in the Netherlands found $2^{10} - 1 =$ 1,023 heptacubes. The results of an earlier program were proved faulty by Klarner's father, who had built a set of wooden heptacubes that included several the program had missed.

Bouwkamp, who also works at the Philips Laboratories, informs me that he wrote a program in 1970 proving that J. M. M. Verbakel's way of replicating the F-pentacube with the 12 solid pentominoes is unique. "It is understandable," Bouwkamp comments, "that in Golomb's book the replication of this pentacube was left undecided, and most remarkable that Verbakel hit on it by trial and error."

THE AMATEUR SCIENTIST

An observatory built in a pond provides a good view of aquatic animals and plants

Conducted by C. L. Stong

A depression in the ground that fills with water to form a shallow pond spontaneously attracts a population of plants and animals. The initial conditions in the pond favor certain species. These species multiply, altering the environment in ways that encourage the growth of other organisms, which also thrive for a time, thereby preparing the pond for still other forms of life that similarly become transient links in a fascinating chain of biological succession.

An inspection of the surface of the water barely suggests the continuing drama of successional change, even if the pond is clear. Ideally observations should be made below the surface of the water without disturbing the environment or the population. One can do so in comfort with a submerged observatory forming an integral part of a pond that can be filled and drained as desired. An observatory of this kind has been developed by Ernest C. Bay, professor of entomology at the University of Maryland. He explains the details of the facility and its use as follows:

"In 1967, while studying the ecology of chironomid midge larvae and their predators in temporary ponds, I became dissatisfied with the limitations of conventional sampling methods that are used to investigate changes in populations. A tadpole or a crayfish placed in a jar reveals little more about its place in the world than can be learned about the behavior and natural dominion of a shark in an aquarium. I longed for a way to actually enter the ecosystem as an observer.

"Diving apparatus is obviously impractical. There is hardly enough water in the shallows of a pond to cover a man lying prone in scuba gear. Moreover, the presence of an observer would alter the environment. Ultimately I hit on the idea of a waterproof bunker of concrete, constructed as a feature of the pond, from which I could observe unobtrusively the interactions of prey and predator at any moment of the day or night and where nature rather than I would determine the quantity, selection and availability of food. I named the proposed structure a pond benthobservatory. *Benthos* is the Greek word for organisms that live on or in the bottom of bodies of water.

"Before undertaking the construction I consulted Theodore W. Fisher, a colleague who was also engaged in aquatic research at the University of California at Riverside, where I was then stationed. Together we worked out the details of a practical observatory. The pond was made by excavating an area of about 400 square feet to a depth of 18 inches. A hole about five feet wide and seven feet long was dug in the center of the pond to a depth of about five feet. The bottom of the hole was covered with a slab of concrete from which a set of anchor bolts protrudes. The bolts engage the watertight observatory that was subsequently installed in the hole [*see illustration on opposite page*].

"The structure consists of a plywood room covered on the outside with fiberglass cloth cemented in place. The room is entered through a hatch in the roof. The ceiling is insulated with fiber-glass wool protected by vinyl upholstery. Fresh air is drawn into the observatory through louvered slots in the walls of the removable roof section. The air is circulated and exhausted by a system of squirrel-cage blowers. Electricity enters the structure through a buried cable that connects to continuous strip outlets on three walls above the windows. Two 18-by-24-inch windows of plate glass are built in each long wall and one is built into each end wall.

"No artificial light is provided inside the structure, but an eight-foot fluorescent fixture is installed below the portion of the roof that overhangs the front of the observatory. This fixture is covered with a red sheet of transparent plastic to minimize the influence of white light on organisms that are observed at night. During the day the interior, which is painted battleship gray, is illuminated by sunlight that filters through the water. During late afternoon the rays of the sun enter the west windows through a prism of water that casts a giant solar spectrum on the facing work surface.

"The work surface consists of desk-high shelving 12 inches wide and two inches thick that girdles the room just under the windows. The corners of the planks are mitered to form a structural framework that helps to resist the inward thrust of the surrounding mud. Each of the shelves is supported by triangular brackets cut from the same planking. The observatory is entered through the hatch by first stepping on the shelving, then on a stool and finally to the floor.

"The pond is filled with irrigation water from a nearby reservoir. The water, which can be diverted through a filter of sand and gravel, enters the pond through an adjustable float valve and leaves by percolation through the soil. The pond can be drained quickly through a four-inch plastic pipe. Rapid draining is occasionally needed for maintenance and for altering experiments. The drainage system is also designed to accommodate overflow if the float valve should stick or be accidentally damaged. The pond is normally filled to within an inch of the top of the windows. The lower edges of the windows are recessed below the pond's muddy bottom.

"After a population has become established in the pond casual visitors who enter the observatory are invariably awed. The hatch is closed to exclude direct sunlight and reduce reflections. Within minutes the eyes become adjusted to the relative darkness. An eerie glow from the windows fills the interior. Depending on the stage of biological succession, clouds of daphnia and copepods may hang suspended in mid-water, while individuals jiggle in front of the windows. Dragonfly nymphs and beetle larvae can be seen stalking their prey through fields of bubbles anchored to the sediment.

"Frequently we fence off sections of

the pond in front of one or more of the windows with plastic screening that can be extended from the observatory to the edge of the pond. In these experimental enclosures the visitor can see fishes skimming below the surface in search of the scant remaining organisms that continue to multiply in the sections beyond the screen. Masses of snail eggs affixed to the windows glisten in the sunlight like clusters of yellow-centered beads in a gelatinous case.

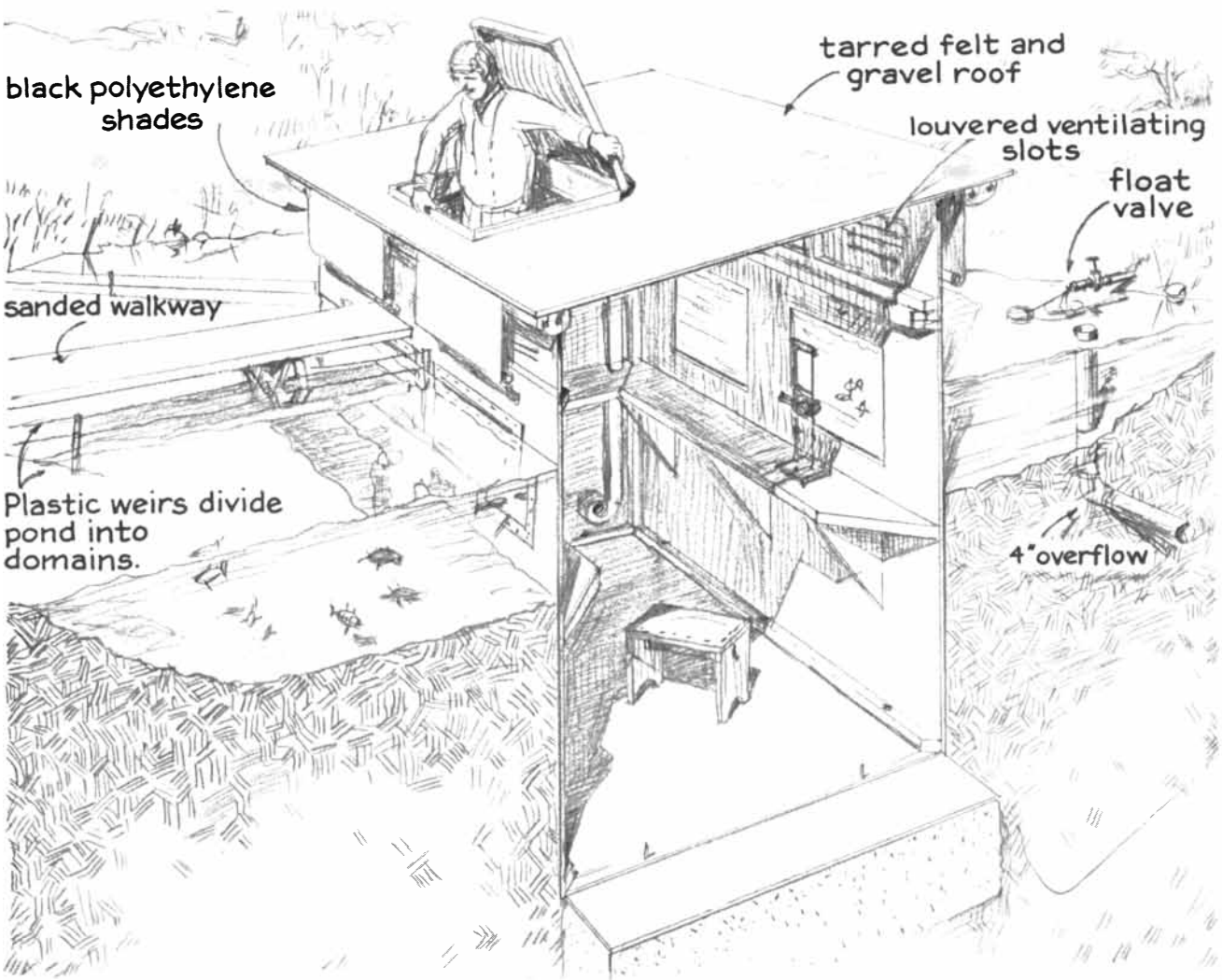
"The dramas that unfold in this Lilliputian world can be brought close to the eye with a specially mounted binocular microscope. The instrument is supported by a movable fixture that can be maneuvered both vertically and horizontally for inspecting any area of a window. The microscope includes an accessory objective lens for focusing on organisms several inches from the glass.

"Among the more commonly viewed organisms are tubifex worms. Feathery gilled *Branchiura* are often seen undulating gracefully, with their heads buried in mud. Ostracods and beetle larvae browse among their fellow creatures.

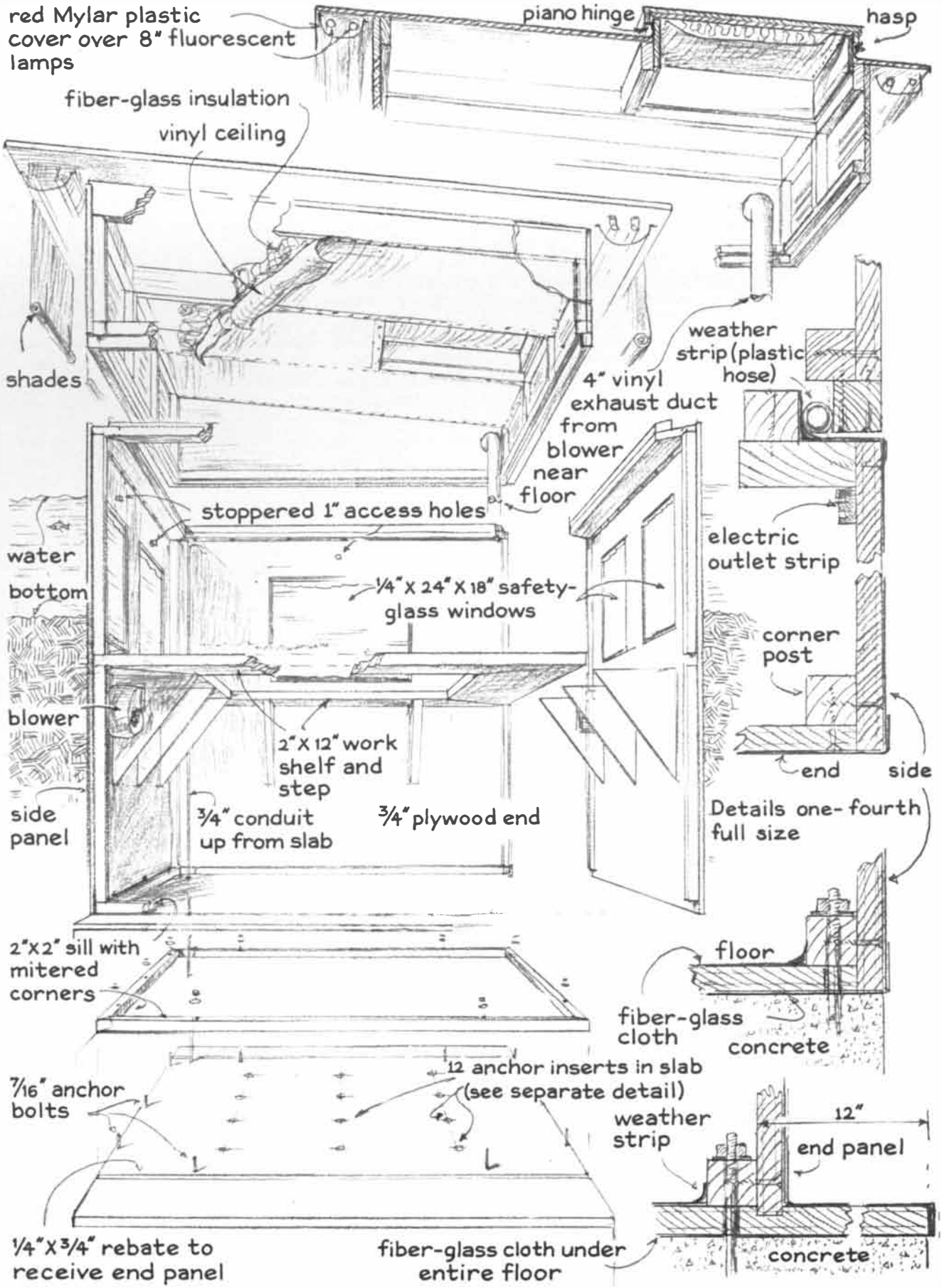
"Bloodworm larvae can be studied in their tubes as their predaceous cousins, tanypodine larvae, wander among grains of sand in search of paramecia and other microscopic prey. One wonders what protects tanypodine larvae from the voracious hydras into which they repeatedly bump. The mere touch of a mosquito larva triggers the hydra's deadly sting! At certain times of the year hydras attach themselves in curtain-like colonies to the observatory's windows, where their feeding habits and seasonal population can be studied in intimate detail.

"A number of organisms other than the hydra attach themselves to the glass. For example, snails deposit their eggs here. Snail eggs serve as a substrate on and in which the larvae of midges construct tubes and to which other organisms are attracted as if to a miniature coral reef in a sandy waste. For the study of these creatures the glass windows serve the function of a microscope slide.

"Of particular interest among the many aquatic insects that use masses of snail eggs for a transient resting station is the beetle *Laccophilus terminalis*. This animal lays its eggs among snail eggs. Although the beetle also lays eggs elsewhere, the masses of snail eggs provide the most revealing site: the stage for a drama that is related to overpopulation. The ecological succession of the pond begins soon after the pond is filled. During each succession various organisms appear and for a time assume dominance. Frequently some organisms vanish as abruptly as they came, without evident cause. It is much like observing the evolution of life on earth in microcosm, complete with the development and extinction of species. Some species exist only briefly, like insects on land. Others seem to adapt and persist through various changes in the pond's



Ernest C. Bay's "benthobservatory"



Details of the observatory

evolution. The *Laccophilus* beetles are among these.

"Whenever the pond at Riverside was drained and refilled, except during the winter, *Laccophilus* beetles were attracted to it almost immediately. Mosquitoes and midges also appeared promptly. They laid many eggs during the first few evenings after the pond was filled, but then the rate declined. The newly filled pond was usually clear at first, but it became murky during the period when midges and mosquitoes laid eggs.

"From within the observatory the microscope revealed that the apparently muddy water was actually a broth of swirling rotifers. These organisms appear brightly iridescent in sunlight. Moldlike colonies of sessile rotifers also attach themselves to various surfaces at this time. The colonies diminished as populations of midge and mosquito larvae became dominant.

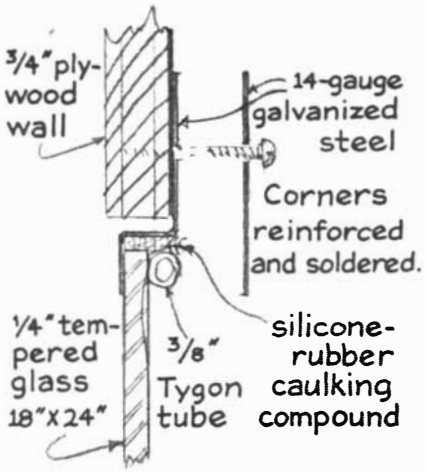
"Occasionally the cause of the murkiness changes as the rotifers are replaced by unicellular green algae. Within days microscopic animals (mostly daphnia) appear, reproduce and clear the water by feeding on the plants. By this time snails enter the pond, presumably through the water inlet, and begin laying eggs on various surfaces including the windows. The masses of snail eggs become favored sites for egg-laying by *Laccophilus* beetles. Adult females can be observed alternately surfacing for air and returning along a specific path to a particular mass of snail eggs. Presumably they follow a spoor. An average of two eggs are laid during each visit. Every detail of the egg placement can be observed as easily as if the gelatinous mass of snail eggs were a crystal ball.

"The self-regulation of the beetle population becomes evident after the density of midge and mosquito larvae declines. Adult beetles continue to visit the snail-egg masses, but for a dramatically different purpose. At great effort they now extract their previously laid eggs and devour them! They completely ignore the snail eggs as well as the developing snail embryos. In time the snails deposit additional masses of eggs. The beetles rarely use these eggs for laying sites, although beetle larvae and adults continue to occupy the pond. Only after the pond has been dried and refilled, or during the normal succession the following year, do the beetles again consume their own eggs.

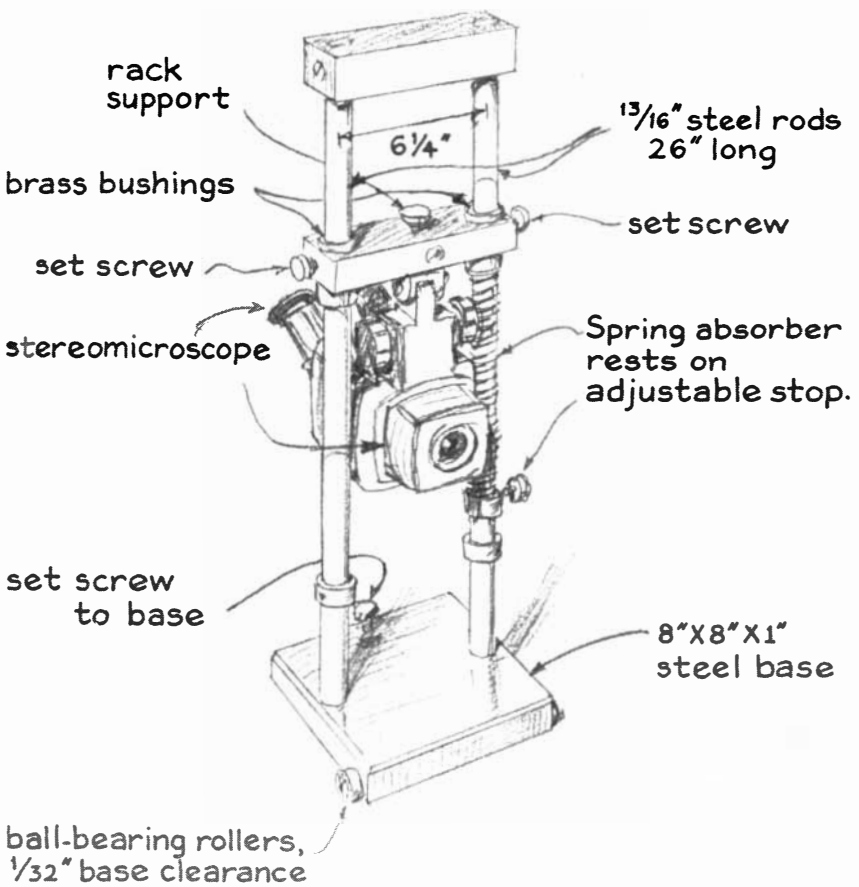
"As I have mentioned, the nymphs of dragonflies and beetle larvae prowl among the small bubbles anchored to the bottom of the pond. The bubbles help to explain an almost unsuspected mechanism by which nutrients and food particles are distributed among the various levels in the community, particularly in pools that are protected from the action of the wind and waves. The bubbles are a by-product of the photosynthesis of microscopic algae that grow as a fine layer over sediment and other surfaces. Although the bubbles cannot be seen from above the water, they are a striking feature below it, particularly on a brilliantly sunny day. As the bubbles form and expand to critical size they detach from their moorings and rise to the surface, trailing bits of organic sediment. Shallow water that may appear to be perfectly clear and still when observed above the surface is seen from the observatory to be filled with effervescence as millions of tiny bubbles distribute food to the population above.

"During the course of 24 hours changes can occur within even the smallest pond that compare with those that span years in the terrestrial environment. There is no rain or wind within the pond, but these elements of weather as well as sunshine and cloud cover exert a strong, if indirect, influence on activity below the surface. Occasionally the combination of environmental factors strikes a balance that is ideal for a specific organism. Almost overnight the pond becomes the scene of the population explosion known as a bloom. The environment recovers within a matter of days.

"A good site for a benthobservatory is one that has a constant supply of inexpensive water and is reasonably secure from vandalism. Ideally the site should



Window seal



Microscope assembly for the observatory

be close enough to related facilities so that the observatory can be visited conveniently at various times of the day or week. If the site is near an existing pond or stream, care should be taken to protect it against flooding.

"The site should also be selected with the intention of constructing the pond around the observatory rather than placing the structure in an existing pond. Several advantages support this choice. For example, the observatory is much easier to assemble in a dry hole than in a wet one. Moreover, the designer has complete flexibility with respect to features such as flooding and drying, the control of water level, the composition of the substrate, the sectioning of the pond for experimentation, the quality of the water and maintenance. With these factors in mind the designer should also choose a site that facilitates draining. Preferably the pond should be constructed somewhat above the level of the surrounding terrain, perhaps by erecting earth dikes.

"Where feasible the benthobservatory pond should be higher than an existing pond or lake and parallel to a tributary that can be dammed and partially diverted as a water supply. At a site of this kind some windows can face on the stream and others on a quiet backwater. The stream would doubtless provide the observer with a community of organisms that differs from the community found in a still pond. The arrangement has the disadvantage of inviting turbidity during rainy periods and possibly of flooding.

"Clear water, although it is aesthetically pleasing, is not essential. Most observations are made within a foot or two of the windows. Organisms within this range are easier to see against a background that is somewhat turbid than against a clear one. The effect is comparable to observing an insect against a plain sheet of paper rather than against a confusing background of twigs and leaves.

"Useful observations can be made at a distance of between five and seven feet in water that is maintained at a depth of 14 to 18 inches. The horizontal view rarely exceeds that distance. A pond of this size does not unduly restrict fishes, frogs, turtles and other large organisms the experimenter may wish to study.

"The observatory can be built by anyone who is reasonably handy. The construction details and the cost vary with size. The structure at the Riverside campus was made with six sheets of waterproof plywood five feet wide and nine feet long that were bought on special order. Standard sheets of plywood measure four by eight feet.

"The structure was prefabricated and preassembled in the carpentry shop complete with fans and electrical outlets. It was then dismantled for interior painting, the installation of windows and the application of fiber glass to the exterior surfaces. The glass windows were set in frames of 14-gauge galvanized sheet steel. The frames were sealed into the wall cutouts with silicone-rubber cement. The glass was then similarly cemented into the frames against a gasket of 3/8-inch Tygon tubing that had been previously cemented to the inner angle of the frame. A matching pressure plate was then fastened to each sheet of glass with screws.

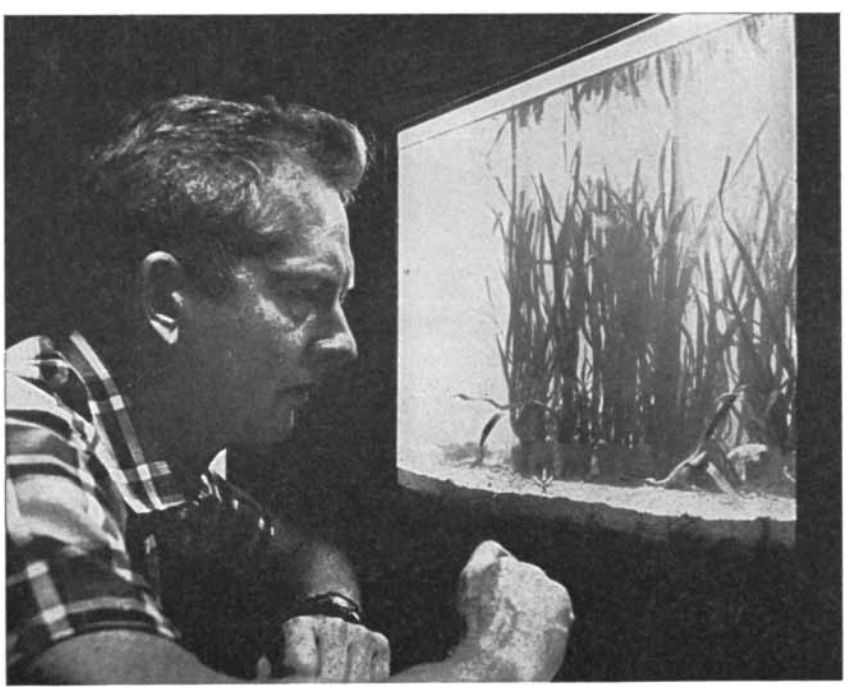
"Oversized sheets of fiber glass were applied to the plywood. The excess is used for overlapping the corners of the structure during final assembly. The observatory is completed by cementing the overlaps in place, bolting the floor sills to the concrete slab and sealing the bolts with aquarium cement. Soil is filled around the structure to the base of the windows. Within a day, after the fiber glass has cured, the pond is ready for filling.

"The observatory requires little maintenance other than occasional cleaning. Exterior maintenance involves only the occasional cleaning of windows and pond renovation when the experimenter recycles the environment or undertakes a special experiment. If the mud contains sharp sand, the danger that the glass will be scratched when the windows are cleaned can be minimized by covering the bottom of the pond with a layer of fine topsoil.

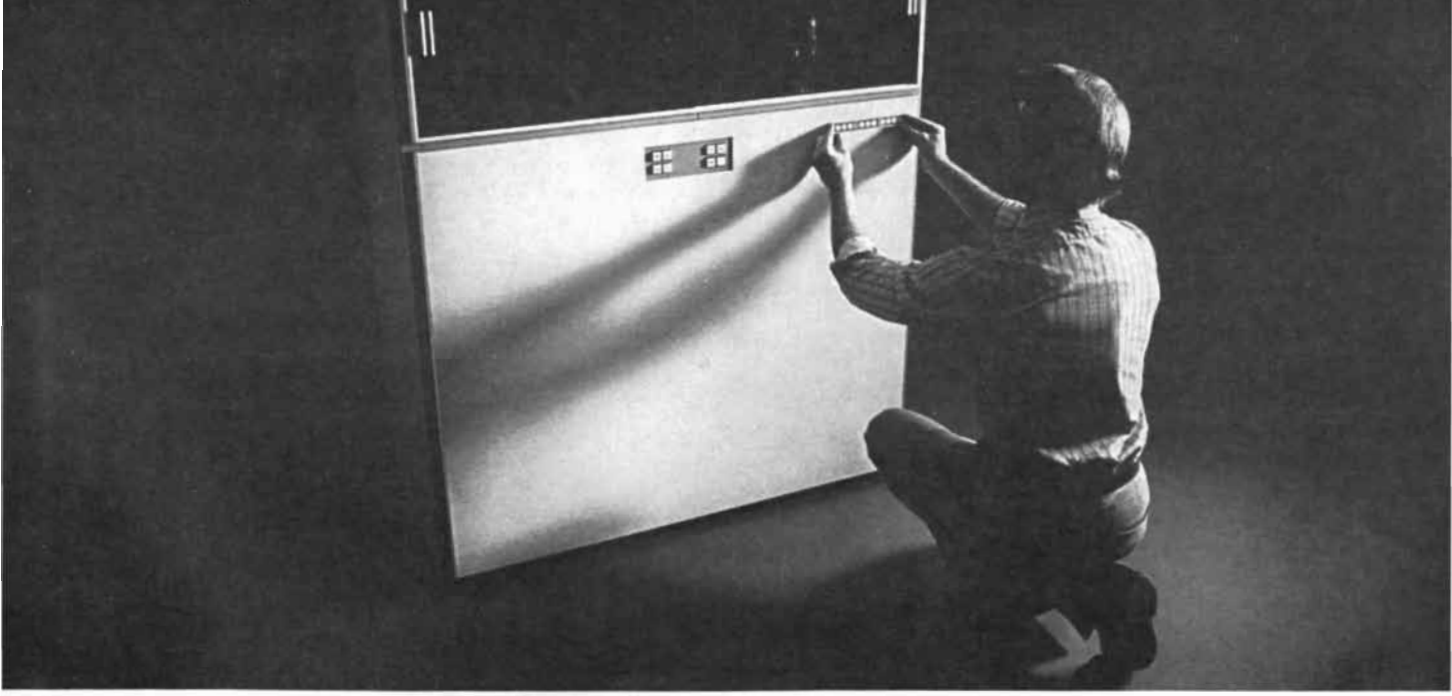
"The windows can usually be cleaned from the roof of the observatory with a short-handled sponge of the type used for waxing floors. Make downward strokes. Then raise the sponge through clear water to wash off the sand that may have been picked up from the bottom.

"If hard algae adhere to the glass, drain the pond and scrape off the organisms with a razor blade. The growth of algae on the glass can be discouraged when the observatory is not in use by installing waterproof shades of black polyethylene sheeting over the windows. Support the shades at the top of the windows by lengths of inexpensive pipe. Weight the bottom edges of the sheets. The growth of rooted vegetation can be restricted by burying sheets of galvanized steel just below the surface of the mud. Holes can be cut in the sheets to serve as planters.

"In some climates it may be necessary to drain the pond and abandon the observatory during the winter. With the coming of spring a completely new set of underwater phenomena can be observed in progression through the summer and the fall. Although pond inhabitants and events vary with location, no pond remains sterile. Where there is water there will be life. For this reason a benthobservatory is certain to yield rewarding adventures."



Bay at a window of his observatory



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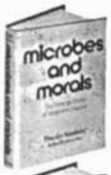

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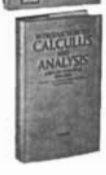

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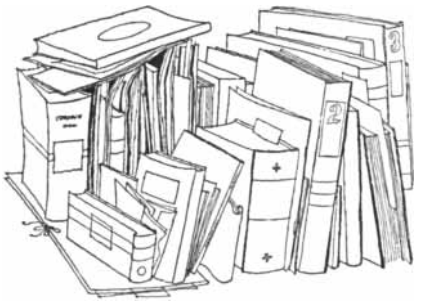

BOOKS

Mitchell Wilson's conversations with scientists around the world

by Philip Morrison

PASSION TO KNOW: THE WORLD'S SCIENTISTS, by Mitchell Wilson. Doubleday & Company, Inc. ($10). Alice knew that the value of a book lay in pictures and conversations. This unusual volume has no scrap of a picture, but it is filled with good conversations. To make it the author, a knowing, experienced writer, himself trained in physics before Pearl Harbor (a classmate of Julian Schwinger, he recalls), circled the world, mainly in the late 1960's. He talked to men and women of science in nine countries about how they came to science, what they did in it, how they saw their problems in science and in life. He seeks to pick out "the differences in national styles in doing science." A shrewd observer, albeit an opinionated one, he conveys the feel of a Pasadena laboratory or a Cambridge common room, of the smart dining hall of the Tata Institute overlooking the ancient dhows of Bombay harbor or the gray kangaroos bounding past the big radio telescope at Parkes in Australia. Famous men enter but by no means dominate his report; the young and the reflective are his particular sources. He watches the U.S. across the years of the late 1960's through 1970, when headlong growth stopped; he finds the present dollar plateau historically inevitable.

Sampling this book by the citation of conversations and observations is the only way to bring the reader in contact with it. One striking generalization can nonetheless be outlined. Wilson asked professional scientists when they first became interested in science. Only a handful had any answer "in English, French, Italian, or Russian" other than "As far back as I can remember" or "I was good at math" or "It was fun to do things with my hands" or "I came across a book." Uniquely the Germans, at least those past 35, had been inspired by secondary school teachers. Wilson traces this to the great tradition of original science in the Gymnasiums, where men such as Ohm and Cantor taught, following the precept of Franz Ernst Neumann of Königsberg, himself the teacher of Kirchhoff. The Indians also come to science not as a first love but as an arranged marriage, out of expediency, through scholarships or a father's advice, just as they had found wives. "It all sounds, to a Westerner, docilely calculating, and passionless."

Hear Maarten Schmidt on the discovery of the first quasar. " 'There were six emission lines altogether. Only six. Their position ... made no sense. Then one afternoon, five weeks later, it struck me that if I ignored two of the lines, the remaining four at least would fall into a sort of regular pattern.' " He thought of the lines of hydrogen, not red-shifted but perhaps simulated by some heavier atom, ionized down to its last electron. " 'It didn't fit. Apparently I had made an error somewhere.... Then I decided to take the ratio of each of these four lines to the corresponding lines of the hydrogen spectrum. Sort of doing it backward.... The fit was perfect!... I thought about it for a while, and thought I was crazy to believe it. So I called my friend into my office and told him about it.... Yes, it's true, he *did* scream.' "

Or hear what an "elderly French scientist" told Wilson, how long ago blond Jean Perrin and dark Paul Langevin often met in a Paris street, each with a parcel, both headed for the same destination. These two young university professors, soon to be world-famous, were each going to a place "not twenty minutes away: the nearest branch of the Mont de Piété—the government pawnshop." Some 15 years ago Wilson found the old French penury still dominant at the Sorbonne, where they frugally kept the cable from which Foucault's celebrated pendulum had swung a century before, held not as a piece of history but as a source of strong iron wire! The budget has much increased in the past decade, but attitudes change more slowly. French science lives "thanks only to the steadfast devotion of those men and women to whom science and research is as much a part of their lives as life itself."

At Dubno in 1958—another age, to be sure—Wilson spent a social evening among the Russian scientists at a time of great and covert strain. "In another room, the telephone rang. Conversation stopped dead.... White-faced, [a guest] got up ... to take the call." He returned "looking ten years younger, his face wreathed in smiles.... It happened three times, four times, five times." Some kind of revolution? A crucial experiment that would mold the lives of these men? No: " 'Today is the day when the universities and institutes announce which students have been accepted. Those ... calls are from our children.' "

Dr. Nagata, a research engineer at Hitachi, said among the pine woods an hour outside Tokyo: " 'When I was in the sixth grade ... my teacher had taught us how to make ... electric motors and buzzers out of paper clips.... When I was in high school, there were a lot of American B-29's that had been shot down during the war still lying there in the burned-out places, and we boys ... took lots of materials.... Many who are research engineers here today learned about electronics from the scrap pieces they picked out of the shot-down B-29's.' " Another man there was proud of his firm: Its machines " 'were all Japanese: ... Japanese-engineered, Japanese-financed. We have no financial ties ... to such foreign electrical companies. ... We are *purely* Japanese.' " Wilson pointed to his own Hitachi tape recorder. " 'It's a fine instrument,' I said. 'Which engineering features in it are Japanese? Do you have Japanese patents?' He looked at me with astonishment.... 'Ideas, no! Everything else, though,' he said again, stubbornly. 'Everything else is Japanese.' "

In India there is no lay appreciation of science. Yet there is a priest in Benares who "lived cramped into a tiny room studying Sanskrit and philosophy." He has also been "driven to understand nature experimentally, [working like] 'a 12-year-old boy in Europe' " to make a machine out of junk to boil his rice at a

specified time. He has made a crystal radio and a primitive phonograph; he has worked out for himself the Archimedean theory of levers as if there had been no Greece. A London traveler reports: " 'This monk has discovered the experimental method all by himself. He is a living example of how modern scientific thought grew from the medieval. Discovery at the time of Galileo must have been like this.' "

HOW ANIMALS WORK, by Knut Schmidt-Nielsen. Cambridge University Press ($5.95). Dogs and ostriches pant, men sweat, kangaroo rats calmly hoard their scarce water and the swift oryx "can stand in the hot sun all day." Ingenious engineering of flow is how they all do it: the flow of oxygen, heat, blood and water, of gas to the high-pressure swim bladder of the deep-living fish, of sodium ions to the already concentrated urine leaving the kidneys. These sharp, lively lectures, meant for readers at the undergraduate biology level, are devoted mainly to that large theme, taking a unifying view of this aspect of the mechanism of living forms. Most of the hard work of measurement, let alone the gifted insights, has been the lot of the past 25 years of the author and his colleagues, who have been seized with these questions ever since the urbane Norwegian came fresh from his physiological studies in Copenhagen to the Arizona desert, to find an "abundant animal life, which for me was quite unexpected."

"To understand function we must have some knowledge of structure." The structures here under study are chiefly visible ones on the scale of microns to millimeters, some even measured in meters; there is little reference to the molecular level. Here we are students of chemical-engineering process design rather than of chemistry. The ruling processes are diffusion, bulk flow, evaporation and mechanical pumping; the ends sought are locomotion, temperature control and ventilation. Professor Schmidt-Nielsen moves so masterfully within this classic domain to display his simple solutions to hard questions that the reader is both delighted and enriched.

One key device ("a cheap trick," he calls it) is the countercurrent array of tubes, the heat exchanger dear to the process designer. The oryx keeps a cool head in a feverish body (temperature up to 116 degrees Fahrenheit) by a network of hundreds of fine arteries into which the carotid artery divides as blood passes to the brain. Around this network is a pool of venous blood, fresh from the nasal passages where it has just been cooled by evaporation. With a similar device the whale reduces the heat loss from its flippers, only here the object is not to cool but to keep the core of the body warm. The tuna manages to hold the dark muscles that power its basal swimming at a temperature 25 degrees F. higher than the temperature of the sea; such fishes are in their way warm-blooded like the whale. In the skull and along the spine of the whale there are branching networks of arteries like those in the oryx, but they are not exchanger systems; there is no venous blood nearby. What these arterial networks do is not known; it has been suggested that they shield the brain from deep-dive pressure, but they have no valves for that function.

This steady-state device is of course not the only trick uncovered. The large nasal passages of mouse and man act as countercurrent devices by virtue of a time cycle. The cool, dry air that comes in must be heated and moistened before it encounters the warm, humid diffusion area of the delicate lung. When the air is exhaled, much of what has been added to it is conserved by the animal; since the nasal passage is already cool, it takes up heat and moisture. The task is reflected by the structure of the nose. This scheme anticipated the ingenious heat-regenerator piston of the Stirling engine. The iguana humidifies the air flowing through its nostrils by taking up water from an adjacent salt gland. The process concentrates the salt in the water of the gland to the degree that the lizard can virtually excrete crystalline salt; indeed, salt crystals are found around the animal's nostril openings.

When a dog pants to lose heat, it controls the loss by adjusting the fractions of the air flowing through the nose and the mouth. It is the one-way air motion through the mouth that effectively removes heat and water; the air flowing through the nose cools much less because it moves both ways. The control mechanism does not call for any change in the frequency of panting. Hard panting is steady panting; a light heat load is lost by intermittent panting. The panting frequency is always some 10 times the normal breathing rate, the elastic resonant frequency of the dog's respiratory system. If the dog were to drive the system off resonance, the heat load of the muscle work would exceed the dissipation secured by panting!

Measuring airflow with probes in the complicated air sacs of the ostrich, a king-sized working model of the typical bird breathing system, these physiologists have all but unraveled a complicated story. Air flows through the bird lung in the same direction both on exhalation and on inhalation. This apparently allows a countercurrent exchange between air and blood in the lung; the absence of such a system in bats proves that it is not a prerequisite for flight, but it does seem to be needed for flight at any altitude. At pressures such as those encountered at the top of the Andes sparrows remain alert, active and able (if reluctant) to fly. Mice "were comatose, lay on their bellies, and could barely crawl."

The remaining topics in the book are, broadly speaking, concerned with scale. One sees clearly that locomotion requires less energy per gram for big animals than for little ones. Swimming is energetically the least costly means of getting around; sperm cells and the salmon fit neatly on the same curve of energy expended v. size. Surprisingly, flying is easier than walking or running, on the scale of energy per gram moved over a mile of track. (It was not easy to train the rhea to run in the heat, but it yielded the data just the same!) It seems that a moving Volkswagen falls pretty close to the energy-weight curve for land mammals. The surface area of vertebrates is "quite regularly" about twice the area of a sphere of the same weight, although beech trees beat that folding by a factor of eight. In spite of what seems like a promise, the book ends without making it quite clear why the basic metabolic rate of warm-blooded animals rises not proportionately to their heat-losing surface area but to that area raised to a power a little above 1.1. Indeed, correction for the weight of the skeleton, viewed as inert load, would fit the data almost too well, although it could hardly explain why unicellular organisms follow the same curve. There is much more to know on the plane of this kind of macroscopic study, let alone to know how the cellular mitochondria adjust to life within an elephant.

EUROPE'S FIRST MONUMENTAL SCULPTURE: NEW DISCOVERIES AT LEPENSKI VIR, by Dragoslav Srejović. Translated from the Serbo-Croat by Lovett F. Edwards. Stein and Day, Publishers ($20). Downstream from Belgrade the Danube flows quietly through the Serbian plains until it reaches the Transylvanian Alps. There it bends sharply this way and that, finally forcing its way through a long gorge, "one of the most remarkable natural regions in Europe." It is a confined but varied space 60 miles long, the steep,

rocky hills rising up to a couple of thousand feet above the swift river. In English it is known as the Iron Gates; in Serbo-Croatian, the Djerdap gorge. At the fastest stretch of the river the Danube carves huge sculptures from the rocks of its bed as it flows through rapids. A great whirlpool in the midst of the river is called Lepenski Vir.

In 1970 the eddying river was turned to a quiet lake by a hydroelectric dam that raised the water level 12 meters at Lepenski Vir. Before that, in 1960, a small Neolithic site had been noticed on the narrow riverbank. There in 1965 Srejović, an archaeologist at the University of Belgrade, "cut a couple of trial-trenches across the imperilled site. The results were truly astonishing." So writes the editor, Sir Mortimer Wheeler. This handsome book tells what has been found there since, and introduces us as well to a powerful and creative scientific community of which we readers in English know all too little.

Lepenski Vir has long been sheltered from the icy winds; it has a special flora largely unchanged from the days before the ice advanced over northern Europe. Mediterranean varieties such as the edible hackberry flourish. The bank itself is narrow, infertile and stony, but beyond it is the virgin forest, full of game and abounding in fruit-bearing trees, and below it is the river, dangerous with swift eddies but rich in fish. Scree slides steadily from the hilltops, and from time to time there are falls of heavy rock. "The greatest physical effort is needed to penetrate this world and a prolonged stay in it can induce nervous strain."

Even though the river has claimed some of it, the stage occupied by mankind at Lepenski Vir was never large, at most some 600 feet by 150. Here we find in depth nine village levels, the first seven belonging to three settlements of one unique culture, the last two to a single settlement, part of a widespread Neolithic culture of the Danube basin called the Starčevo group. The shallow layer of shards that had first been noticed was "not of any great extent . . . and was very poor," but when Srejović cut through it, he found a culture that was "truly astonishing." That culture is "isolated in time and space." It has its "precursors but not its ancestors; its heirs are known but not its descendants."

For a period that is not securely known but is between 7,000 and 5,000 years ago an inbred group of people numbering a couple of hundred at any one time built a life at the edge of the river. About 100 skeletons testify to a robust folk, many of whom lived to a

ripe old age. The women's bones scarcely look different from the men's; all must have shared the hard work on equal terms. Infant bones are few; most have gone into the river. Grave goods too are few, and the implements and tools are conservative and unchanging. There is no material to be found that required a trip of more than 30 kilometers.

The world of the Lepenski Vir culture was nonetheless defined by a strict architecture of mathematical proportion. Above the lowest level all the dwellings were built on the same fan-shaped foundation, the size varying but the 60-degree angle remaining constant. It seems certain that these foundations were laid out by observing a careful proportion of lengths. The " 'architect-magician' " knew how to bisect lines, draw concentric circles and inscribe circles. "There is not one definite number," so that "although the model was certainly obtained by some rational procedure it . . . appears as something irrational and mystic." The foundations are of wood and local stone; over them was poured a kind of plaster, made by baking the local limestone and adding sand, water and gravel. Only a little is known about the roofs, from a few carbonized beams. The houses had slanting timber walls; they may have been either simple or rather complex. We are not sure. The floor plan and the overall village scheme, however, remained broadly the same for the entire life of the culture, even though the settlement was rebuilt in varying degrees of thoroughness.

At first each house had a stone hearth. By the time of the second layer it has been augmented by an egg-shaped central boulder. Then suddenly the arrangement becomes more complex: stone "tables" and sandstone sculptures appear. The sculptors did not employ the boulders that lie by the thousands on the riverbank but exclusively used large pieces of a coarse yellowish sandstone with red patches, found 10 kilometers away along the course of a single tributary stream. The images stand beside the hearths in pairs, carved deeply in the round, some with goggle eyes and grimaces, some resembling a vulva, some ornamented with furrows and friezes, one like the head of a fish god. These are the oldest sculptures known to represent the human head at life size or more than life size. (Older heads, known from Jericho alone, are molded, some on real skulls.) About 50 sculptures are known, and half of them are figured in this book, enigmatic, strong, rude.

The Lepenski Vir people lived as hunters and gatherers. They collected wild fruits, trapped marten and badger, but mainly hunted deer, ox and boar as the animals made their way through the narrow defile. Fish was a mainstay; in 1968 the eddies still offered the best fishing in the gorge. Fishermen awaited the fish in the shallows where the current drove them; they were taken in dams and traps, almost without any kind of tackle. Big sturgeon and giant catfish up to 400 pounds were sometimes taken. The people had one domesticated form: a small dog.

"The end of the Lepenski Vir culture is as enigmatic as the beginning." The last layer shows no burning or destruction; it is "covered by a fine layer of dark sand, giving the impression that the settlement was suddenly abandoned and, for some time, lay desolate." Then the Starčevo people came. They had pottery and raised pigs and cattle, sheep and goats. They knew nothing of their predecessors; their houses were irregular semiburied huts of earth and wood. At its peak the Starčevo village was ruined by flood. The site long remained uninhabited but was "a mysterious and hallowed spot" that was chosen for grave sites. In the time of Tiberius the Roman army built a watchtower there that was garrisoned occasionally up to the sixth century, perhaps 5,000 years after the end of the Neolithic village.

The waters of the new lake cover the site, but the remains of the villages at Lepenski Vir are safe above the water, raised by a remarkable plan for preservation to a hillside shelf nearly 100 feet higher. The engineers moved many house floors foundation and all, taking them a meter below the floor, freeing the entire 50-ton mass by inserting steel tubes into the rock. All the levels are resettled now, covered by a light roof on a handsome mesh of steel cables, with a small museum to house the movable finds. The visitor must find it a cloistered, brooding and romantic spot, with the terrible whirlpool now hushed, the stones of the past spelling their half-read story of one more extraordinary human link between the gifted artists of the old, free, mammoth-hunting times and those bound like ourselves to the land who count on reaping no more than they sow. They were strong and lonely, the folk of Lepenski Vir. Were they happy and proud?

FIELD GUIDE TO LANDFORMS IN THE UNITED STATES, by John A. Shimer. Drawings by Genevieve Shimer. Sections and Landform Maps by Erwin Raisz. The Macmillan Company ($8.95). A MODERN GEOGRAPHY OF THE UNITED STATES, by Robert Estall. Quadrangle Books, Inc. ($10). School geography was never like this: the landforms of the U.S. are set out in text and line by a geologist with a flair for explaining his science with neither pedantry nor condescension. He gives us a volume in two parts; the first portion treats 21 distinct "geologic provinces" (all 50 states), with an average of six pages for each, laying out against a sketch of the geologic background a tale of how the characteristic "flavor" of hills, valleys and plains came to be. The whole amounts to a readable summary, always close to what the traveler can see by the roadside or from the air of the physiography of our country, within the customary framework of that specialty. The second part—indispensable for any but expert readers—summarizes processes and features by an explanation of their nature and origin rather than by location. Between the two the reader is brought to interpret the landscape with pleasure and understanding. The book is a fine companion for the road.

There are three types of illustration, each admirable. The first is a set of photographs, mostly made from the air, showing one characteristic form in nearly every province. The second is a set of a couple of hundred clear small line drawings; they present kettle pond and talus slope, stratovolcano and pingo, each crisply drawn within the area of a large postage stamp. Finally, the book contains not only the 16 U.S. deep geologic sections drawn by the late Erwin Raisz years ago but also his splendid detailed landform map of the entire U.S. It is reproduced here in full scale on 26 pages, his sharp pen full of the look of the land. Here are the Plains of St. Augustine in New Mexico, Mount Monadnock's rocky remnant rising out of the low New Hampshire hills, and the dry falls of the Grand Coulee, high in the lava layers of the Channeled Scablands, witness to "the former presence of floods of water streaming southward across this now-barren region." A remarkable vividness and completeness characterize this map, our entire country shown at 75 miles to the inch, with just about every plain and upland, valley and range given distinctive look and correct name.

A Modern Geography of the United States, written by a cool, conservative economic geographer at the London School of Economics, is another surprise for readers who remember learning the products of the states. Professor Estall discusses not the full complexity of our country ("a laboratory without peer for . . . the patterns, trends, and problems

Books that make the life sciences more lively:

Vaughan: MAMMALOGY

A well-balanced, comprehensive treatment of mammalogy. The reader will find an even balance between chapters on orders and those on more general topics such as the ecologic, physiologic, and evolutionary aspects of mammalogy—topics equally suitable from both taxonomic and ecologic viewpoints. *By Terry A. Vaughan, Northern Arizona University, 463 pp, 587 figs. August 1972. $14.50. Order no. 9011.*

Turk et. al: ECOLOGY, POLLUTION, ENVIRONMENT

A new, provocatively written supplement for any science course. It takes a good look at all the crucial aspects of ecology—from pollution to population to the ecologic balance of environment. The authors discuss relevant topics in the physical sciences, then go on to explain and discuss society's role in solving environmental problems. *By Amos Turk, City College of CUNY; Jonathan Turk; and Janet T. Wittes, Univ. of Pittsburgh. 207 pp. ill. Jan. 1972. $3.95. Order no. 8925.*

Spencer: THE PHYSICS AND CHEMISTRY OF DNA & RNA

In this brilliant new text, the author clearly examines the nucleic acids as macromolecules, considers their physico-chemical properties, discusses the macromolecular phenomena they exhibit, and details the physico-chemical methodology of study in them. Helpfully and extensively-referenced. *By John H. Spencer, McGill University. 143 pp. ill. Soft cover. July 1972. $12.50 Order no. 8513.*

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Accompanied by 300 illustrations, here is a rigorous, definitive book which clearly discusses the taxonomy, phylogenetic relationships and physiology of amphibians and reptiles. The author clearly describes the anatomical and functional characteristics of herptiles, then progresses to such subjects as environmental adaptation and reproductive isolation. *By Kenneth R. Porter, Univ. of Denver. About 576 pp. 290 figs. Ready Oct. 1972. About $14.00. Order no. 7295.*

Miller & Keane: ENCYCLOPEDIA AND DICTIONARY OF MEDICINE AND NURSING

Convenient, graphic and easy-to-use, this brilliant new encyclopedia fills over 100 pages with definitions, salient information, helpful illustrations. Special sections are included on most diseases, conditions and operations. In addition, there are extensive charts, tables and diagrams, as a well as a complete guide to drugs and their nomenclature. A welcome addition to any reference shelf. *By Benjamin F. Miller, M.D., and Claire B. Keane, R.N. 1089 pp. 122 figs (16 in full color). March 1972. $9.95. Order no. 6355.*

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of an advanced, mature economy") but rather some key aspects of our life and economy placed against a regional background of the nine census divisions from New England and the Middle Atlantic to the Pacific Coast. After a couple of overall essays on population and land Estall treats the major economic activities—agriculture, minerals and manufacture—and concludes with an account of urban problems and the Federal Government, leaving in his mind "no doubt that... the activities of government... will prove to be the greatest of all the agents of geographic change."

One theme Estall sees in many of our problems is the "passion for low-density development," which he views partly as a persistence of the Jeffersonian myth of agrarian virtue. "Americans, being human, would like the best of all worlds." They will not live like yeomen because they want comfort, yet they also prefer grass and trees, space and fresh air. If millions .seek rurality, however, "they inevitably destroy what they are seeking." The new rural black migrants have had to trade "a rural slum for a ghetto slum in a sea of concrete" and have not uniformly improved their lot. Estall sees a straw in the wind: the growth of the black population in the suburbs, and even beyond, may have begun in 1964–1969.

Down on the farm the Cotton Belt is irreparably broken, perhaps in part the other side of the bitter ghetto coinage. The growth of feed crops, of specialized broiler-chicken production and of large-scale feedlot operations for beef production are three important trends. Estall says little about economic concentration, although it is plain on the farm.

In industry the divisions and their fortunes are treated in terms of patterns of growth. The growth industries everywhere depend heavily on Federal funds, particularly in research and development, where the Pacific Coast has of course led. The Los Angeles concentration, made of three contiguous Standard Metropolitan Areas, forms "one of the greatest industrial complexes in the world," outranked in employment in manufactures within the U.S. only by New York–New Jersey. The core cities, like New York, are losing out as the suburbs—hardly rural—gain the newer factories. Only Federal action is likely to construct the wider metropolitan polities that could make planning real.

The Mesabi Range is no longer the chief supplier of iron ore to American industry. Foreign imports by river and sea have pride of place. The Mesabi is not exhausted. Open-pit mining on a large scale, and heavy investment in ore beneficiation, will maintain it hard at work. The deep pits spread; if they continue, "the Mesabi range, 120 miles long and 3 miles wide, will eventually become a gigantic lake." Here in strip-mining (coal, to be sure, takes far more land than iron) as in energy use only Federal resources and Federal standards can guard the national estate.

The volume is a sober, prudent one, without easy cures or much excitement about trends. It is nonetheless a reasoned starting point for those who would press remedies in a dozen major issues.

SWEETNESS AND SWEETENERS, edited by G. G. Birch, L. F. Green and C. B. Coulson. Applied Science Publishers, London (four pounds). SWEET AND DANGEROUS, by John Yudkin, M.D. Peter H. Wyden, Inc., New York ($5.95). Ants, men and horses: all like sugar. "Sugar" when here unqualified means table sugar, the pure compound sucrose. It is a natural dimer of two linked molecular rings, one link the simple sugar glucose and the other fructose. Sucrose is common in plants; it is commercially prepared from cane and beet, the identical product resulting from either source. Sugar is sweet, inducing in humans one of the four primary tastes. At least 50 compounds are known that are not sugars at all yet induce sweetness to varying degrees, even certain lead salts. By determining taste thresholds against dilution, or by matching solutions with respect to sweetness, panels of tasters—theirs is a subtle psychological as well as statistical task—can assign degrees of sweetness to various substances. If one takes sucrose as unity, the other common natural sugars vary from lactose, or milk sugar, at 1/6, up to fructose at 1.1. (The accuracy implied is hard to defend.) There are synthetic compounds up to 4,000 on that scale, although they are rather toxic, and certain West African fruits and berries contain large natural molecules 1,500 times sweeter than sucrose. The miracle berry causes such sour foods as lemons and rhubarb and even dilute acids to "taste delightfully sweet." Everyone knows that saccharin is sweeter than sugar, some 300 or 400 times by weight, but it is too heat-labile to be used in cooking. Sodium cyclamate, now illegal, is 30 times sweeter than sucrose. Only saccharin now yields legal sweetness at a cost less than sucrose (20 times less), although of course sucrose adds to food texture, bulk and plenty of calories.

What causes sweetness? A new proposal suggests that the key step is a strong hydrogen-bonded chemical union —always in water solution—between the taste-bud receptor site and the molecular species; everything that tastes sweet has that bonding ability, with a neat three-angstrom distance from the proton nucleus of hydrogen to the other end of the bond. No fit, no sweet taste. This is only a precondition. Around the sweetness receptor there is a stereochemical barrier past which only certain shapes can find their way. Mirror images of sweet amino acids are not sweet; they could bind, but they cannot fit into the site. Mirror-image sugars, however, do taste the same, because the right bond can form on either side. Those miracle fruit proteins may act simply by binding tightly to the receptor region, which would hold their sugar groups in contact for a long time. These studies are full of promise for molecular understanding of taste, but it will not be a simple story.

Men have enjoyed sugar as a luxury since antiquity. Nowadays its use in economically developed lands is not short of epidemic. The price has fallen with respect, say, to butter or eggs about two-hundredfold since Columbus' day. The Americans and the English, and they are not alone, currently take about a sixth of all their calories with that pleasing three-angstrom fit. The average person consumes about 18 heaping teaspoonfuls per day, perhaps two-thirds of it in a wide range of factory-prepared foods and one-third at the table. The kids take even more, and the teen-aged boys lead everyone. Even the Eskimos increased their intake fourfold in a decade, while rural Zulu use grew tenfold from 1953 to 1964. National use correlates well with national income, and very well with national deaths from that plague of the well-off, coronary disease.

There is a "*Reader's Digest* view" of coronary disease: "just a matter of cholesterol levels in the blood." In actuality there are "at least twenty indicators that often [are abnormal] in people [who] have severe atherosclerosis." We really do not know the cause of that major syndrome of our affluence. Epidemiology cannot prove the case, but sugar use and coronaries grew together in some populations that eat little fat, whereas some meat-eating groups without sugar consume plenty of fat but do not have coronaries. There are always complicating issues: genetics, exercise and the like. Coronary patients have shown a high sugar intake in several but not all clinical studies; they have shown a high fat intake, we are told, in none.

The chain of events is plausibly reconstructed, although far from proved. A high sucrose intake is split almost at

once into the simple sugars, and within minutes it increases the glucose concentration in the blood. Hence the "quick energy" of the advertisements. That quick rise induces, at least in some people, a complex balancing hormonal response, probably ending up after many years in a chronically high insulin level. Rats with too much insulin show a high cholesterol level in the blood passing through the aorta. High insulin levels in men do correlate with coronary disease. Since the effect is hormonal at the base, it can reveal itself in a multiplicity of changes in the body. These changes are strange but reasonable enough for the upset of a major control system; they are less understandable on the basis that one direct metabolite, such as fat, is mainly involved.

Sweetness and Sweeteners reports a 1971 Anglo-American symposium of experts in the food industries. Its aim is given by the title; one goal is plainly the devising of a cheaper and safer source of sweetness, perhaps from the hydrolyzed syrups now widely made from corn and other cereals. It is a calm and guarded work, hardly meant for the general reader, although it is full of diverse interest. The book by Professor Yudkin, a London nutritionist, is different. It is a winning, frankly tentative, very popularly written effort at direct persuasion. He puts forward his admittedly unproved but reasonable case that sugar is a public-health danger, particularly for infants and children who use a lot and can form a habit. Sugar is at its most dangerous, he thinks, taken in snacks between meals, when the rapid glucose-level changes are not buffered by the slower absorption of other foods.

For him the matter is clear enough as a matter of risk. "There is no physiological requirement for sugar; all human nutritional needs can be met in full without having to take a single spoon of white or brown or raw sugar, on its own or in any food or drink." We have been misled by that palatable three angstroms and its energy coupling. Sugar use is an order of magnitude too high at least. But it is a quantitative problem, not an absolute one: "No great harm will come to you if ... you accept something special ... for the occasion." Finally, "if only a small fraction of what is already known about the effects of sugar were to be revealed in relation to any other material used as a food additive, that material would promptly be banned."

The American publisher has unfortunately made a careless job of Professor Yudkin's provocative book, omitting his most interesting tabular material.

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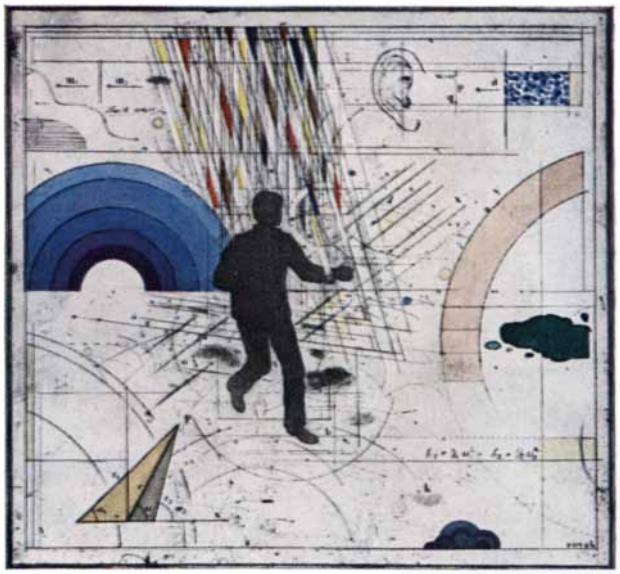

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